Open Building Manufacturing

Core Concepts and Industrial Requirements

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ManuBuild

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Preface

Background and Introduction

The construction industry is primarily characterised as a craft-based one producing one of a kind products and services. Other manufacturing sectors such as aerospace and automotive sectors in comparison primarily rely on standardised components that can be configured and assembled to provide a specific product or service.

Open building manufacturing is an attempt to bring some of the salient features of efficient manufacturing to the construction sector. This should allow for significant savings in construction and maintenance costs, fewer errors and rework, more choices and value to the customer, new products and services that can be configured and assembled in mobile factories at construction sites, etc., as is reported in different chapters in this book.

The ManuBuild project is leading European efforts in the open building manufacturing area through the creation of an Open Building Manufacturing System, a new paradigm for building production by combining ultra-efficient manufacturing in factories and construction sites, and an open system for products and components offering diversity of supply in the open market.

The ManuBuild Project

ManuBuild - "Open Building Manufacturing", is an industry-led collaborative research project on Industrialised Construction, part-funded by the European Commission. Commencing in April 2005, it is a 4-year project involving 25 partners from 10 countries across Europe.

The ManuBuild vision is of a future where customers will be able to purchase high quality, manufactured buildings having a high degree of design flexibility and at low cost compared to today. For the first time, inspirational unconstrained building design will be combined with highly efficient industrialised production.

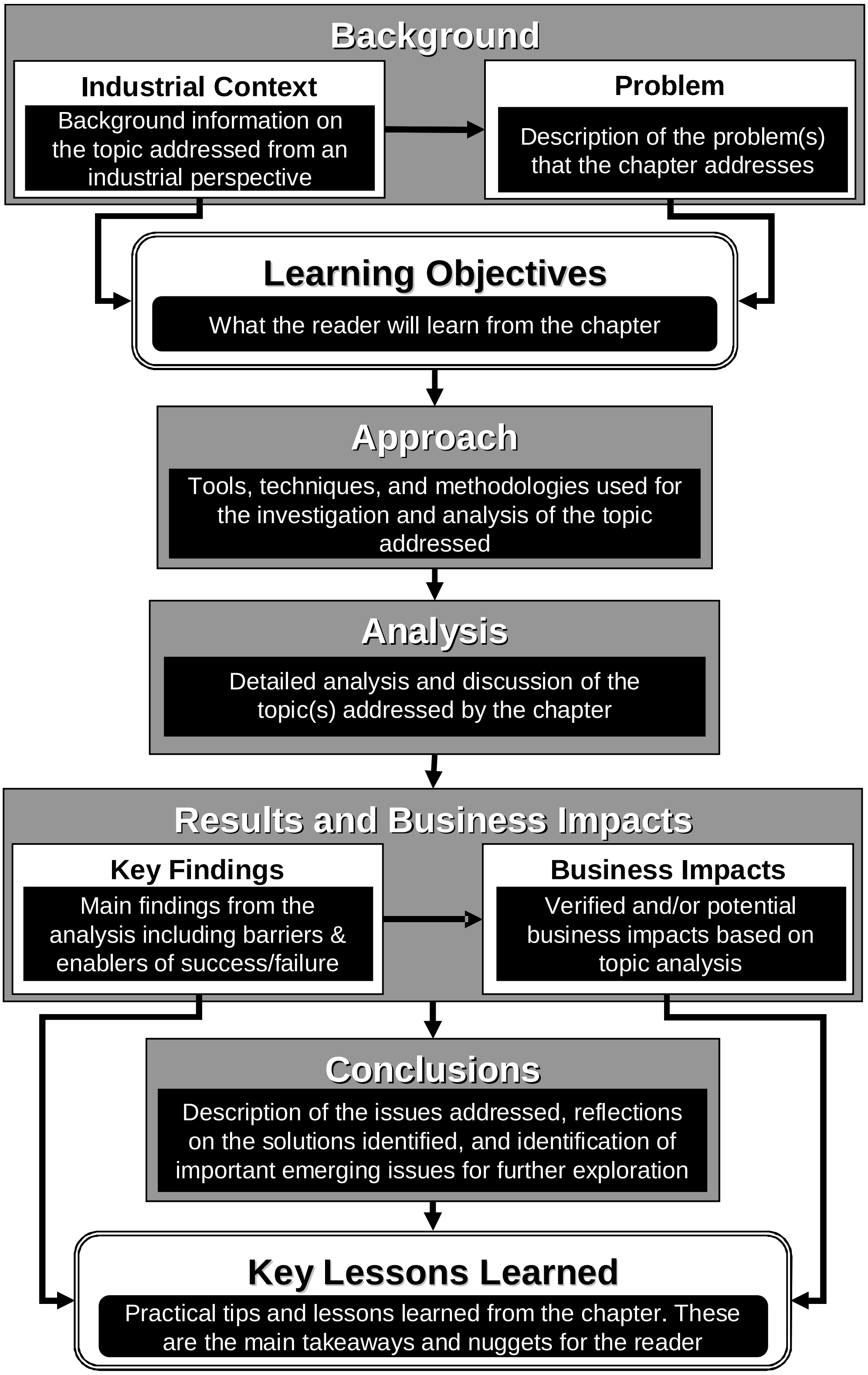
Open Building Manufacturing: Core Concepts and Industrial Requirements

This book, “Open Building Manufacturing: Core Concepts and Industrial Requirements” was launched by the ManuBuild project consortium to both share its own findings with a wider audience, and to learn from the experiences of others engaged in practice and research in the area of open building manufacturing. Of the more than 25 extended abstracts received for this book, only 18 were invited for full chapter submission. These chapters were peer-reviewed and based on the peer-reviews, 16 were retained for final inclusion in this book upon further improvement in response to the peer-reviews.

ManuBuild expects to follow-up this book with publications showcasing the results and findings of ManuBuild and others on key technologies and potential applications, and, applications and industrial case studies on open building manufacturing.

Content Structure

The chapters presented in this book have been organised around a common content presentation structure to foster ease of reading and understanding. Typically, each chapter features sections on industrial context, problem definition, learning objectives, approach, analysis, key findings, business impacts, a set of conclusions, and most importantly, offers a valuable set of key lessons learned.

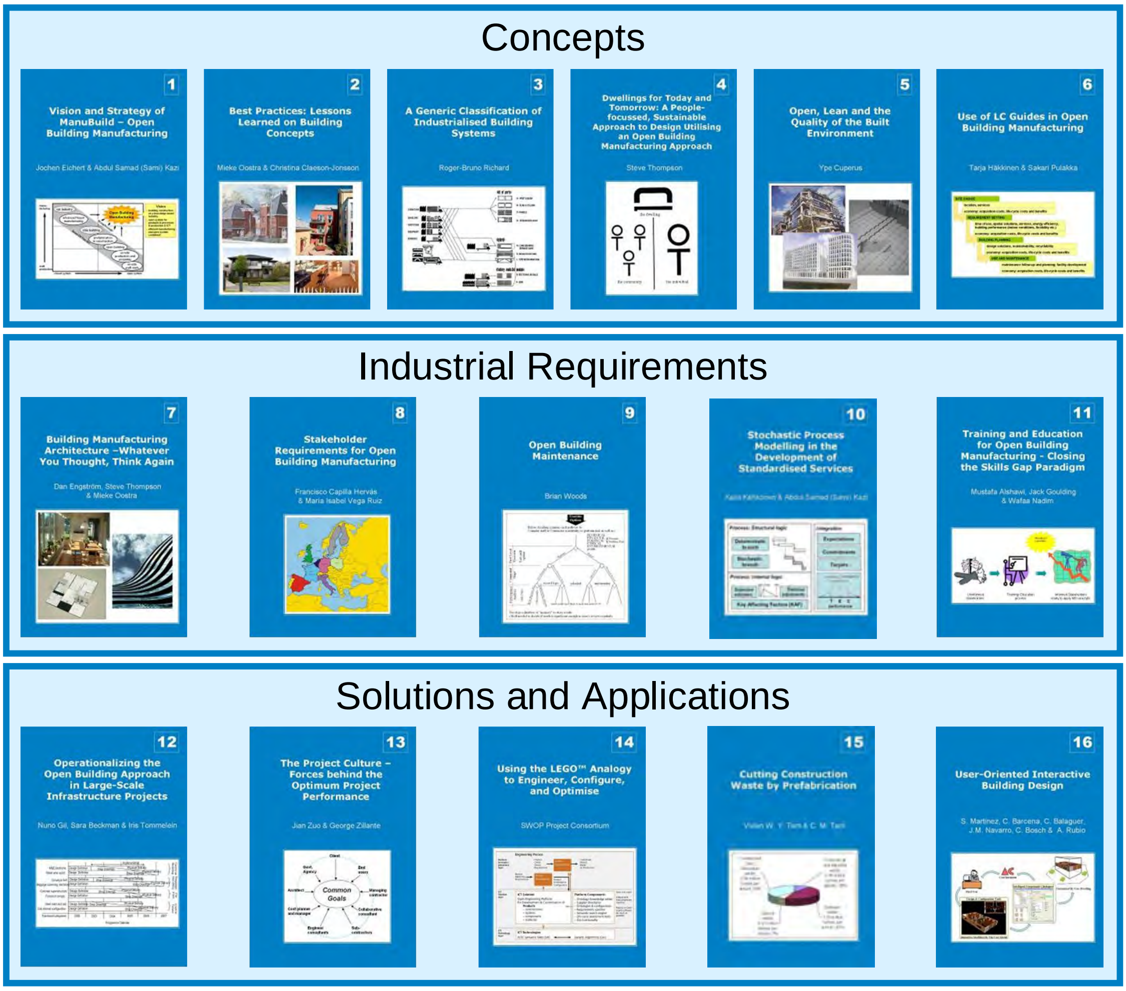


Overview of Chapter Structure and Content Flow

Portfolio of Book Chapters

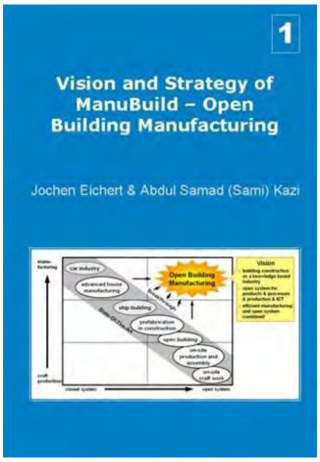
This book contains sixteen chapters that have been clustered under three broad and yet complimentary themes as follows:

- *Concepts:* The chapters under this theme cover the vision for open building manufacturing as seen by the ManuBuild project consortium, lessons learned on building concepts from industrial best practices, classifications of industrial building systems, and different approaches to the understanding and use of different concepts in open building manufacturing.
- *Industrial Requirements:* The chapters under this theme focus primarily on different requirements for open building manufacturing. They cover different perspectives to building manufacturing architecture, stakeholder requirements, the need for open building maintenance, the need for use of stochastic process modelling to support open building manufacturing services, and the need for training and education to close the skills gap which is an impediment to the understanding and use of open building manufacturing.
- *Solutions and Applications:* This theme presents different initiatives in the form of solutions and applications of open building manufacturing concepts. The chapters present the operationalisation of open building manufacturing in large infrastructure projects, how project culture influences performance, use of the Lego™ analogy for product and service engineering, configuration and optimisation, reducing waste through prefabrication and user-oriented interactive building design.



Structure of this Book

Concepts



Vision and Strategy of ManuBuild – Open Building Manufacturing

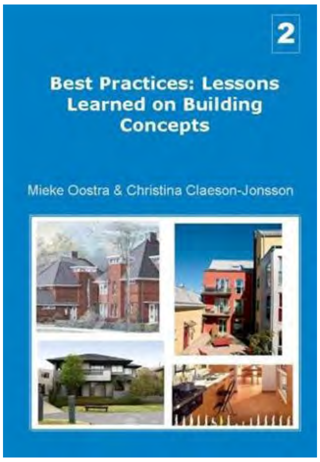
Jochen Eichert & Abdul Samad (Sami) Kazi

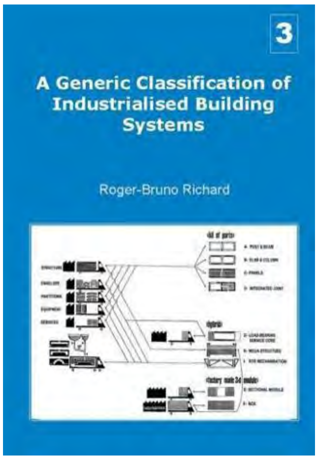
This chapter presents the open building manufacturing vision, strategy, and components of the ManuBuild open building manufacturing system. It advocates the need for a radical paradigm shift from the current "craft and resource based construction" towards "open building manufacturing" that enables highly customised buildings using manufactured, knowledge based components from the open market and assembling them efficiently on site.

Best Practices: Lessons Learned on Building Concepts

Mieke Oostra & Christina Claeson-Jonsson

The concept of open buildings is an area where several attempts have been made in the past and there exist several building systems in the market today. This chapter analyses and captures the best practices of systems through some Dutch, Swedish, English, and Japanese examples. Key elements considered by the study includ: representing product concept, building process, manufacturing process and provided services.





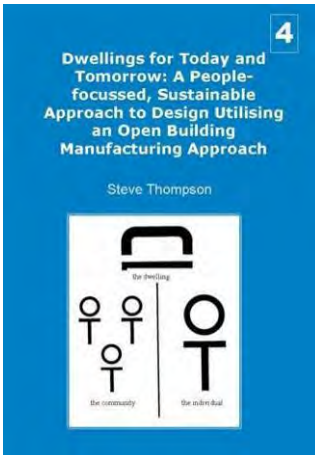
A Generic Classification of Industrialised Building Systems

Roger-Bruno Richard

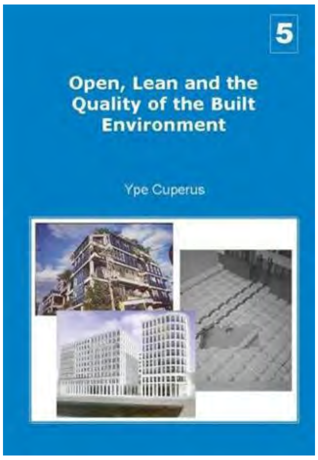
A Building System is a set of parts and rules where the details are solved before actual buildings are planned: the same parts are re-used for a large number of buildings, different as products but generated by a similar process. This chapter argues that owing to the fact that buildings are site-related and technology factory-related, three basic building systems strategies can be outlined: I - the Site-intensive Kit-of-Parts; II - the Factory-made Module; III - the Hybrid.

Dwellings for Today and Tomorrow: A People-focussed, Sustainable Approach to Design Utilising an Open Building Manufacturing Approach

Steve Thompson



Dwellings are typically designed in either of two ways. The first is to design with the needs of a specific household in mind. The second is to design on a speculative basis, assuming a typical household that will live in the dwelling. This chapter advocates that the most sustainable way to dwelling design is a people-focussed, not product-focussed approach, both on an individual and community level.



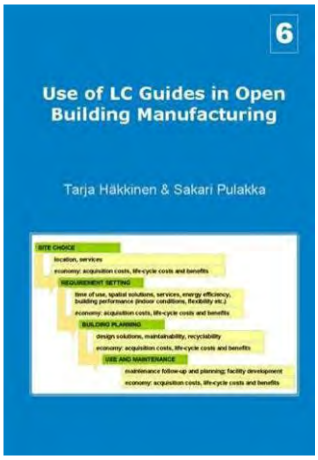
Open, Lean and the Quality of the Built Environment

Ype Cuperus

Any industry that does not satisfy its clients will not survive, except the housing industry, as it seems, so something must be basically different. Will this sustain or is it time for a radical change? This chapter advocates that combining the concepts of open building and lean construction can help us to better understand and improve the performance of the construction industry resulting in a better built environment rather than only a better construction industry.

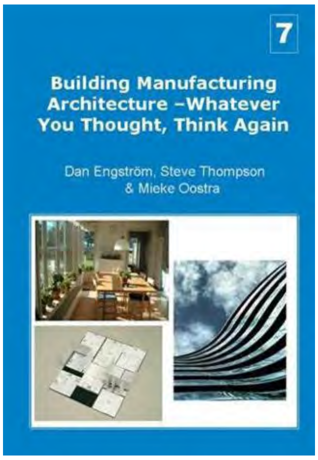
Use of LC Guides in Open Building Manufacturing

Tarja Häkkinen & Sakari Pulakka



This chapter discusses the availability of Life Cycle (LC) guides and assesses the usability of these LC guides, methods and tools from the view point of open building manufacturing. LC guides include standards, national voluntary methodologies and different kinds of methods developed in national and international research projects. It advocates that open building manufacturing needs LC methods in order to be able to state its LC requirements and consider user needs, to be able to design for the required performance and life cycle, and to be able to make decisions between alternative options.

Industrial Requirements



Building Manufacturing Architecture – Whatever You Thought, Think Again

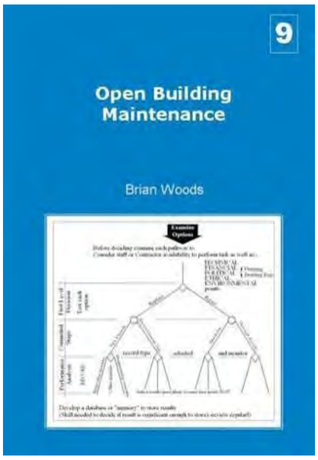
Dan Engström, Steve Thompson & Mieke Oostra

Whatever you thought, think again. The overall aim of ManuBuild is to facilitate the industrial creation of contemporary state-of-the-art architecture. This chapter summarises the work done in ManuBuild on architectural quality and gives the principles and some examples of the brief for ManuBuild architecture. With the brief, building owners and architects can work on the design of industrially produced buildings with confidence that important issues are not overlooked.

Stakeholder Requirements for Open Building Manufacturing

Francisco Capilla Hervás & María Isabel Vega Ruiz

To ensure the acceptance of Open Building Manufacturing in the construction sector, it is of vital importance to introduce the “voice of the stakeholder” into its development. This chapter presents the results of 112 interviews that were done. It identifies the main barriers and most efficient measures to succeed in the introduction of this new and revolutionary philosophy (open building manufacturing), as well as the main market requirements and trends.



Open Building Maintenance

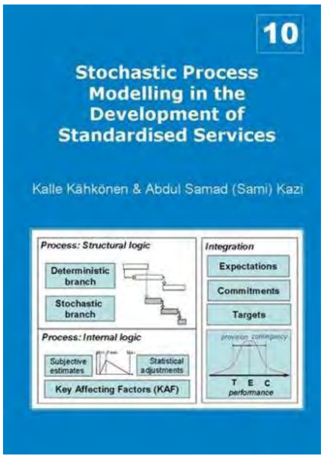
Brian Woods

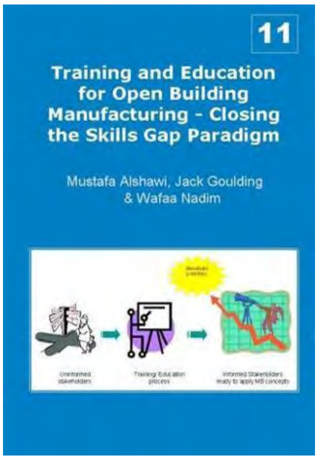
Buildings produced using open building systems are going to need maintaining and those responsible for them should consider this at the outset. Maintenance requirements of a building through its life and how these impinge on the continuing and changing use of a building and the comfort of its users are considered, and a draft checklist of questions developed. The principal message is that clients, architects and their advisors should ask fundamental questions at the earliest stages of project development and review decisions at intervals.

Stochastic Processes Modelling in the Development of Standardised Services

Kalle Kähkönen & Abdul Samad (Sami) Kazi

This chapter presents stochastic process modelling as an approach in the development of standardised services for environments such as open building manufacturing. Key elements of stochastic process modelling are presented through three industrial case studies. The paper argues that stochastic process modelling can be successfully applied in understanding service processes within open building manufacturing settings.





Training and Education for Open Building Manufacturing - Closing the Skills Gap Paradigm

Mustafa Alshawi, Jack Goulding & Wafaa Nadim

The construction industry is constantly confronted with challenges, and opportunities in new markets. These are often passed over, predominantly because of the lack of relevant skills. Similarly, “Open Building Manufacturing” opens up new high quality job opportunities (which will require new skills). This chapter presents the main requirements for and the ManuBuild training and education concept to close the skills gaps that may impede the understanding and take-up of open building manufacturing.

Solutions and Applications

Operationalizing the Open Building Approach in Large-Scale Infrastructure Projects

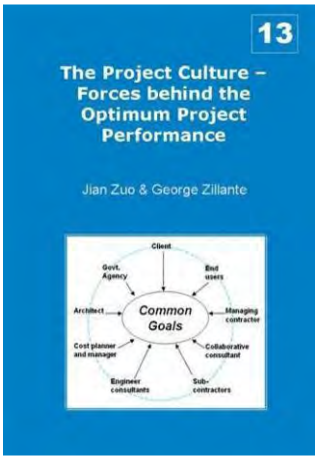
Nuno Gil, Sara Beckman & Iris Tommelein

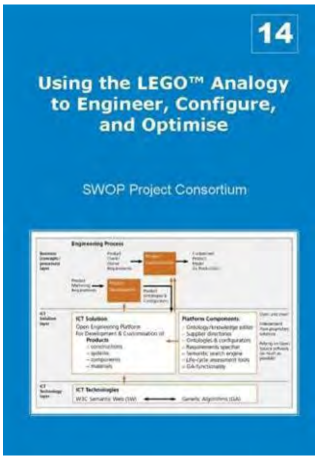
The study presented in this chapter examines the appropriateness of alternative coordination strategies to manage the application of design postponement, or the overlapped approach, in the development process of large engineering (physical infrastructure) projects, and what the trade-offs are. This chapter informs that efforts to prefabricate base-building modules off-site do not automatically lead to flexible infrastructures with modular architectures.

The Project Culture – Forces behind the Optimum Project Performance

Jian Zuo & George Zillante

This chapter presents the findings of a case study on how open building manufacturing related methods and techniques were adopted in the redeployment of a hospital facility. It is advocated that open building manufacturing related methods such as innovative procurement approach, ICT support, and value-driven performance evaluation help to achieve better project outcomes and improved satisfaction of user requirements.





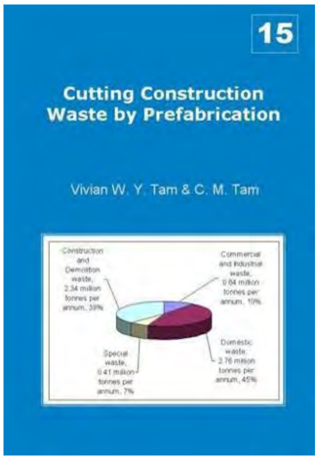
Using the LEGO™ Analogy to Engineer, Configure, and Optimise

SWOP Project Consortium

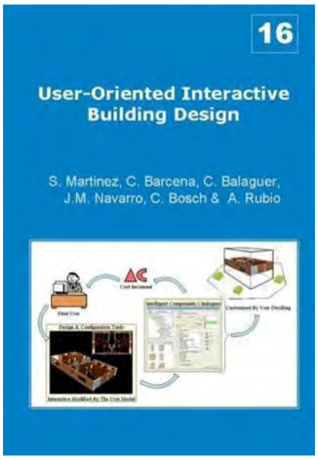
This chapter presents some of the main findings of a project that provides a semantic web-based open engineering platform to design and configure different parametric products and services. It presents how semantic modelling can be used as the basis for efficient and effective virtual engineering and commerce, and demonstrates the possibility to tightly bind back office design and production to front office sales, marketing and customer relations.

Cutting Construction Waste by Prefabrication

Vivian W.Y.Tam & C.M.Tam



Open building manufacturing aims to provide a high degree of design flexibility at low cost. It is commonly combined with high efficient industrial production. This chapter presents the findings from four case projects where prefabrication was used to minimise construction waste and reduce construction costs. It demonstrates that using open building manufacturing techniques, 100% of waste can be reduced in plastering; from about 73.91% to 86.87% for timber formwork; from about 51.47% to 60% for concrete and from about 35% to 55.52% for reinforcement bars.



User-Oriented Interactive Building Design

S. Martinez, C. Barcena,C. Balaguer,
J.M. Navarro, C. Bosch & A. Rubio

This chapter presents the role and means of engaging an end-user into the overall building process from in particular conception to construction. It advocates the automatic translation of architectural and design models to “user models”. These user models ensure active participation of different stakeholders, in particular the end-user from the start of construction to the end of the life cycle of the dwelling.

Acknowledgements

First and foremost, we would like to acknowledge and appreciate the enthusiasm and contributions from the numerous authors who have shared their experiences and lessons learned in this book. This book would not have been possible had it not been for them.

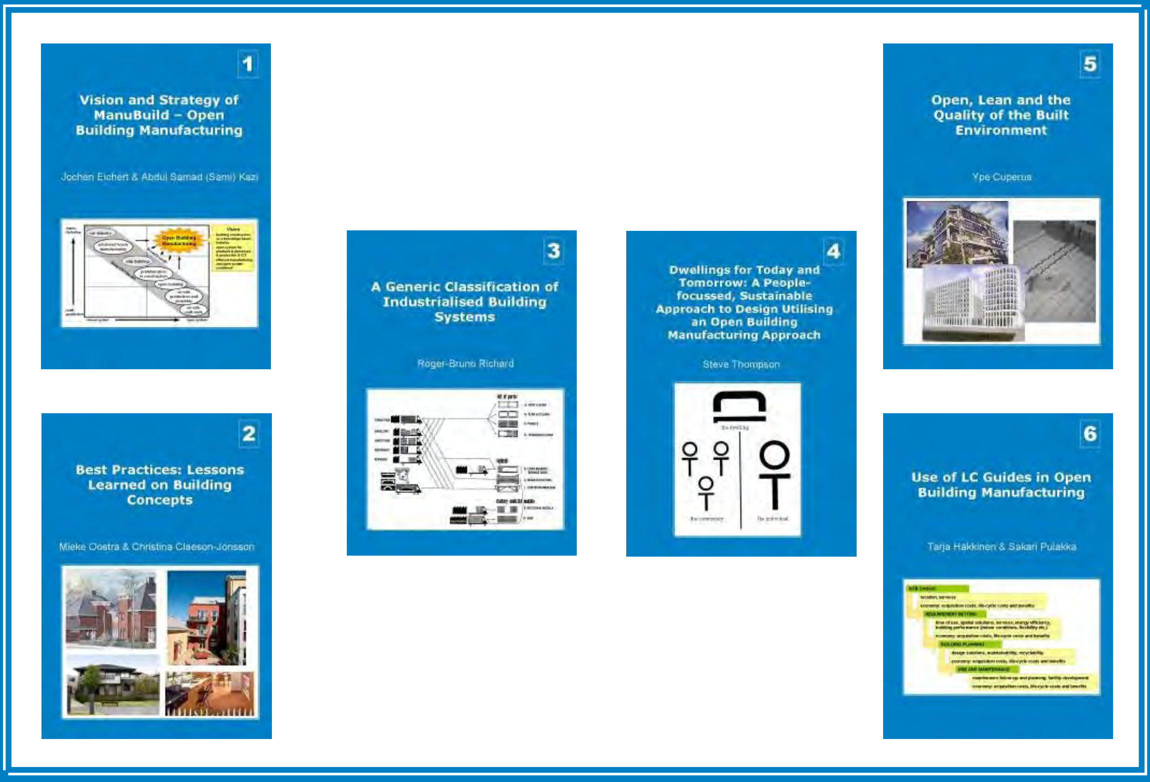
The ManuBuild project consortium was instrumental in not only championing the need for this book, but in also sharing its vast findings and experiences in open building manufacturing. We would also like to acknowledge the support of the European Commission and in particular its NMP programme for partly funding the ManuBuild project.

We would like to thank you, the reader, for taking the initiative and time to explore and learn from the concepts, industrial requirements, and solutions and applications for open building manufacturing presented in this book.

Dr. Abdul Samad (Sami) Kazi, Chief Research Scientist

VTT – Technical Research Centre of Finland
Espoo, Finland, April 2007.

Concepts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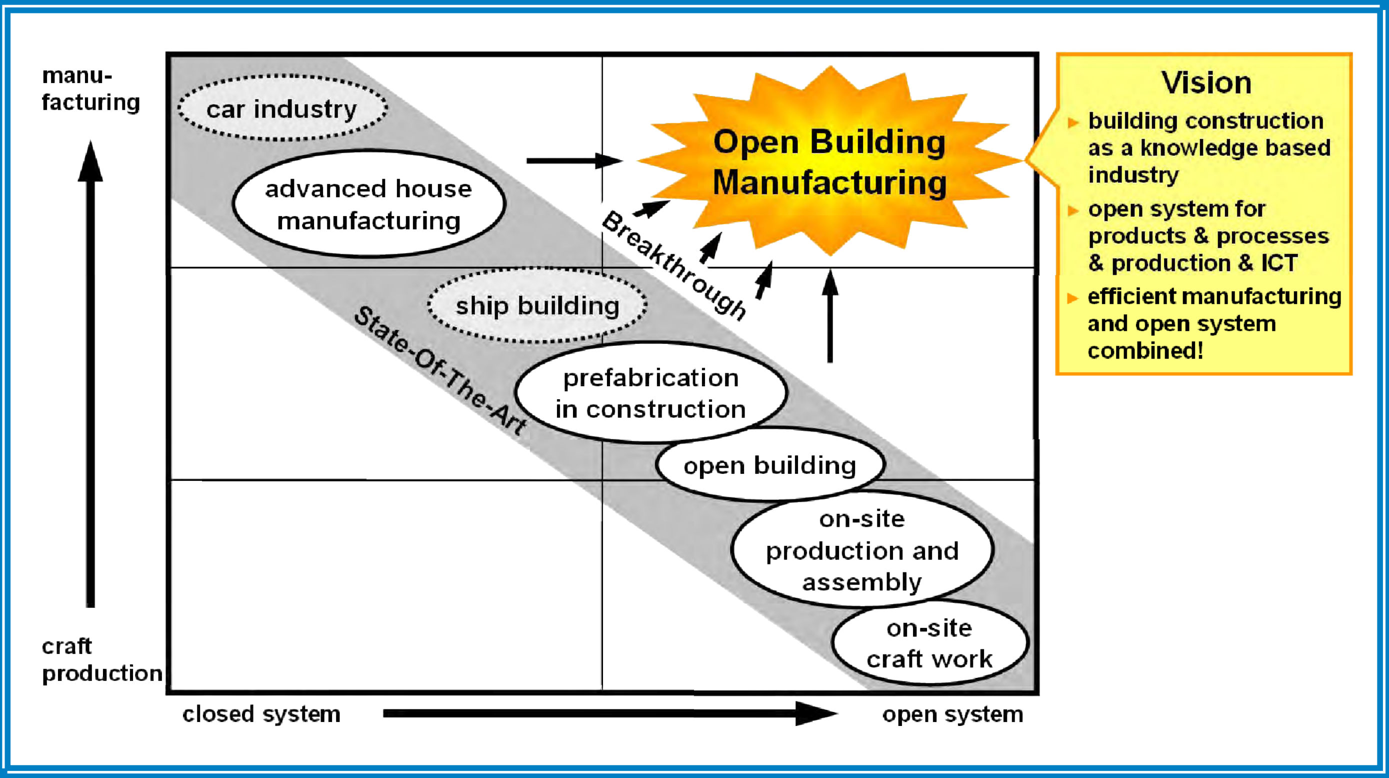

Vision and Strategy of ManuBuild – Open Building Manufacturing

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Abstract

In order to be prepared for the future and to stay competitive there is an increasing need for construction to take appropriate actions to improve in many areas and also to keep pace with current technological achievements and innovations especially when compared to advancements in other industries. ManuBuild is targeted at providing a holistic approach to solve highly relevant problems construction is currently facing.

The vision of ManuBuild is open building manufacturing, a new paradigm for building production and conceiving business by combining value driven, innovative, efficient and safe manufacturing and assembly in factories and on construction sites and an open system for products and components offering diversity of supply and building component configuration (on demand) opportunities in the open market.

The core of the strategy of ManuBuild to cope with construction's challenges, to drastically improve customer orientation and thus for achieving the overall goal Open Building Manufacturing, is driven by the necessity to completely and consistently combine the concepts of "open systems" AND "efficient manufacturing". By having for the first time buildings designed for manufacture and customisation, using ambient manufacturing, the production of buildings will be taken far beyond today's pre-fabrication concepts, which (up to now) are little more than "bringing construction indoors". The result will be much more customer oriented, customisable, open, scalable, cost-efficient and at higher quality.

To this end the ManuBuild Open Building Manufacturing System is developed, which is an integrated system that holistically incorporates Building Concepts, Business Processes, Production Technologies and ICT Support as well as Training and thus enables future construction to act as a flexible, agile, value-driven and knowledge based industry and most of all to be highly customer-centric, efficient and competitive.

Keywords: ManuBuild, Open Building Manufacturing, Vision, Strategy, ManuBuild System

Background

Industrial Context

The construction industry is characterised as a project based industry that delivers one of a kind products and services (Kazi and Hannus, 2003). Within many different participants (organisations) involved in a typical construction project (according to Crowley, Hager, and

Garrick, 2000, subcontracting of the main contractors work can reach to up to 95% in Australia), it is a challenge to coordinate and manage processes that involve the engagement of these participants who may not necessarily be contractually linked (Kazi and Charoenngam, 2003). This lack of knowledge and control over the construction process as a whole has resulted in an industry that is slow to innovate and unable to develop or even effectively implement new technologies (e-Business W@tch, 2005a) particularly those cascading from technologically more advanced industries (e.g. aerospace and automotive). It is only by addressing everything related to the construction process that radical changes in performance and competitiveness can be achieved.

Improvements in productivity in the construction sector have to date been marginal (Veiseth, M., Rostad, C.C., and Andersen, B. 2003). It has proven amazingly difficult to introduce new technologies and methods in the construction sector when compared to other sectors (e-Business W@tch, 2005b). Indeed, construction productivity lags significantly behind that of manufacturing due to a lack of understanding and use of concepts such as lean production and concurrent engineering in the construction sector. (Koskela, 2000). For example, recent studies have shown that the productivity increase in construction is only marginal when compared to that of the manufacturing industry in general (National Competitiveness Council, 2006). This can stem from the fact that within a typical construction project, not only is productivity difficult to monitor and measure, it is rarely properly recorded (Kazi, 2004).

According to Edgar, Doherty, and Meert (2002), while there are 3 million homeless in Europe, 18 million have inadequate housing due to a lack of adequate affordable housing. The current demand for affordable housing in Europe exceeds supply by 3.5 million units. This cannot be simply resolved by using the traditional construction methods simply because the associated building costs are too high, which is also due to the fact that today nearly every new building is in fact a prototype being planned and built from scratch. For quite some time, there has been a call for a need for new methods, techniques and ways of working to deliver affordable housing that can help resolve the problem (Barlow, 1999).

The European construction sector today constitutes 2.3 million enterprises (mainly SMEs) of which 96% employ less than 20 employees. At the same time, the sector is the largest in terms of employment in the EU with a GDP contribution of 9.8% and an overall employment rate of 7.1% of the European workforce (e-Business W@tch, 2005a).

Problem

The construction sector is characterised by collaboration between many stakeholders who work together in projects for limited periods of time. Other key characteristics include the complexity and long life cycle of products. Therefore it is only natural that the current use of ICT is fragmented serving specific tasks, stakeholders and life cycle stages. The main challenge for the construction sector is to achieve holistic and integrated ICT support covering the complete project life cycle from conception to demolition. Yet the construction sector lags significantly behind other manufacturing sectors (e.g. manufacturing, publishing and printing, automotive, pharmaceutical, etc.) in terms of basic ICT infrastructure, ICT for internal processes, supply-side e-business activities, and electronic marketing and sales(e-Business W@tch, 2005b).

Concerning the working environment, the sector has always been struggling with its bad image of being dirty, difficult and dangerous. Today most construction workers stop working before reaching retirement age, sometimes as early as at age 35 because of work related accidents and health problems (Tolkki, 2005). Physically demanding conditions at construction sites are one of the main reasons why women are grossly under-represented in the industry (in fact 96-99% of the construction workforce is male). By enhancing the working conditions more women will consider working in construction and thus a significant source of human capital and knowledge will be opened. It is estimated that by moving 80% of the "outdoor" activities into "indoor" factory environments, the safety levels already present within the manufacturing industry could be readily achieved. This would result in a radical reduction of the number of workers seriously injured or killed by a factor of 10 and 20 respectively, which in turn would save social costs of approx. 2 billion € per year

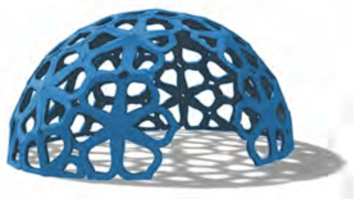
In order to be prepared for the future and to stay competitive there is an increasing need for construction to take appropriate actions to improve in many areas and also to keep pace with current technological achievements and innovations especially when compared to advancements in other industries. The need for action has been most commonly accepted by the sector and first corrective objectives have already been defined as published in the strategy plan issued through the European Construction Technology Platform (ECTP) for example. ManuBuild is targeted at providing a holistic approach to solve the industrial problems stated in the previous paragraphs. Following section present the vision of the ManuBuild Consortium, and its strategy to achieve this vision.

Learning Objectives:

- Transformation of the construction industry from a craft-based industry to an open building manufacturing one
- Vision and strategy of the industry led ManuBuild project
- Key elements of the ManuBuild open building manufacturing system

Vision

The vision of ManuBuild is **open building manufacturing**, a new paradigm for building production and procurement by ***combining*** highly efficient **manufacturing techniques** in factories and on construction sites ***and*** an **open system** for products and components offering diversity of supply and building component configuration opportunities in the open market



In a first step for guiding the construction sector into this future centred around open building manufacturing, and in order to initiate the visionary paradigm shift from construction's current state being mainly "craft and resource based" towards its future state characterised as "agile, value-driven and knowledge based", the ManuBuild Project was founded. As the vision states the "dream of future construction" at long sight, the ManuBuild Project (being limited to four years) must be understood more in the sense of laying the cornerstone for Open Building Manufacturing for the whole construction sector to build upon, for enhancing and advancing it and to adapt to.

Strategy

Objectives and Targets

The key elements that are essential to be addressed within ManuBuild include novel Building Concepts, Business Processes, Production Technologies and ICT Support and their integration into one holistic approach forming the ManuBuild Open Building Manufacturing System. To appropriately prepare the construction employees to the future way of doing business, it also introduces suitable concepts for training and education. With that, it sets out the basic rules and principles, concepts and processes and production technologies as well as supporting tools in consideration of the complete life cycle of buildings.

The envisaged paradigm shift (as stated in the vision) in terms of targeted changes coming from construction's current state towards the anticipated future state by providing an integrated holistic approach (the ManuBuild System) is illustrated in Figure 1. Thus ManuBuild paves the way for Open Building Manufacturing as a new concept and in this context a new way of conceiving business and for building production for the whole sector.

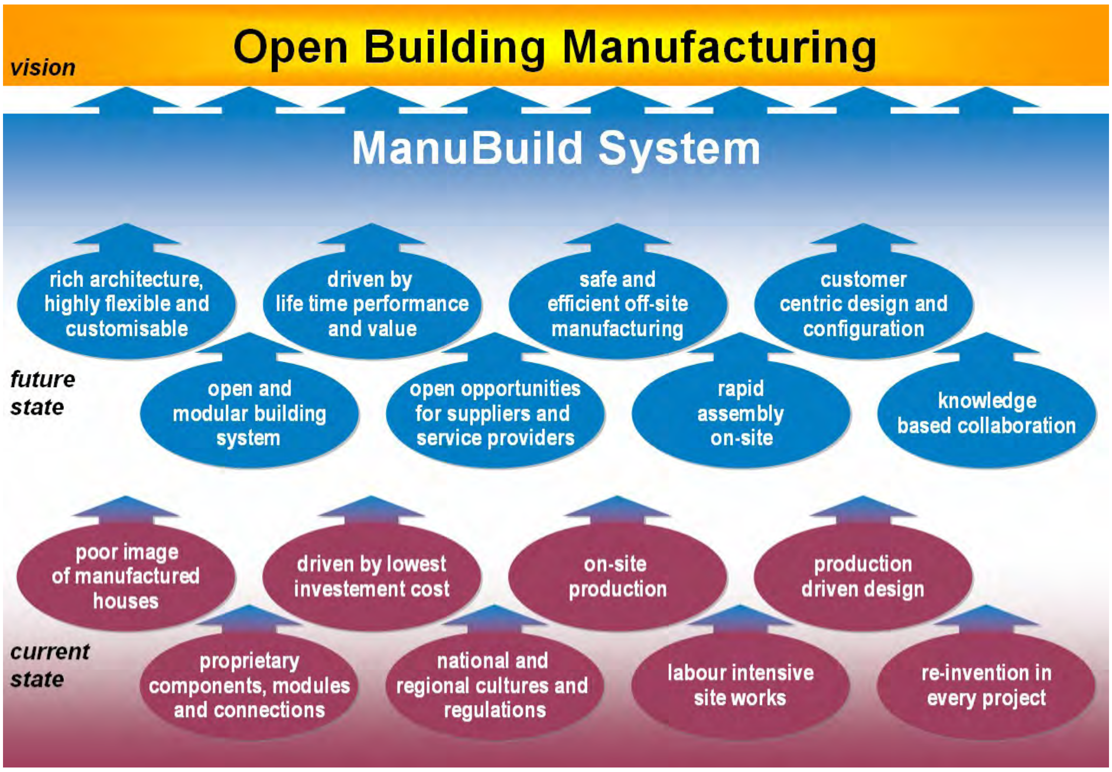


Figure 1: From Current State to Future State – Via ManuBuild System towards Vision

To achieve these goals (from current state to future state) ManuBuild has to define the appropriate principles and rules for developing concepts, methods, tools, technologies and products as well as for working in an open building manufacturing world. Based on these principles and rules, ManuBuild establishes an open system to demonstrate and validate the new paradigm. This includes new conceptual designs (architecture), modular and industrialised construction with flexible production suitable for (pre-)manufactured products and components but also for their easy assembly. The emphasis of all activities within ManuBuild is on increasing value for all involved stakeholders and on reaching real customer orientation (i.e. placing the customer at the very heart of the construction process). By applying new, value added and innovative processes stakeholder collaboration is encouraged and the end-user involvement is ensured. This also implies that highly efficient manufacturing techniques have to be adopted and developed in combination with inspirational design and supported by corresponding ICT tools. All of these requirements and necessities have to be considered and implemented in the resulting ManuBuild Open Building System. As an indicator how this contributes to the overall vision, the most radical changes targeted, are summarised below:

- transformation of design from "re-invention in every project" to standardised custom-configuration before the project as well as on the fly re-configuration during the project
- shift from unique results of handcraft to pre-manufactured ready to be assembled products with high architectural and aesthetic quality

- development of new system concepts for flexible architectural and spatial typology
- implementation of on-site manufacturing and pre-assembly with mobile factories
- implementation of efficient off-site manufacturing methods, concepts and technologies
- application of new materials, integrated multifunction modules and smart components
- community and customer driven building configuration, production and fully integrated urban planning, supplying clients with a new quality of life as a service of society
- implementation of new concepts for networked and distributed organisations for design, manufacturing and assembly
- development of future concepts for intelligent maintenance services in the sense of product service co-design

Openness and Manufacturing

To gain sustainable breakthrough, benefit and impact it is not sufficient to address known problems independently or to advance isolated developments in specific areas. Instead it is essential to apply an integrative approach that considers all relevant and affected aspects that are related to a building not only at technical level but also to ensure the wide promotion of the ManuBuild approach and the adaptation of its achievements by all involved stakeholders throughout the European construction industry.

The core of the strategy of ManuBuild, to cope with the aforementioned challenges and for achieving the overall goal "Open Building Manufacturing", is driven by the necessity to completely and consistently combine the concepts of "open systems" and "efficient manufacturing". By having for the first time buildings designed for manufacture and customisation, using ambient manufacturing, the production of buildings will be taken far beyond today’s pre-fabrication concepts, which (up to now) are little more than "bringing construction indoors". The result will be much more customer oriented, customisable, open, scalable, cost-efficient and at higher quality.

Figure 2 provides an overview of state of the art examples from different industrial sectors in terms of their manufacturing degree in relation to their open system character.

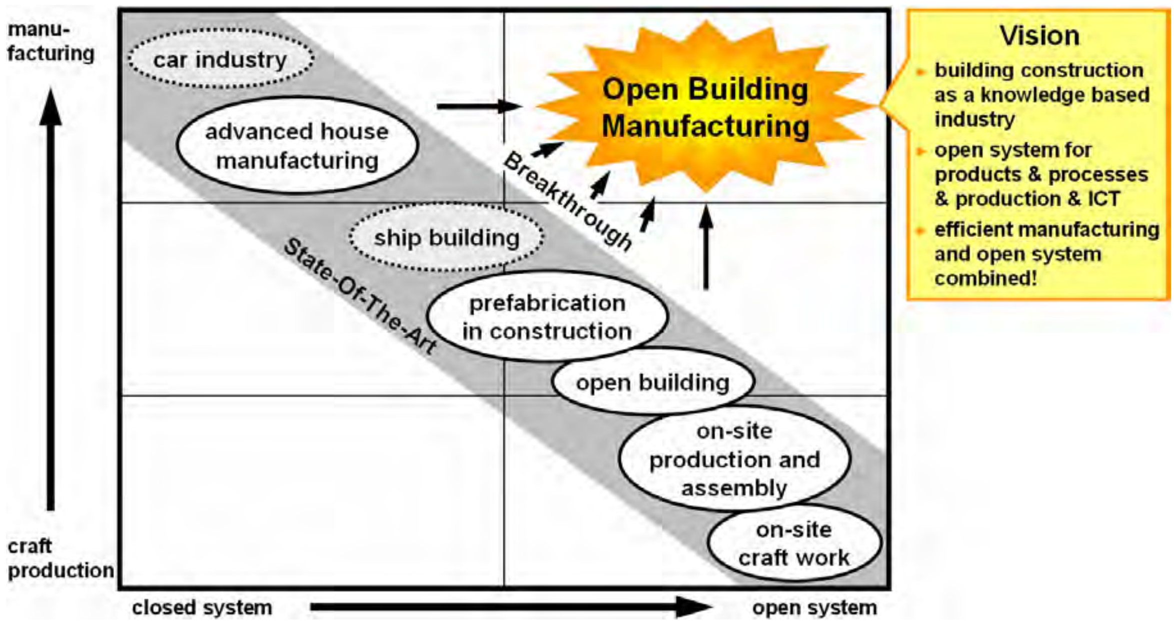


Figure 2: Current State in Relation to Open Building Manufacturing

All current examples shown in the figure have one thing in common, that is by raising the degree of manufacturing they loose their open system character and vice versa.

In this context it is necessary to have a closer look at the differentiation between open and closed systems. At a very elementary and abstract level, the definition of an open system is, that it can be influenced by events outside of the actual or conceptual boundaries of the system, whereas a closed system is self-contained, meaning that outside events are separated from the system. From these definitions it is obvious that distinguishing between an open and a closed system very much depends on the declared boundaries of the system. For example the car industry is considered as a (very restrictive) closed system. A car is a very complex product, which on its part again consists of a multitude of different and unequal sub-systems, i.e. motor, seats, radio etc just to give some striking examples. But with the car being the boundary, the system is closed. A customer does not have the freedom to choose where these different parts come from. However one advantage of this closed approach is that cars can be produced with a very high degree of efficient manufacturing and standardisation, at constant quality, with deterministic processes and workflows in a safe, healthy and clean environment. On the other hand traditional construction can be seen as an open system. A building also is a very complex product consisting of numerous sub-systems, which in contrast to a car's can be chosen and combined (almost) without limitations, i.e. the customer can specify a large variety of the materials to be used or even request changes to installations during the construction process. But the price for the system being open in traditional construction is that most of the work is craft-based with a limited degree of manufacturing, resulting in long construction times, high costs and unchecked working conditions.

As a summary of the current examples from the figure and as outlined above, for ManuBuild it is essential to avoid the pitfalls that each approach bears in itself when being examined separately and to completely eliminate the compromise solutions or even disadvantages obviously accepted in current attempts.

The ManuBuild Open Building Manufacturing System

ManuBuild strives for building construction to tackle the challenges of the sector, acquire the conceptual benefits and advantages of manufacturing, adopt or develop and implement corresponding processes and technologies and at the same time to satisfy the open system character. It is targeted at evolving construction into an industry that is open for individual designs, competition between suppliers, alternative assemblies, future changes, information and knowledge exchange, integration of modules and technical systems, reuse and recycling based on the highest degree of manufacturing for each step within the construction process.

The **ManuBuild Open Building Manufacturing System** is ***an integrated system that holistically incorporates*** **Building Concepts**, **Business Processes**, **Production Technologies** and **ICT Support** as well as **Training**.
This enables future construction to act as a flexible, agile, value-driven, and knowledge based industry, and most of all, to be highly customer-centric, efficient and competitive.

The five strategic key elements, that the ManuBuild System is composed of are presented in figure 3 and are shortly outlined in the following paragraphs.

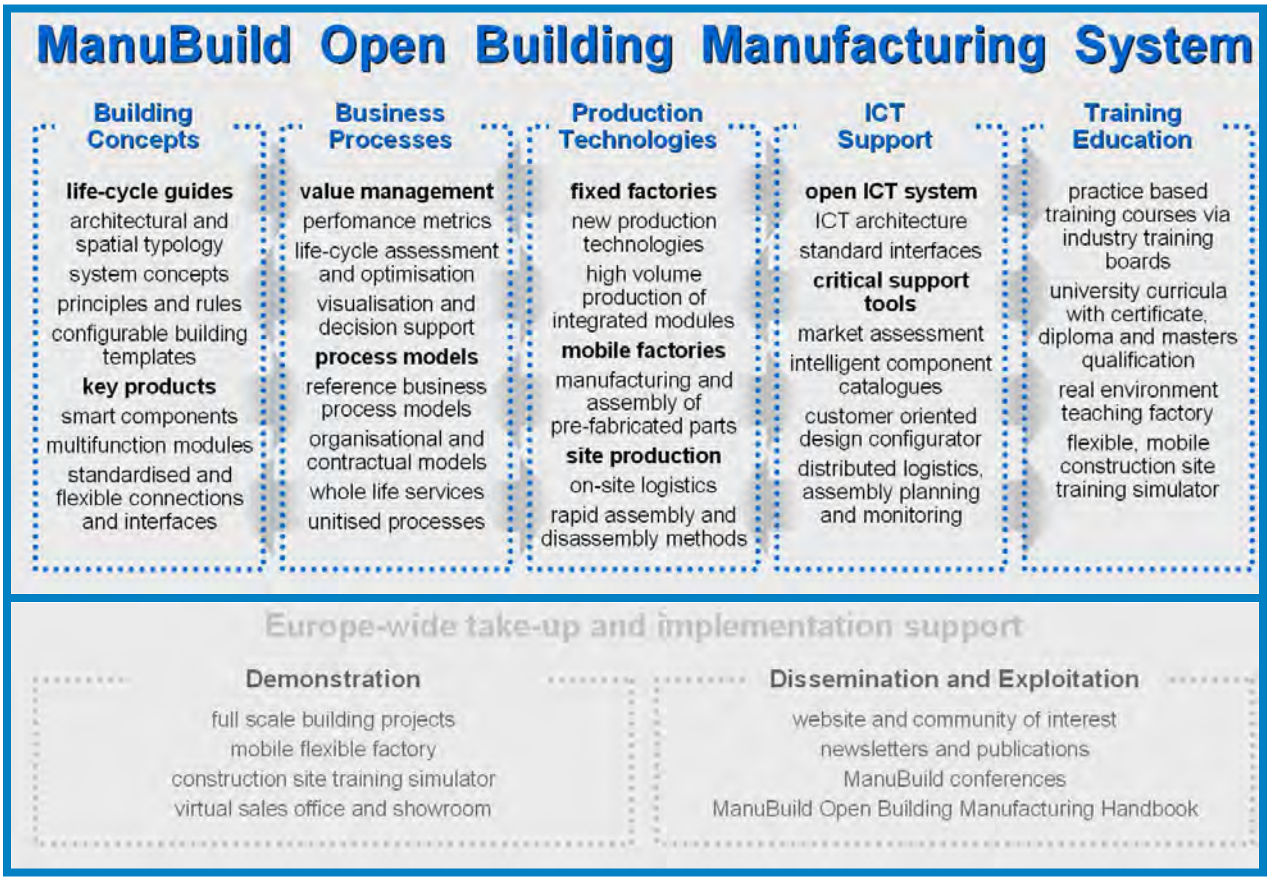


Figure 3: Key Priorities of ManuBuild

Building Concepts for efficient assembly of (pre-)manufactured buildings:

- flexible system typology supporting 30% of all building types through life cycle concepts, principles, guides and templates, simultaneously enabling rich architectural expression, flexible manufacturing, assembly and options for mass-customisation
- smart components and multi-function integrated modules (e.g. wall panels with services already integrated) representing 50% of a building’s value, suitable for customisation, manufacturing and rapid assembly and open for future integration of existing and emerging innovative materials, technologies and systems
- connections and interfaces enabling rapid and easy "plug and fix" assembly on site covering 80% of a building’s structural connections by using complementary approaches for standard connections, flexible connectors and usage of new materials

Business Processes for customer and community involvement in planning, design, configuration and customisation:

- performance driven production and delivery processes including assessment methods and indicators for 95% of the significant components, systems and whole buildings
- concepts and scenarios for value driven business processes, such as "a cost-sensitive world", "an energy-dependent world" etc by involving and working in collaboration with Europe’s key stakeholders
- organisational models for networked, virtual cooperation ("virtual factories"), identifiers for incentives and barriers for new contractual "win-win" solutions in an open market
- service models covering the full life cycle requirements of buildings including repair and maintenance, adaptability, reuse and recyclability

Production Technologies for efficient on-site and off-site manufacturing and assembly:

- off-site manufacturing and pre-assembly offering highly flexible, scaleable, efficient, and automated methods and systems, enabling the delivery of customer ordered modules and components within 5 days
- mobile factories that will bring efficient manufacturing and pre-assembly operations to building sites providing safe and clean working environments and reducing the number of transport kilometres needed to building site with up to 80%
- logistic system for efficient and lean handling and delivery of modules and components within supply chains and from all production units to the final assembly of buildings that support a stock turnover more than 10 times per year
- on-site assembly methods and systems for rapid, safe and precise handling and assembly of modules and components with an average target time from delivery on-site to being assembled in buildings of less than 20 minutes
- quality and safety assurance methods to secure safety, quality and environmental requirements and goals in manufacturing and assembly, in order to deliver buildings with zero defects, that are produced and assembled with zero accidents and injuries

ICT support:

- market analysis method and tool for creating demand and price level forecasts based on measuring marketing data thus enabling to plan production capacities according to actual demands and eventually also supporting and enabling the development of further components and products as a reaction to future market trends and requirements
- intelligent component catalogues, based on standardised description languages, for categorising, encapsulating and publishing product related data and knowledge
- interactive building configuration and assessment tools for customer driven, individual planning of aspects like design, functionalities, eco-efficiency, recycling etc and by making use of the intelligent component catalogues, thus enabling a reduction of design and planning time by 60%
- logistics management and assembly planning and monitoring tools for coordinating the supply of components from different sources and locations, for rapid (re-)planning and simulation of alternative assembly sequences and for having ambient access to product location and status thereby reducing overheads by 50%

Training to prepare the employees for the ManuBuild Open Building Manufacturing System:

- development of a multicultural and multidisciplinary training plan covering the necessary specifics including e.g. production technologies, system theory, electrical, mechanical and material science engineering, computer sciences, etc
- establishment of training courses through national industry training boards and European curricula for university education
- implementation of teaching facilities in a real factory environment for practicing and developing skills in advanced manufacturing of building components and modules
- development of a mobile and portable construction site training simulator, a virtual environment for the new working conditions of the "construction site of the future"

For involving the widest range of construction stakeholders, raising awareness, promoting the idea of ManuBuild and demonstrating its achievements and to initiate the Europe-wide take-up, implementation and use of the ManuBuild Open Building Manufacturing System, the five primary priorities are accompanied by Demonstration and Dissemination as strategic priorities for Europe-wide take-up and implementation support (see figure 3).

Demonstration to validate the ManuBuild results and prove usefulness in daily business:

- full scale building projects
- mobile flexible factory
- construction site training simulator
- virtual sales office and showroom

Dissemination and Exploitation for raising awareness and informing the European Community:

- stakeholder involvement and concertation
- website and community of interest
- newsletters and publications
- ManuBuild conferences
- ManuBuild Open Building Manufacturing Handbook

Conclusions

The ManuBuild Project and its ambitious goal of open building manufacturing is the first step for guiding the construction sector into a promising future centred around openness, efficient manufacturing and pure customer-orientation as well as for initiating a paradigm shift from construction's current state being mainly "craft and resource based" towards its future state characterised as "agile, value-driven and knowledge based".

The development of the ManuBuild Open Building Manufacturing System sets the cornerstone for future construction. But for achieving sustainable impact and continuous improvement it is vital that this idea not only is driven by the consortium of ManuBuild and merely accepted throughout the sector, but that it is adopted and implemented by the majority of stakeholders and further to this that it also experiences and benefits from a large number of additional developments coming from all across the construction sector.

Key Lessons Learned:

- Need for a radical paradigm shift from the current "craft and resource based construction" towards "open building manufacturing" that enables highly customised buildings using manufactured, knowledge based components from the open market and assembling them efficiently on site.
- Potential impacts from open building manufacturing include: construction cost reductions in excess of 50%, time reductions in excess of 70%; reduction in work related accidents of 90%; new knowledge based industry offering quality jobs; new business opportunities; safety at work; reduced waste; better job satisfaction; more value to customers (society), configurable, adequate, and affordable housing, etc.

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2

Best Practices: Lessons Learned on Building Concepts

Mieke Oostra & Christina Claeson-Jonsson

Best Practices: Lessons Learned on Building Concepts

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Abstract

This chapter focuses on the manner in which examples for the ManuBuild Building Systems have been evaluated. The development of ManuBuild Building Systems does not start in a tabula rasa situation. Open Building is an area where quite some attempts have been made in the past and where there are several building systems currently being used in the market that can provide ManuBuild with some valuable lessons. Furthermore, these examples can also guide industrial partners developing their own industrialised concept.

A comparison was made of building concepts currently available on the market. The parameters chosen for the comparison were based on the requirements necessary for the inventory of requirements for the ManuBuild System framework. In order to be able to score the different examples, not only on performance of the building system, but also as a complete entity on its overall performance, an evaluation method that included manufacturing process, business concept and related services was necessary. By analyzing where these current systems score high or low, it can be easily determined whether or not and where they can potentially be used as inspiring examples.

As a result, an evaluation tool was developed in order to evaluate current best practices. This tool can be used to set the aims and wishes for a ManuBuild System that an industrial partner is planning to develop.

Keywords: Evaluation Tool, Open Building Concepts, Industrialised construction, Best Practices

Background

Industrial Context

The development of a client oriented, flexible building systems framework with state-of-the-art architecture at the ambition level of the ManuBuild project cannot start without looking at the past as well as the present. In this chapter, will we focus on some building concepts currently operational in the field of Open Building and Industrialisation that can be of interest when developing a ManuBuild System framework. This is also helpful for industrial partners wanting to develop or benchmark their own ManuBuild Building Concepts. It will provide them with a way of comparing different initiatives. It will help them to answer the question on what aspects these concepts are interesting, and how well they perform according to the ambitions set within the ManuBuild project. In order to carry out this task, an evaluation tool was developed.

Learning Objectives:

The reader of this chapter can expect to learn:

- The method used to evaluate Best-Practices in ManuBuild.
- And to receive information on four current Best-Practices.

Approach

As a first step in the development of concepts, principles, rules and indicators and guidelines for manufactured buildings, an inventory was made of Best Practices. Different examples were gathered from European countries (Sweden, Finland, Netherlands, UK, France, Poland, Estonia, Spain, Italy and Germany), the United States and Japan. The information collected included both building systems and building components that either had an industrial focus or dealt with the customer choice issue. Obviously, when studying different building concepts, the trap for an interested engineer is the eagerness to collect all possible information on relevant systems. Consequently, the risk of information overload is evident. How do you avoid falling in such a trap?

In order to be able to analyse the collected concepts, we had to determine what aspects were most important to us. Of course, these aspects were related to the ambitions set in the ManuBuild project on the part of the building system. But since the building system is intertwined with business process, manufacturing process and related services, like ICT tools, we decided to incorporate those in our evaluations as well. Since our focus lies on the level of the entire concept, it seemed important to leave out the information we gathered on components only, but store this for later use.

The next step was to structure the information we gathered on building systems and finding visual means to create an overview. This resulted in different graph templates that could generate plots to provide insight how much current Best Practices are already (partly) achieving goals set by the ManuBuild project.

In order to determine what aspects of past and current developments are of most interest for the evaluation in the context of the ManuBuild System framework, we first made an inventory of the elements relevant for the four different aspects relevant to the ManuBuild vision, namely, product concept, business process, manufacturing method and offered services.

Looking more closely at the different concepts for an open manufactured building or product concept, the following elements were regarded as crucial:

- Customization
    - Made to order
    - Flexibility
    - Transparency
- Architectural & structural typology
    - Design
    - Functionality
    - Impact
- Multi-function integrated modules

- Smart components
- Smart connections and interfaces

The plot in Figure 1 shows the results of the evaluation of the above elements on some of the best practice concepts.

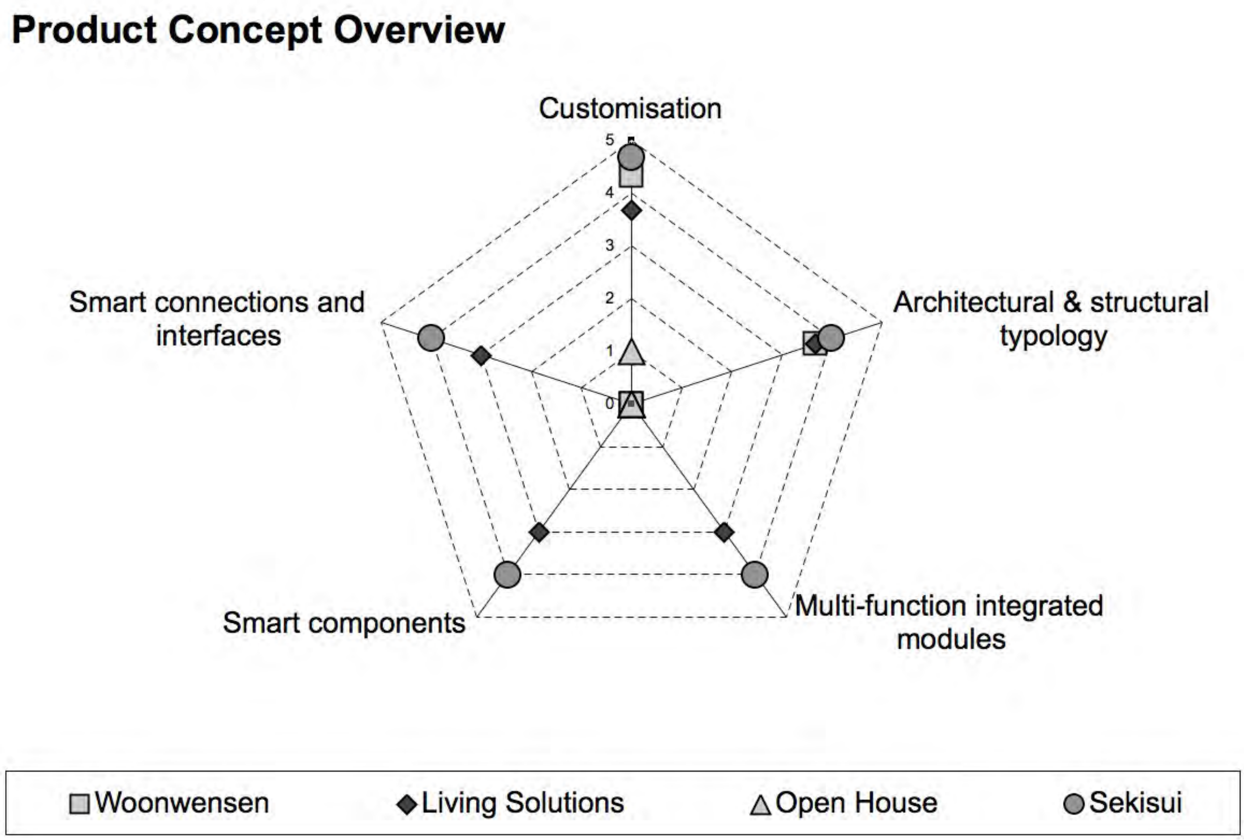

Figure 1 Results of the evaluation on some concepts based on the essential elements of an open manufactured building.

For business process the following aspects were analysed:

- New business concept
- Service models
- Organisational & contractual models
- Performance metrics

For manufacturing methods:

- Off-site manufacturing
- Developed technical systems

For services:

- Use of ICT
- Other services

In order to create insight on the level of the total building concept averages were calculated of all aspects concerning on the four categories of product concept, business process, manufacturing method and services. These averages were plotted in Figure 2.

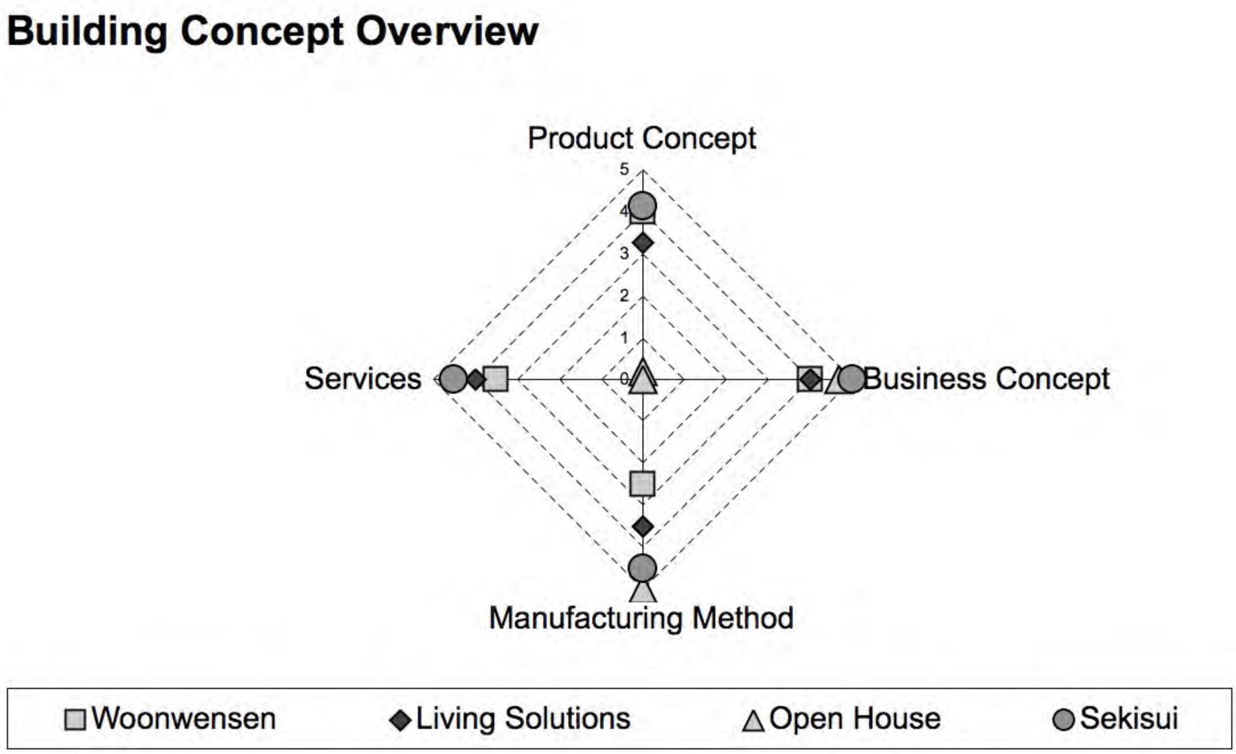

Figure 2 Evaluation of building concepts based on the four ManuBuild processes and their criteria.

In order to be able to generate an overall picture that displays more information at once, a composite graph was developed on basis of the following elements:

- Customer focus: to what extend are houses produced according to the needs and wishes of customers
- Supply chain management: to what extend is the production and logistics optimized and is it prepared for customer choice.
- Long-term relationships between participants: in order to be able to facilitate learning process between partners in a delivery chain it is important that participants can build on existing experience. In order to be able to do that continuation, standardisation of processes, procedures and people have to be guaranteed.
- Planning a control of processes: how well is the process pre-engineered and how easy is it to control it for timely output, quality and use of resources.
- Systematic performance measuring and re-use of experiences; does the entire chain learn from its experience? Does it draw the benefits from repetition and possibilities of standardisation?
- Off-site manufacturing of building parts: what part of the work is being done at the building site? This with regard to the fact that a construction site does not often provide the best

conditions to produce a quality product, and does not necessarily result in optimized logistics.

- Development of technical systems; how clever is the structuring in components when looking at production, logistics, assembly, maintenance and environmental issues?
- Use of information and communication technology: both in the front office (to communicate and facilitate customer choice) or in the back office (either between partners in the production chain or in the own production process)

Figure 3 shows a graph according to these specifications, and a table with the requirements for a specific score can be found in the appendixes.

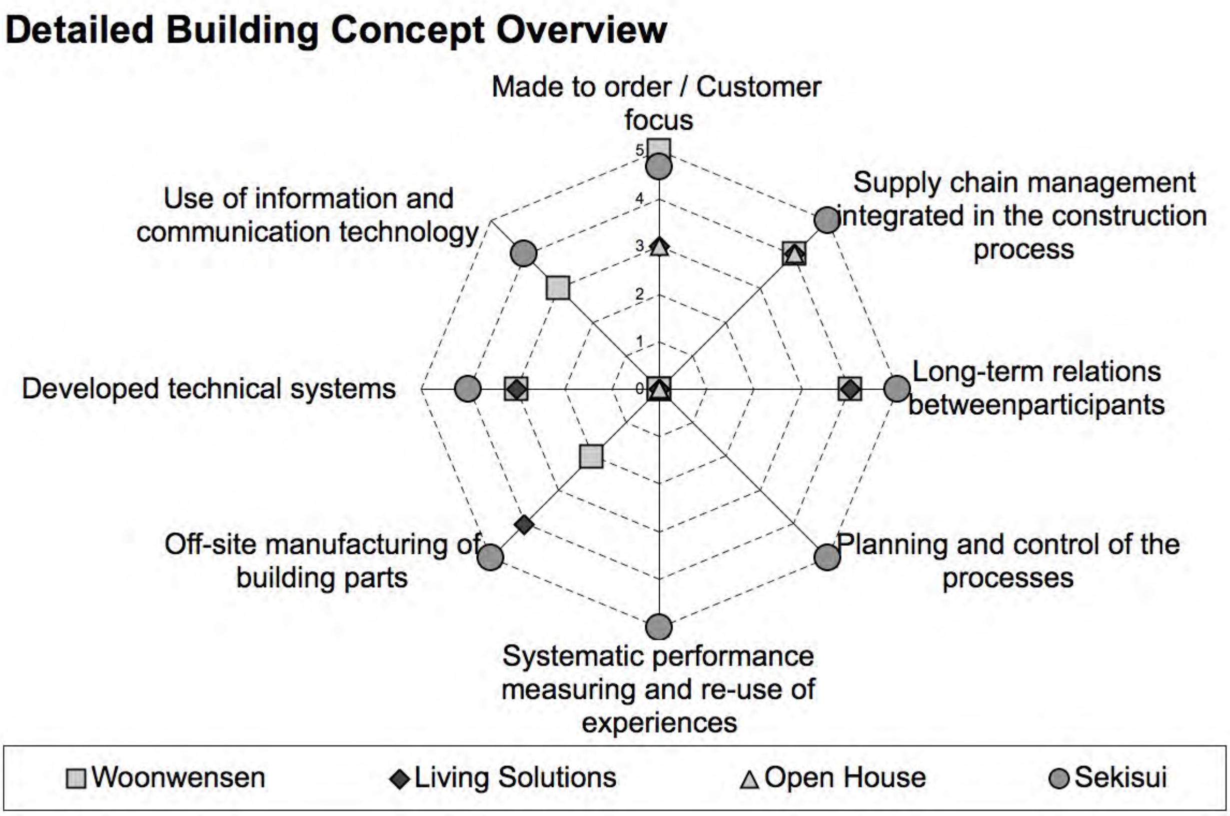

Figure 3 Results of the evaluation on some concepts based on the essential elements of product concept, manufacturing process, business concept and related services that give insight in entire building concepts.

Examples

In order to provide an idea of why some Best Practices perform in the way presented in the developed evaluation method, information will be given on a selection of four Best Practices in the field of current available Building Concepts.

The model was used to evaluate various examples from different countries. At the start we scored some projects to compare if different people would come to the same scores. We discovered in this process that it is not easy to collect all the relevant data in order to be able to score all the systems on all aspects and elements. The scores must therefore been seen within the restrictions of the information available at that time to the ManuBuild consortium. Here we will give a rough sketch on four of these Best Practices that were analysed within the ManuBuild project to provide a glimpse on the current state-of-the-art.

Dutch Example – Wenswonen

Heijmans, one of the bigger contractor firms in the Netherlands developed the Wenswonen concept as a way to provide buyers of newly build homes with real choice. Potential buyers are provided with a CD-rom on which the 3D choice model, the "Woonplanner", is presented, accustomed to the project in which they have showed interest. With the choice of an option, price consequences are presented directly. For the home buyer this makes the choice process very transparent. Furthermore, the CD-rom offers them a way to think choices through in an environment they chose together with the people they think are relevant. This tool has become an example in how choices can be presented to potential buyers of new housing projects and is therefore often used as a reference in the Dutch market. Possible choices presented at the client: size of the house, the amount of rooms, outside appearance of the home and even garden layout options. The exact options are determined per project and predefined in this customer-oriented tool.

Since the goal of Wenswonen was not to provide an integrated approach to the actual realisation process and follow up after the choice of customers was made clear, no real connection is made to the realisation process of the project. It is therefore more a marketing tool, not only directed at potential home owners but more specifically at local communities and housing cooperations, the direct clients of the contractor, in order to help them realize their aims for customer-oriented housing.

Figure 4 Examples of projects developed with the Wenswonen concept[1]

Swedish Example – Open House

Open House builds multi-storey apartment houses (3-8 stories) and is owned by Norwegian OBOS Group. The Open House concept is based on three foundations – the patented modular multi-storey technology, an industrialized production system and a standardized programme of basic modules. Open House Production AB provides a complete chain of quality, from architectural support, through project management, on to industrialized indoor production and

[1] Pictures from www.wenswonen.nl visited at October 29, 2006.

ending with the final assembly of the turnkey residential house at the building site. Their aim is to provide a better quality to a lower cost and shorter delivery time.

The houses are made with a high level of prefabricated components. The floors and walls are produced, fully equipped and assembled to 3-D modules in the factory. The building technology based on lightweight solutions and quite small tolerances. All packages are 3.90 meter to fit transportation requirements and can be divided lengthwise and widthwise. A module weight is 5500 kg. Everything is documented in manuals to ensure that everything is repeated in the same and exact manner and there is continuously work on feedback and review.

Figure 5 Assembly of modules on the construction site

The openness is limited. However, equipment for heating, water and sanitation etc. is bought from external suppliers. Open House has subcontractor contracts with selected suppliers; and to some extent developed collaboration with subcontractors and subcontractor-subcontractor.

The material logistics are co-ordinated to some extent. Design is integrated in the production. However, no 3D-model is used neither in design nor production. This is an area where further development is needed.

Regarding architectural freedom, Open House writes on their homepage “Large or small apartments, high or low standard, 3 storeys or 8 – the palette of choices is in the hands of the investor. We supply the industry-leading concept to make it possible”. They mean that their patented module based technology is different from all other module concepts. It is open, not confined to four restricting walls. This gives the architect the same freedom as in any other housing development: The freedom to choose façade and roofing material, the placing of interior walls etc.

Figure 6 Example of a housing project built by Open House

English Example – Living Solutions

Corus developed with Living Solutions a concept in which complete rooms are assembled and put into place at the construction site. An ensemble created of several of these rooms can be finished with different options, like brick, corium, render, composite panels, metal cladding, terracotta cladding or cedar cladding. There are different scheme options, which include a pitched room of timber or light steel frame, flat roof, lift shaft, staircases, balconies and canopies.

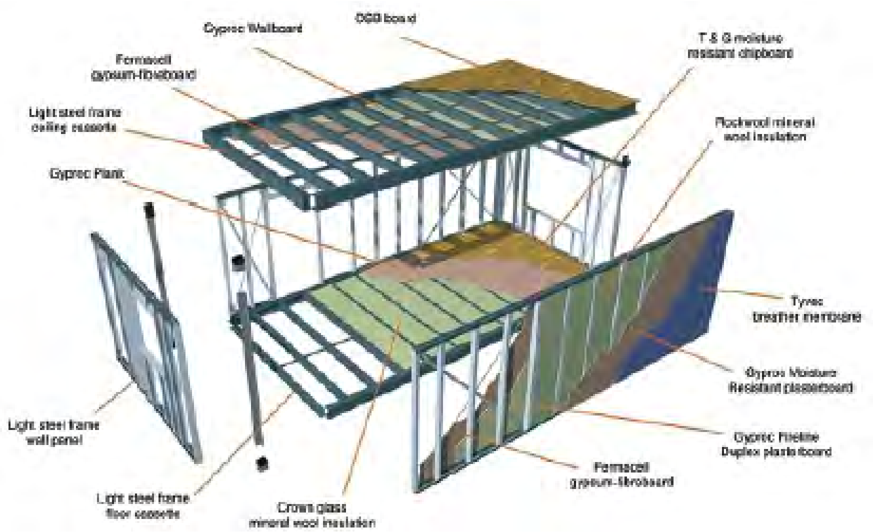

Figure 7 The basic structure of the prefabricated rooms of Living Solutions.[2]

[2] Picture from the brochure “Corus Living Solutions; Start building with rooms” May 2005 available at www.coruslivingsolutions.com.

At the basis of the initiation of the business concept of Living Solutions lays the idea of introducing the principles of the manufacturing industry in construction. They will work with a certain supplier until another supplier can provide them with better solutions. In addition, they will look for cooperations models that will create benefits for both. Since a supplier will only be motivated to invest in new products and innovative solutions if they can foresee enough sales. Corus has been looking for ways to collaborate with contractors in this field, with whom they operate on bases of open cost book approach. The concept does not include direct contact with every end-user. However, by choosing a certain niche, investing in understanding the needs of end-users and facility managers as a group, and, to specialise their salesforce, an extra selling argument is created. One such segment is soldier homes. For example, a soldier has to be able to put his riffle against the wall without creating damage. Thus, by proving clients and architects with solutions to the real needs and wishes of the endusers, a unique selling point has been created.

For manufacturing they have equipped an old Corus building with all the facilities they need for production according to the principles of the manufacturing industry. Central is the pre-engineering and production of rooms that can be standardized. The approach proves ideal for repetitive niches like soldier homes or hotel rooms. While construction in general does not profit repetitions, this concept does.

Figure 8 Prefabricated rooms put together on site.

For Living Solutions show modules prove to be a very powerful tool towards both clients and architects. They are also used later in the client process as a reference module to avoid conflicts around the acceptance at delivery, right at the end of the production line. ICT tools are used in the back-office.

Figure 9 Examples of projects erected with the Living Solutions concept

Japanese Example – Sekisui Home

At the level of building systems Sekisui offers three different construction types: a basic, a more advanced steel construction system and a wooden construction system. These systems can be used to construct three different categories of buildings: residential homes, condominiums and apartments. Directed at the customer of residential homes, Sekisui has developed a whole gamma of house types, interior styles and garden designs from which the customer can chose. Customers also have the possibility to chose some extra options like a home-cinema entertainment system, a system to diminish the effects of possible earthquakes, facilities for pets and all kinds of adjustments belonging to different age groups (from babies, to youngsters and elderly people), handicaps or pregnancy.

Figure 10 Options for different age categories become available as results of Sekisui's R&D department[3].

A ten-year guarantee is given to every house sold. Customer Service Centre will check the houses regularly to make an inventory of necessary maintenance and wishes for remodelling. An offer will be presented afterwards on basis of the actual maintenance state of the house. The check-up is free of charge. Maintenance service for the garden is also possible.

Sixty-three days are needed to finish a house. Two weeks of which are used for production in the factory and seven weeks on site to erect the construction and applying the internal finishings. For the manufacturing process principles from lean production are used, like Just-in-Time and long-term relationships with suppliers. Employees of Sekisui are expected to submit 10 ideas a month for improvement. Every idea will get paid and reviewed by the staff. Once a year the best idea will be rewarded with a price, being a considerable sum of money.

Figure 11 Factory of Sekisui House and model home close to Tokyo

On service level, Sekisui will provide interested customers with information via internet, all kinds of brochures and a special introduction visit. Sekisui will first send potential customers an information parcel. An introduction visit will be planned including a movie in the Sekisui Dream Factory which will show the life of happy families in a Sekisui neighbourhood. The film will be

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[3] Pictures from www.sekisuihouse.com visited at October 27, 2006.

in accordance with the season of that moment. After this visit the screen will roll up and doors will open to the houses of the neighbourhood you have just seen. In one of these houses all kinds of tests are performed to prove to you the excellent quality of the Sekisui house. Afterwards you can visit some fully equipped houses, to give you a real feel of what your house could look like. In a next visit an architect will help the interested customer to make the necessary decisions.

Analysis

The examples clearly show that in order to achieve the ambitions of ManuBuild, not everything has to be invented from scratch. There are several currently available concepts that partly fulfil these. At a European level, the gap to the current state-of-the-art is much bigger than seen from a global perspective. But even then there are still some aspects that have not been fulfilled to this point. The evaluation tool helped us evaluate on what aspects ManuBuild Building Concepts would be unique in the world. First, it would be unique in the way it is open to system architects. Since the principles of the ManuBuild Building System are open and therefore accessible to the interested outsider, additionally components can be made that can be used within the system.

This is probably a prerequisite to the next unique aspect of the ManuBuild Building system, namely that it incorporates regional differences and is open to architectural change. Such a system is still non-existent at the moment. Finally, to truly integrate the four elements into one building system is quite a challenge.

Conclusions

Some aims of the ManuBuild System framework have been partly realized in a Building Concept that is currently available somewhere in the world. By analyzing where these current systems score high or low, it can be easily determined whether or not these examples can potentially be used as inspiration. In order to get a clear picture on what relevant examples are on the aspects we can use in ManuBuild we first made an overview of the elements that are of importance in our study. These elements, representing product concept, building process, manufacturing process and provided services, are:

- Made to order/customer focus
- Supply chain management integrated in process
- Long-term relations between partners
- Planning and control of the processes
- Systematic performance measuring and re-use of experience
- Smart production procedures for building parts
- Development of technical systems
- Use of information and communication technology

This tool makes it possible to weigh Best-Practices, the ManuBuild Building System and your own Building Concept that is currently under development, or a concept that is already available for commercial use. It makes it clear which examples could be relevant on specific aspects.

Key Lessons Learned:

- The method used to evaluate Best-Practices.
- A tool that makes it possible to weigh your own Building Concept that is currently under development, or a concept that is already available for commercial use. It helps to identify which ones of the gathered examples could be relevant on specific aspects.
- The aspects that make a ManuBuild Building System unique to the world.

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Authors' Biographies

Mieke Oostra works for TNO as a senior researcher on building process innovation and leads a team of researchers working in this area. She graduated as an architect at Delft University of Technology. After her study she became a researcher on innovation processes in construction at the department of Building Technology from the same university from 1994 to 2001. In 2001 she obtained her PhD on the role of architects in product innovation. After that theory was brought into practice in a four-year period at Slavenburg's Bouwbedrijven, a Dutch contractor. Here she was responsible for the implementation of innovations that proved to be relevant for both clients and the firm.

Christina Claeson-Jonsson works for NCC Engineering as senior project manager for Research and Development, where her main tasks are to initiate and lead projects related to processes and industrialised construction. In ManuBuild, she works mainly with the building system and leads the work package on open building systems. She has a M.Sc. in Structural Engineering and holds a Ph.D. in design of concrete structures.

Appendixes

Table 1: Industrialisation characterization and exemplification of level of achievement, from Lessing et al (2005)

Area	Level	Characteristics
Planning and control of the processes	0	No information available
	1	Scarce structure of process planning and control. Time schedules are not definite, unclear responsibilities and management has poor control of the process.
	2	A clear holistic structure of the project processes. All participants respect delivery dates and schedule.
	3	Developed planning in early phases of projects where key participants collaborate to give input to schedule. Developed structure for design delivery.
	4	Clear gates between sub-processes where certain tasks must be fulfilled. Detailed planning of all processes supported by structured planning system. All tasks in manufacture and assembly are thoroughly prepared.
	5	Planning and control systems supported by advanced ICT-tools and integrated with planning of supply chain activities. Performance measures give important input to planning.
Off-site manufacturing of building parts	0	No information available
	1	No off-site production
	2	Simple parts of the building are manufactured off-site. Examples are roof trusses and concrete elements.
	3	More advanced parts are pre-assembled off-site. It can be façade elements, complete wall- and slab elements and stairs with ready surfaces.
	4	Advanced parts are pre-assembled and integrated with other pre-assembled parts. It can be volume elements with all surfaces completed, completely equipped bathroom modules and pre-assembled service elements.
	5	Advanced parts are pre-assembled, design and manufacture are supported by IT-tools, advanced logistics principles and planning system.
Developed technical systems	0	No information available
	1	Minimal use of developed technical systems. Hand craft methods dominate
	2	Developed technical systems are used occasionally but without a clear strategy. Systems can be frame-, façade- or service systems.
	3	Developed technical systems are designed and used for certain parts of the building, based on a technical strategy.
	4	Complex technical systems used for a majority of the parts of the building. Systems are designed to fit each other and developed in partnership with suppliers.
	5	Complex technical systems are used, continuously developed in partnership with other participants, based on experiences from projects and supported by IT-tools

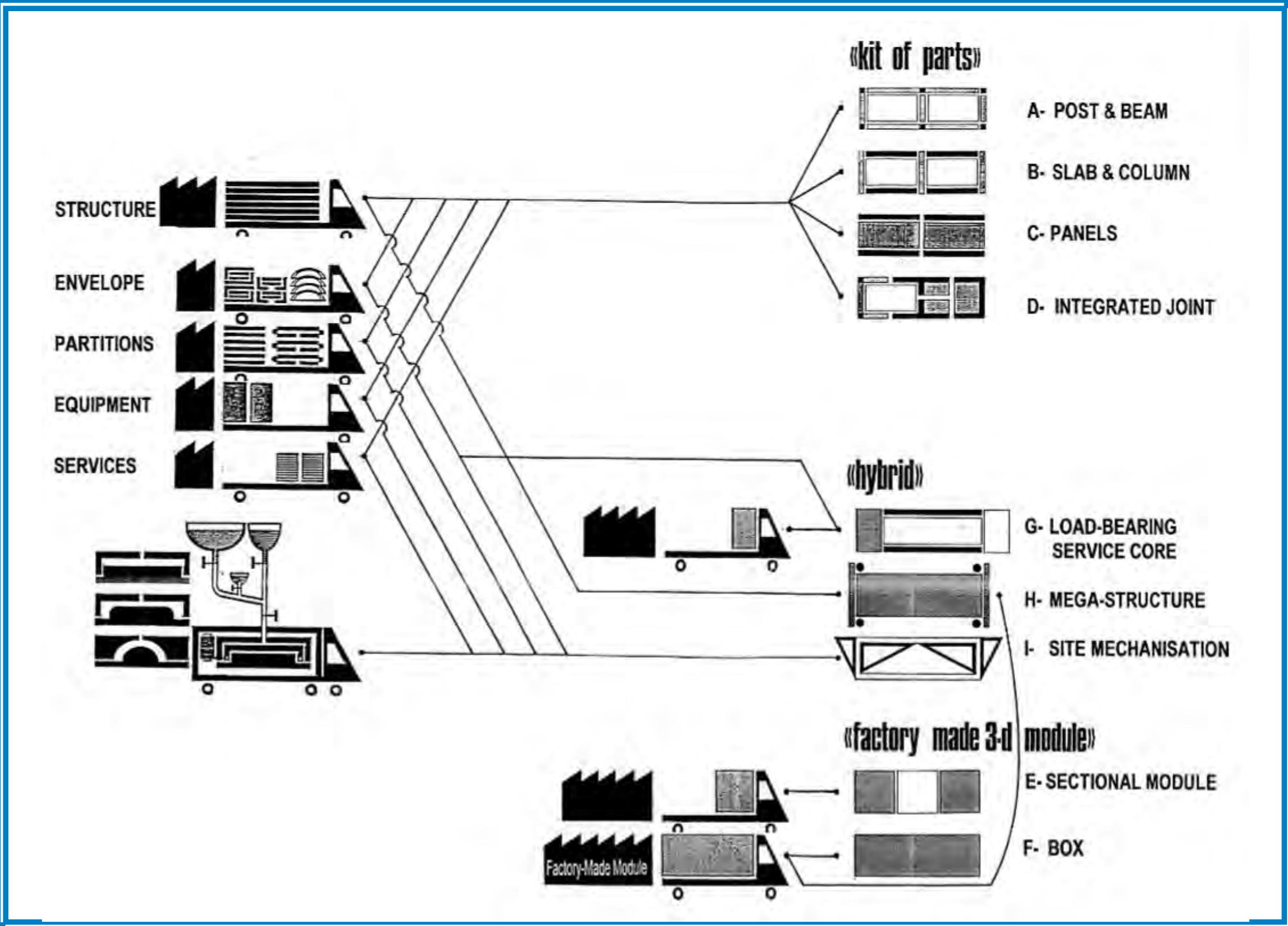
Area	Level	Characteristics
Long-term relations between participants	0	No information available
	1	No long-term relations are established
	2	Some relations are identified as more important than others. Relations are established but not in a systematic way.
	3	Long-term relations are established with key participants. Activities to strengthen the relations are done. The partnering concept is used occasionally
	4	All participants are involved on long-term basis. The participants work together as a team. Strategic partnering with key participants
	5	A structured program is used to work actively to develop the relations and cooperation. Evaluation is supported by IT-tools. Strategic partnering is thoroughly used.
Supply chain management integrated in the construction process	0	No information available
	1	Logistic activities are not on the agenda
	2	Solutions for better materials handling are used. Sufficient storage, delivery patterns and information exchange with key suppliers are examples of efforts.
	3	Just-in-time principles are applied. Strategic work with low storage levels, adjusted deliveries, packages and developed relations with key suppliers.
	4	Supply chain activities integrated in the construction process. It includes developed supplier services and information flow enabling advanced technical solutions.
	5	Supply chain activities are fully integrated as natural parts of the construction process. Supported by ICT-tools for planning, purchasing, scheduling and design.
Customer focus	0	No information available
	1	The customer is anonymous and un-known.
	2	General insight about basic end-customer priorities, e.g. equipment preferences, apartment size. Clear perception of who the company's customer is.
	3	Basic investigations about end-customer needs and priorities for different cost levels and customer segments. Topics for investigation can be equipment, service needs and apartment layout.
	4	Systematic investigations about customer needs and priorities, follow-ups with moved-in tenants. ICT-tools supporting investigations and analysis of the material.
	5	The customer investigations and follow-ups are integrated with other areas, e.g. the technical development, manufacturing and assembly process and the project planning. ICT-tools make the information transparent in the whole process.

Area	Level	Characteristics
Use of information and communication technology	0	No information available
	1	No ICT-tools are used
	2	ICT-tools are used by some participants in the process.
	3	All participants are using ICT-tools to support their own activities. No common strategy is used.
	4	All participants are using ICT-tools integrated with each other. A common strategy is applied for the area.
	5	Advanced ICT-tools used by all participants to support other developed areas. ICT-tools support and integrate design, manufacturing, planning, performance measuring and purchasing.
Systematic performance measuring and re-use of experiences	0	No information available
	1	No measuring and no systematic re-use of experience.
	2	Experience exchange in some parts of the process like regular meetings with manufacturing staff or the design team. Limited documentation.
	3	Measuring of tasks in some parts of the process. It can be key activities in manufacturing, assembly time, follow-ups in design. Documentation handled by individual participant.
	4	Performance measuring in all parts of the process but limited co-ordination. Experiences well documented by process owner.
	5	Performance measuring in a number of areas, experiences collected and spread systematically, with developed ICT-tools. This supports work with customer focus, relations, planning and the industrial manufacturing.

3

A Generic Classification of Industrialised Building Systems

Roger-Bruno Richard



A Generic Classification of Industrialised Building Systems

Roger-Bruno RICHARD, Université de Montréal (roger.richard@umontreal.ca)

Abstract

INDUSTRIALISATION is a Generic Organization (continuous interaction between all the participants) based on Quantity (large enough to amortize the investment in a process capable of simplifying the production and thereby reducing the costs) and offering an Individualised Finished Product (in an industrialised building industry, the products are not buildings but building systems).

A BUILDING SYSTEM is a set of parts and rules where the details are solved before actual buildings are planned: the same parts are re-used for a large number of buildings, different as products but generated by a similar process. Therefore, construction is not re-invented each time a building is planned, as is often the case with the traditional "professional service" approach today. Altogether, there is no "best system in the world" but a wide variety of options to choose from: the context (needs and resources) should then lead the generation, the development or the selection of an appropriate Building System.

Owing to the fact that buildings are site-related and technology factory-related, three basic building systems categories can be outlined and, in a sense, considered as the basic three colours (i.e. blue/red/yellow) from which the "palette" of 9 types of building systems is generated: the Site-intensive KIT-OF-PARTS (A- Post & Beam; B- Slab & Column, C- Panels; D- Integrated Joint), the Factory-made 3D MODULE (E- Sectional Module; F- Box) and the HYBRID (G- Load-Bearing Service Core; H- Megastructure; I- Site Mechanization). The main functions of the building generate its sub-systems: Structure, Envelope, Partitions, Equipment and Services.

Keywords: Industrialised Strategies and Technologies, Factory Production, "Palette" of options.

Background

Industrial Context

Industrialisation can be defined as a generic organization based on quantity and offering an individualised finished product.

(a) ***A generic organisation*** means grouping all the participants (manufacturers, assemblers, designers, managers, distributors, installers, etc.) into a continuous interaction, either as employees, sub-contractors or partners.

(b) ***Based on quantity*** means aggregating a large market to feed the continuity and to amortize the investment in a process capable of simplifying the production.

(c) ***Offering an individualised finished product*** means addressing diversity through mass-customisation. Four strategies are available and frequently used by other industries to generate individualisation within mass production: Flexibility of the Product, Flexibility of the Tool, Multipurpose Framework and Combinability.

Therefore, the basic strategies of Industrialisation result from the three elements of that definition. Technologies will follow. As mentioned above, “a process capable of simplifying the production” is the key to both quality and economy (Richard, 2005.08); because most contemporary processes are readily capable of high precision and because their costs can be eventually reduced to small fractions per unit produced.

Problem

As far as the product is concerned, the situation with buildings is quite different from most other types of product. In a truly industrialised building industry, the products are not buildings but Building Systems. Whereas all industrialised products are factory made, things are different with buildings, because buildings have to be positioned on a site. So any process will have to meet two requirements: simplifying the production and proposing a clever distribution of the work between the factory and the site.

Learning Objectives:

- A Building System is a set of parts and rules where the details are solved before actual buildings are planned: the same parts and their details are re-used for a large number of buildings which are different as products but generated by a similar process.
- The main parts of the building system are its sub-systems, which generally correspond to the main functions of the building. A building system is usually composed of five sub-systems: STRUCTURE, ENVELOPE, PARTITIONS, SERVICES and EQUIPMENT.
- Owing to the fact that buildings are site-related and technology factory-related, three basic building systems strategies can be outlined :

  I- the Site-intensive Kit-of-Parts;

  II- the Factory-made Module;

  III- the Hybrid.

Approach

The relationship to a site is the determining factor distinguishing the three categories of Building Systems**:**

1. the Site-intensive Kit-of-Parts;
2. the Factory-made Module;
3. the Hybrid.

A group of 9 building systems types can be generated from the three basic categories (Richard, 2004-01): from “A” to “I” together with complementary “Open” Sub-systems when a system is incomplete.

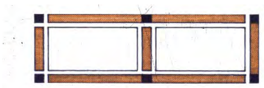
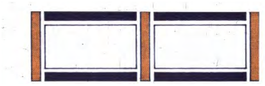
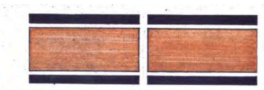
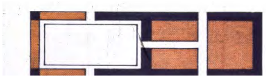
Analysis

1 - The Site-Intensive KIT-OF-PARTS ("Meccano")

In the Site-Assembled KIT-OF-PARTS ("Meccano") category, all sub-systems, including the structure, are made at specialized plants and transported to the site as separate parts, which means an important jointing operation at the site.

The Site-Intensive KIT-OF-PARTS involves a few simple factory-made components produced in large quantity and designed to be assembled at the site as well as to generate a diversity of building forms. The site assembly is however subjected to an elaborate series of jointing and connecting operations.

The four types of systems within that category are distinguished by the geometry of the structural sub-system which determines the jointing to do at the site: the Post & Beam ("A"), the Slab & Column ("B"), the Panels ("C") and the Integrated Joint ("D"). As one moves from "A" to "D", the work on the site is simplified: Post & Beam systems need more connections and infill than Slab & Column; and Panel Systems allow more room for connections and offer a more distributed structure. The Integrated Joint is the most daring solution as it locates the joint outside the geometrical meeting point.

I- Site-intensive KIT OF PARTS	Specificities	Sub-Divisions
 A- POST & BEAM	**Skeleton open to horizontal and vertical infill**	• **Segments** • **Continuous Column** • **Continuous Beam**
 B- SLAB & COLUMN	**Continuous horizontal elements**	• **Solid Slab** • **Ribbed Slab** • **Slab Incorporating a Perimeter Beam**
 C- PANELS	**Load-bearing flat components providing a linear distribution of the loads**	• **Lightweight** • **Reinforced Concrete** • **Pre-stressed Concrete** • **Mixed**
 D- INTEGRATED JOINT	**Monolithic component locating the joint outside the geometrical meeting point**	• **Point to point** • **Framed** • **Planar**

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Strategically, distributing the tasks to a large number of available specialised manufacturers can reduce the initial capital investment for each one of them.

Functionally, all the sub-systems can be relocated and demounted when dry (mechanical) joints are used thereby allowing for flexibility and sustainability.

A- POST & BEAM: Skeleton open to horizontal and vertical infill on site.

Advantages:

- Loads concentrated on point axes = maximal planning freedom;

- Appropriate for "Open Systems" as the framework can serve as connector between horizontal slabs and vertical panels;
- Adaptability in three directions.

Limitations:

- Higher structural costs due to the concentration of loads;
- Large amount of site connections and infill.

The components themselves can offer multiple choices, like the many modular holes present on a piece of the Meccano set. As demonstrated by projects like GenterStrasse in Munich, designed by Otto Steidle (Kossak, 1994), multiple-corbels columns can be combined with other off-the-shelf components to generate a fully-fledged Industrialised, Flexible and Demountable (IFD) system. The twin post and simple/double beam system developed by Vittorio Gregotti for the Scientific University of Palermo (Rykwert, 1996), notably with the purpose of integrating all the conduits, is an eloquent testimony of the rich architectural vocabulary possible with imaginative component design.

B- SLAB & COLUMN: Simplification through the introduction of a single horizontal element.

Advantages:

- Horizontal integration of the structure = no infill required;
- Horizontal al adaptability as the areas between the columns are open;
- Possible integration of the services within the structural slab;
- Adaptability in two directions.

Limitations:

- Conflict between the uniform distribution of loads in a slab and the concentration required to meet a column; therefore, the "Ribbed Slab" and the "Slab Incorporating a Perimeter Beam" are the prevailing Sub-Divisions.

C- PANELS: Load-bearing flat components distributing the loads on a continuous line.

Advantages:

- Direct economical distribution of the loads from the vertical to the horizontal axis without any transfer;
- Usually integrating the soundproofing and fireproofing performances.

Limitations:

- The vertical axis generates a continuous wall which governs the planning, an easy situation in housing due to the large number of partitions required anyway;
- Adaptability limited to the structural bay.

The Descon system (HUD, 1968), only non-US winner of Operation Breakthrough, is a very clever Open System in precast concrete, innovating and generating variations within the realm of available "off-the-shelf" technology. For instance, the bolted structural connections were using oval holes punched through standard steel angles and tees. Descon was inviting local and regional manufacturers to bid on the basis of three documents: performance criteria, modular coordination rules and interfacing details. Descon itself had absolutely no manufacturing facility.

D- INTEGRATED JOINT: Monolithic component simplifying the connections by locating the joint outside the geometrical meeting point.

Advantages:

- Simplification of the jointing operations = A series of single (one to one) connections rather than dealing with 4 to 6 components (sometimes heavy) converging at the geometrical meeting point;
- Accelerated site assembly;
- Reduction of the structural requirements by taking care of both positive and negative moments.

Limitations:

- Some components can be quite bulky;
- Adaptability conditioned by the geometry of the structural sub-system.

As the jointing of an Integrated Joint system is done away from the geometrical meeting point of the axes, only two parts are meeting each other at each joint. The best example of an Integrated Joint system would be Componoform (Componoform, 2003): it is basically a joint-to-joint system, generating an open skeleton identical to the configuration of a Post & Beam system as far as the other sub-systems are concerned.

2 -The Factory-Made 3D MODULE

In the Factory-Made 3D MODULE category, all spaces and all components of the building are entirely made, assembled and finished at the plant as 3D modules requiring only simple connections to the foundations, between themselves and to the main service conduits once at the site.

Of course, carrying the module from the factory to the site means paying to transport “air”, since most of the volume is occupied by empty space and since transportation is usually calculated in terms of volume. When the 3D modules are in concrete, the weight becomes a major factor and the building would logically be limited to three or four stories, unless the loads are transferred, an elaborate process that could neutralise the economy of full factory production.

II- Factory-Made 3D MODULE	Specificities	Sub-Divisions
 **E-SECTIONAL MODULE**	**Small and easy to transport modules providing only a part of the building**	• **By Addition** • **Checker Board** • **By Compaction**
 F- BOX	**Autonomous unit entirely completed at the plant**	• **Framed at the Edges** • **Panelized** • **Monolthic**

Strategically, an important capital investment is required to initiate and operate a 3D Module plant.

Functionally, the dimensions are limited by the highway regulations and therefore the adaptability inside the box is restricted by the geometry of the box and by the configuration of the box acting as a structural shell.

E- SECTIONAL MODULE: Small and easy to transport modules but incomplete, as they need a complementary component or process once they reach the site

Advantages:

- Compact transportation as only ± 30 to 50% of the space is factory made, the rest being generated at the site.

Limitations:

- Necessity of an important site team to complete & finish the building, which could cost more than the transportation savings;
- The Sectional Modules can be relocated, conditional to the site counterpart.

The classical example of the “By Addition” Sectional module is the Nakagin building in Tokyo (Ginza) by Kisho Kurokawa (Kurokawa, 1992): the circulation tower is cast in situ incorporating a steel structure to which factory-made “capsules” are connected. The Shelley “Checker Board” operation in Jersey City (HUD, 1968) went into bankruptcy mainly due to the large amount of site work to finish and equip the spaces generated in situ by the checkerboard counterparts. The amount of work to fold out “By Compaction” large size modules is most of the time costing more than the transportation of fully completed ones; but the situation can be different with small size modules.

F- BOX: 3D unit entirely completed at the plant.

Advantages:

- Maximal factory production = freedom from the effects of the climate; semi-skilled labour; sophisticated tooling; precision & quality control; rationalisation (notably transversal dispatching of components along the main assembly line) and bulk purchasing of components;
- Minimal work at the site;
- Variable groupings in a low-rise situation (3 or 4 stories).

Limitations:

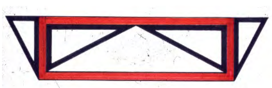
- High initial capital investment & necessary continuity of the demand to amortise it;
- Important but not prohibitive transportation costs;

The Japanese 3D modules (“units”), manufactured notably by Sekisui Chemical, Misawa Homes and Toyota Housing Group (Richard and Noguchi, 2007), are offering container-sized framed-at-the-edges steel structures mainly used for detached or attached single family housing. Being located along the edges, the structure is offering a series of skeletons which can be grouped together to form a large room, closed by infill panels and/or subdivided to host various facilities.

Concrete boxes have to be lightweight to be considered as a feasible solution. In medium and high-rise situations, overloads can be avoided notably by lateral connections to columns or by using ribbed boxes as permanent formwork in order to cast columns with off-set corbels between the ribs; in both cases, a kind of semi-Megastructure is created.

3 - The HYBRID

The HYBRID is aiming at "the best of both worlds", factory and site: manufacturing at the plant the complex parts of the building and entrusting to the site the operations requiring heavy transportation.

III- HYBRID	Specificities	Sub-Divisions
 G- LOAD-BEARING SERVICE CORE	**The "service" area is built at the plant within a module with structural capacity**	• **Linear** • **Point to Point** • **Half Load-bearing**
 H- MEGASTRUCTURE	**Framework to stack boxes**	• **One Storey** • **Two Storeys** • **Three Storeys** • **Four Storeys**
 I- SITE-MECHANIZATION	**Bringing the factory and its tooling to the site as far as the structure is concerned**	• **Mobile Factory** • **In Situ Factory** • **Mechanised Formwork** • **Permanent Formwork**

The Hybrid systems are very often borrowing features, and eventually components or even sub-systems from the other two categories.

G- LOAD-BEARING SERVICE CORE: The "service" area is built at the plant within a 3D module with structural capacity in order to support, once at the site, the slabs and envelope panels generating the "served" area.

Advantages:

- Factory production justified by the concentration of complex services and equipment;
- Easy transportation = self contained container-size module;
- Simple site work = the module acts as a connector to the other sub-systems;
- The "served area" between the Cores offers a completely flexible transversal space;
- Whereas the Core is a closed sub-system, the served areas are offered to open sub-systems, notably to various floor/roof slab options and to various exterior envelope panel options.

Limitations:

- Imposition of a planning discipline;

- Additional facade width due to the presence of the perpendicular core.

The cores are small completely factory-made boxes full of value-added services and equipments, thereby avoiding the high costs of “transporting air”, which is generally the case for boxes accommodating a living-room or bedrooms. Once at the site, large open living areas are generated by spanning slabs and envelope panels between “Linear” cores perpendicular to the facades (Richard 2005). When all the cores are parallel, the building can go from low to mid-rise (± 20 stories); whereas high-rise structures up to 40 stories are available when a number of cores are placed perpendicular to the others.

H- MEGASTRUCTURE: Framework to stack lightweight boxes in order to reach a high-rise status.

Advantages:

- Allowing light-frame factory-made modules or panels to reach higher densities.

Limitations:

- Expensive structural redundancies as the boxes or panels become live loads to the framework;
- The framework can host different types of boxes, but the jointing could be complex.

The Megastructure may appear as a way to stack boxes for many stories without overloading the ones underneath, but there is a high price to pay: the loading redundancy, brought by supporting another structure as a live load, will more than double the cost of the overall structural sub-system.

I- SITE MECHANIZATION: Bringing the tooling of the factory to the site as far as the structure is concerned; whereas the other sub-systems, being complex and compact, would be better served by factory-made “plug-in” or clip-on” components.

Advantage:

- The logic of producing heavy components at a site-plant rather than transporting them one by one from the plant.

Limitations:

- Same as for the Site-Assembled Kits-of-Parts, except for the structure;
- Partial adaptability: most sub-systems besides the structure can be flexible and demountable.

Site Mechanisation is transforming the site into a factory producing the concrete structure. The main sub-options (divisions) are: “Mobile Factory” (literally mounting the prefabrication tools on a “flatbed”), “In-Situ Factory” (using site-friendly processes like Sprayed Concrete, etc.), “Mechanical Formwork” applied directly to the building (Tunnel Formwork, offering an egg-crate structure, or Sliding Formwork, often used to cast a monolithic vertical circulation shaft bracing another system in a high-rise situation) and Permanent Formwork (usually combined with another system).

Results and Business Impacts

Key Findings

By analogy, the three building systems categories are the basic colours (i.e. blue/red/yellow) forming a real "Palette" of options (Figure 1) from which decisions are taken: the designer can identify the most relevant one(s) according to the context and the objectives of a specific project.

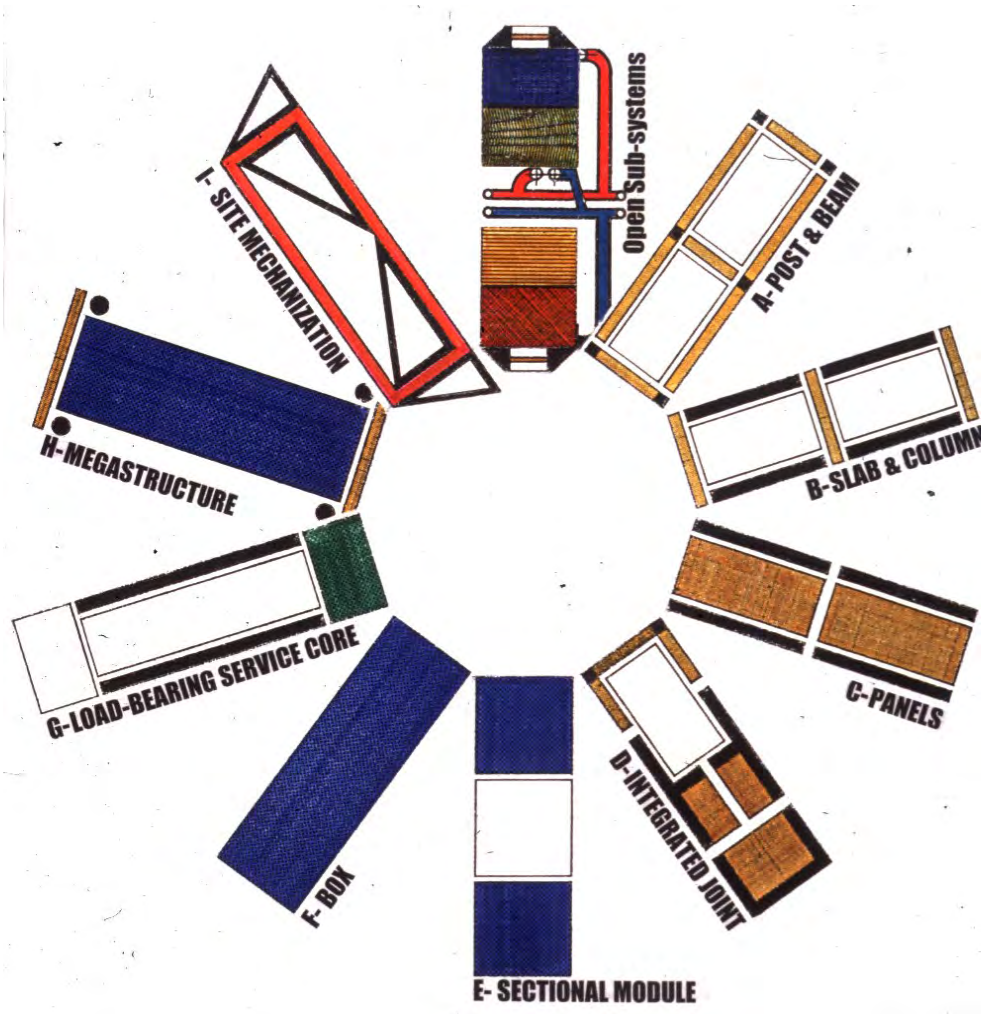


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Figure 1 - The "Palette" of options

Business Impacts

The spectrum of options is governed by a series of business decisions related to the resources, the four "Ms" (Materials, Machinery, Manpower and Money). Decisions taken mainly at the Sub-Systems level as they represent specific expertise areas which can be distributed to different participants of the "Generic Organisation" behind any industrialisation activity.

A "Generic Organisation" does not mean that all the participants are working for the same large corporation or company. The model of the big integrated "vertical" corporation that controls everything from the supply of raw material to the components factories, the assembly line and the distribution facilities is nowadays very rare all around the World. Most large corporations operate as "mixed" structures, generally owning the final assembly line and sometimes some of the production facilities while managing all the operations, from the design to the distribution; many are completely “horizontal”, concentrating on the management and relying on consultants and sub-contractors for the design, the manufacturing of components and sub-systems, the assembly, the marketing, the distribution, etc.: the capital investment can then be as low as 10 % to 20% of the total involved.

Selecting the relevant system is a strategic operation that needs to take into account:

- The performance criteria set forward to meet the objectives and the architectural features of the project;
- The actual or prospective technologies available inside the organisation or outside through various manufacturers and/or sub-contractors);
- The benefits of including all the sub-systems in a closed framework or of leaving one or more as “Open Sub-System(s)”.

Many systems will purposely exclude some sub-systems: either because a sub-system is outside their technological scope or to leave it open to many options, in order for instance to be compatible to different environments. These parts, components or sub-systems are then considered “interchangeable”.

A system composed of interchangeable parts is considered as an Open System. An open system can exchange parts, components and even sub-systems outside its original production environment; an Open System can offer more choices to the user and a larger market to any manufacturer that abides by the rules in terms of quality (performance criteria), dimensions (modular coordination) and interfaces (compatibility).

For the purpose of selecting a strategy, the “Palette” of options can be extrapolated to articulate the distribution of the work between the factory and the site, as shown in the following diagram (Figure 2).

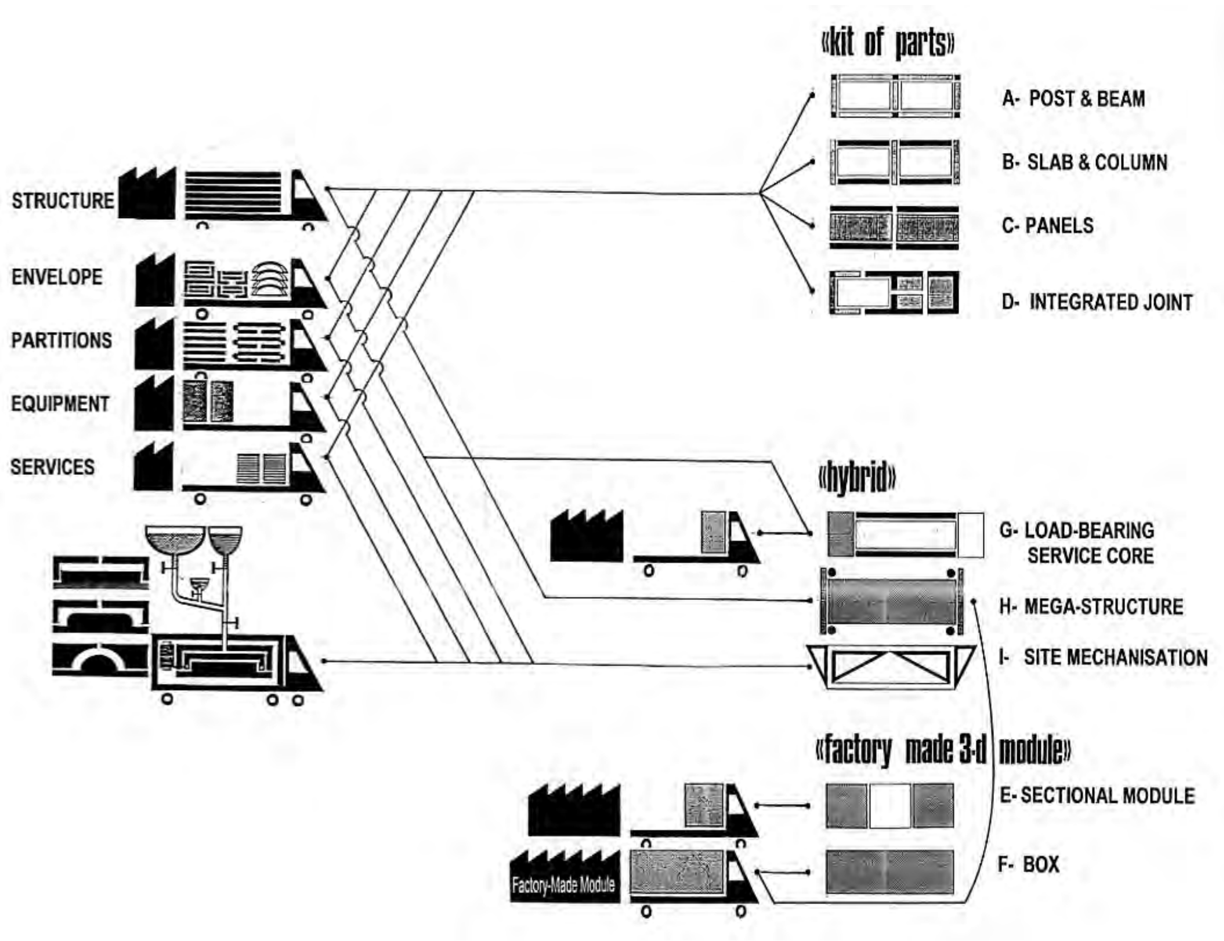

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Figure 2 - Distribution of the work between the factory and the site

Conclusions

By gathering a continuous market, industrialised systems are able to break into small fractions the investment in a process capable of simplifying the production and thereby achieving cost reduction and higher quality at the same time. Industrialised Building Systems offer increased adaptability to change through the precise jointing features of the factory-made components or sub-systems, thereby meeting the constant need for change in each and every building: society and technology are in perpetual evolution whereas individuals are different from their neighbours and different from themselves over time. Very often a building program becomes obsolete even before the building is completed.

Since most factory-made components or sub-systems are designed to facilitate site installation, they can also be dismantled and generate change without any partial or total demolition, thereby addressing the sustainability agenda and contributing to the formation of Industrialised, Flexible and Demountable systems (IFD Quah et al., 2004):

- Flexible components/sub-systems using dry (mechanical) jointing methods allow for change without the usual destruction of partitions associated with renovation.
- Demountable components/sub-systems using dry-jointing methods allow for a major reconfiguration and/or relocation of the building without demolition waste.

The NEXT-21 prototype in Osaka (Osaka Gas, 2000), designed under the direction of Professor Yositika Utida is a significant example of a fully flexible systems open to change over space and time.

Figure 3 - The NEXT-21 prototypical flexible residential building in Osaka

Key Lessons Learned:

- Post & Beam are quite appropriate to the 'Open Systems' approach as their skeleton framework can serve as connector to horizontal slabs and vertical panels;
- Panels offer an economical distribution of the loads from the vertical to the horizontal axis while being capable of integrating the soundproofing and fireproofing performances.
- Monolithic Integrated Joints simplify the connections by locating the jointing outside the geometrical meeting point; and they can also adopt a skeleton framework configuration.
- The full 3D Module ('Box') maximizes factory production and minimizes the work at the site, but a high initial capital investment and a continuity of the demand are required to amortise it;
- The factory-made Load-Bearing Service Cores are small boxes full of value-added services and equipments generating large open and flexible living areas once at the site.
- Site Mechanization brings the tooling of the factory to the site as far as the structure is concerned.
- The 9 building systems types generated from the three basic building systems categories are forming a real 'Palette' of options, from which the designer can identify the most relevant one(s) according to the context and the objectives of a specific project.
- A 'horizontal' Generic Organisation, concentrating on the management and relying on consultants or sub-contractors, can reduce the capital investment down to between 10 % and 20% of the total involved.
- Open Systems offer more choice to the user and a larger market to any manufacturer that abides by the rules in terms of quality (performance criteria), dimensions (modular coordination) and interfaces (compatibility).
- Since most factory-made components or sub-systems are designed to facilitate site installation, they can also be dismantled and allow for change without any partial or total demolition when 'dry' (mechanical) joints are used, thereby addressing the sustainability agenda by generating Industrialised, Flexible and Demountable (IFD) systems.

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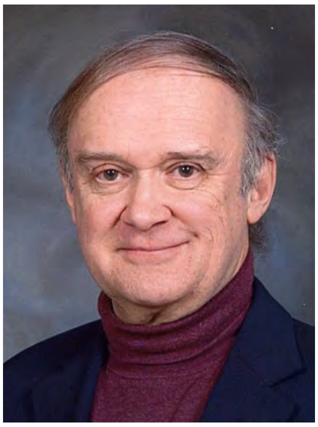
Author’s Biography



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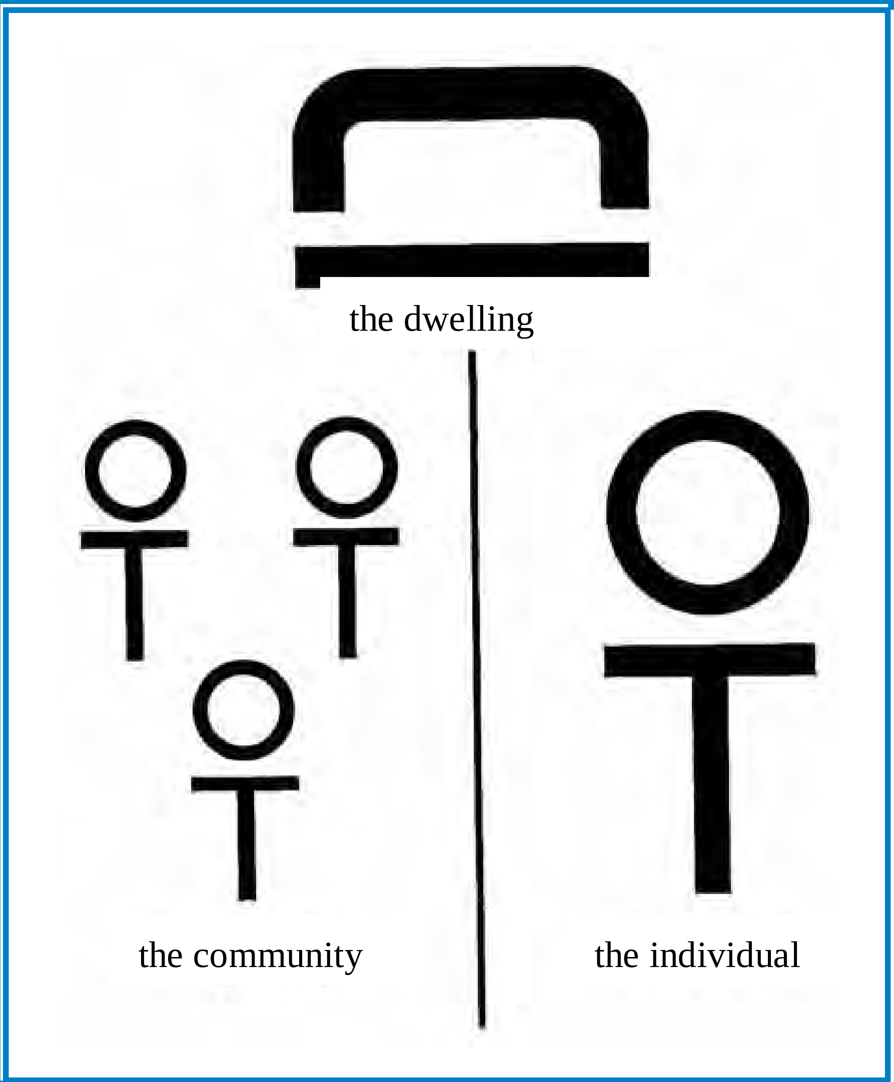
4

Dwellings for Today and Tomorrow: A People-focussed, Sustainable Approach to Design Utilising an Open Building Manufacturing Approach

Steve Thompson



Dwellings for Today and Tomorrow: A People-focussed, Sustainable Approach to Design Utilising an Open Building Manufacturing Approach

Steve Thompson RIBA, Senior Architect, CORUS, UK (Steve.Thompson@corusgroup.com)

Abstract

Dwellings are typically designed in either of two ways. The first is to design with the needs of a specific household in mind. This means a detailed understanding of the needs and aspirations of the user. The second is to design on a speculative basis, assuming a typical household that will live in the dwelling with no direct interface with the client at the design stage. The second method generally leads to a level of compromise by the household that then occupies the finished product. Homes designed for the 'average' family are unlikely to meet all the needs and aspirations of the individual end-user. In addition, buildings are often designed around the capability of a given product, instead of around the end-user, leading to further compromise of the needs of the occupant. This chapter aims firstly, to demonstrate the need for flexibility by highlighting the impacts of social and physical context, end-user needs and aspirations on the design of dwellings. Secondly, to discuss how multi-functional buildings can adapt to meet changing requirements over time, and finally to describe how an open building manufacturing approach can achieve this, and how it affects the design of such systems.

Keywords: Building Concepts, Architectural & Spatial Typology, Flexibility, Sustainable, Multi-function

Background

Industrial Context

Today, there is a greater need to reduce carbon emissions and energy consumption than ever before, and along with this comes awareness of the changes we face. It is clear that this is a global issue; both in terms of the reductions in emissions needed and the impact climate change will have on our lives. There is significant recent evidence to show that climate change will not only have a severe impact on our environment, but also our society and economy on a global scale (Stern, 2006)

The residential sector has a significant impact on global emissions, particularly in developed countries. A range of factors including efficiency of energy supply, dwelling design, use of space, supply and flexibility of suitable housing and its capacity to be upgraded influences the emissions.

One of the largest contributors to residential emissions is the impact of changing demographics (Shorrock and Utley, 2003). The issues go far beyond a simple increase in overall population; they include considerations of household numbers and the size of those households, what the age of individuals are, and how much space they occupy and where they are located. For example, across Europe there is a growing trend towards smaller household sizes (number of occupants), led predominantly by more people living alone (National Statistical Institutes, 2006). There is a significant difference between the energy used and space occupied per person between one and two-person households, with one-person households being far less efficient and using considerably more space per person. Household sizes are also effected by a range of other socio-economic factors, such as rising house prices, increased life expectancy (and increase in the proportion of elderly people), pension under-funding, increased cost of residential care, income, availability of suitable accommodation, employment opportunities, social provision for the young and the elderly, the age at which people move into their own home, and tenure mix (owner occupiers are more likely to invest in energy saving than those in the private renting sector).

Altogether, the residential sector is a complex market with an ever-increasing range of household types. The question is, are these households being accommodated in suitable dwellings, and are the homes now being developed capable of adapting to their ever-changing requirements?

Problem

Unfortunately the answer to the question above is often no. Standard housing layouts and products today are generally unrelated to the people that will live with and in them, most of the decisions already being made by developers, suppliers or regulatory bodies. This can, and does lead to obsolescence of housing on both an individual and community scale, ineffective use of space and land, expensive and often unnecessary demolition or reconstruction, and can develop into run-down, unsustainable communities and cities.

Smaller household sizes and the consequence of more households are major concerns in terms of carbon emissions and resource efficiency. If suitable housing is not provided for these households, then we naturally occupy what is available. For example, if a house and its systems are designed for a 3 or 4-person household, and is instead occupied by a single person there is a potentially a significant misuse of resources. Under-occupancy is not necessarily a problem for the individuals, but it does drive up demand for space and heating per person, and is a factor in driving and compounding fuel poverty.

Designing and constructing without the involvement and participation of the end user limits both choice and suitability of dwellings, whereas designing for a specific household in isolation potentially limits output and integration with the public realm. The likely solution through ManuBuild is mass customisation as opposed to mass production. This means designing for options without anticipating user functions to an extent which begins to define the ‘average’ household, so as to avoid artificial value judgements about individual household needs. Designing quality homes is not all about providing more efficient layouts; it is a case of understanding priorities. In developing solutions with the user, community and lifestyle of the home considered, we can begin to develop sustainable dwellings and communities that will adapt to meet changing needs and context over time. Think about the potential for matching people’s changing needs and priorities with their changing economy and environment. Open building manufacturing through ManuBuild aims to address the potential to customise with the added benefits of efficient and mass production of components and systems across Europe.

Learning Objectives:

The reader of this chapter can expect to learn:

- The need to design homes for people, at both individual and community levels
- The principles of design using activity spaces
- How open building manufacturing can be utilised to create flexible dwellings and allow for occupant participation, and how this affects the design of such systems
- How open building manufacturing can assist in developing sustainable communities

Approach

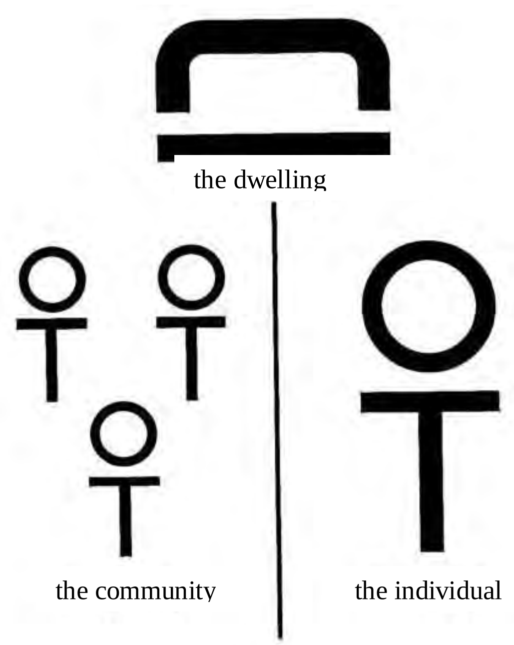
The work covered in this chapter is based on developments within the ManuBuild project, specifically regarding architectural typologies and multi-function. We look at current and previous research, projects and best practice relating to designing homes for people, and the ideas of mass customisation and open building manufacturing. In understanding how to design homes with the occupant in mind, we look at using a qualitative instead of quantitative approach to design to provide added value to the end user, and look at the activities likely to be carried out by occupants instead of developing predefined rooms. The chapter then explores how these methods can be used to develop closer links with the public realm, and assist in the development of sustainable communities. This is a people-focussed, not product-focussed approach, and therefore we will then look at how open building manufacturing systems are influenced by the needs of the users, along with other considerations such as buildability, maintainability and capacity to be upgradeable.

Dwellings for Today and Tomorrow

> '*An environment…is an environment only by virtue of the life that it surrounds…we do not talk about surroundings without reference to the people surrounded, nor should we talk about housing as a thing of intrinsic value separate from the people housed.*' (Turner 1974)

Dwellings today are typically designed in either of two ways. The first is to design with the needs of one specific household in mind. This generally means an increased understanding of the needs and aspirations of the user. The second is to design dwellings on a speculative basis, assuming a typical household that will live in the dwelling with no direct interface with the occupants at the design stage. The latter approach generally leads to a level of compromise in some way by the household that then occupies the finished product. Homes designed for the 'average' family are unlikely to meet all the needs and aspirations of the individual end-user, leading to further alterations, ineffective use of space, or even to the household dealing with their own changing needs and aspirations by undertaking expensive modifications or 'trading up' and moving home. In addition, both of these methods typically consider the building as complete when handed over to the client for occupation, partly due to procurement methods that change responsibilities for the dwelling once constructed, but also because of a historic lack of awareness of the changing needs and efficiencies of a home over time, and over the lifecycle of the building. To add to the problem, buildings (and in particular manufactured buildings) are often designed around the capability of a given product or system, instead of around the end-user, leading to further compromise by the occupant.

By exploring principle user requirements, views and aspirations we can integrate future adaptability and flexibility into the technical development of systems and components without dictating the lifestyle of future occupants.



The 'Natural Relationship'

'Living is an act which takes place in two realms, the public and the private. A dwelling itself has an interior and an exterior.... Living exclusively in the public realm is tantamount to institutionalisation. Living exclusively in the private realm is a kind of exile. The dwelling must therefore straddle both spheres. In previous centuries an individual built his own home within the public realm, but in doing so established his own private realm also. A public authority which builds houses must allow them to be completed in the private realm, otherwise the natural relationship is destroyed and the occupant abdicates responsibility for his dwelling' (Habraken, 1968)

Figure 1: 'The Natural Relationship' (Habraken, 1968)

One of the most outstanding features of Victorian and Edwardian housing in the UK was its flexibility. This has enabled the dwellings to be adapted up to the present day to suit changing tastes and ways of life, but also to accommodate an increasingly diverse set of household types and sizes. One of the benefits of this adaptability in terms of the public realm is that it has allowed whole areas of towns and cities to remain physically intact and retain a sense of community. In creating adaptable dwellings we reduce the likelihood of obsolescence in the future, leading to demolition or expensive conversions. These homes are still being refurbished and adapted today; the issue however is the ease with which this can be achieved, and at what cost. They were not designed to be adapted or upgraded in terms of their built fabric. The technologies were not available at the time, nor were there the need to consider flexibility to the same degree as is important today.

As mentioned in the previous section, in designing homes that are adaptable to meet the needs of either different or developing households, we need to understand the differences between household types including their lifestyles, attitudes and requirements. It is not possible in designing a system to understand every future occupant and their exact requirements and aspirations, but it is possible to understand key similarities and differences between types, and allow the flexibility for choice and future adaptation of dwellings by all occupant types.

The primary functions of a dwelling don't change; we eat, sleep and spend our private lives in them. As our lifestyles, needs and aspirations change however, these primary functions may be supplemented by other secondary functions. Some of us may wish to run a business from home, and as some grow old they may want to look after their grandchildren. In designing a home, we should therefore aim to design and build housing to be adaptable so that it can meet the needs of everybody, irrespective of the users' ages, level of mobility, health or lifecycle.

It is also important to consider the further qualitative aspects of our built environment. Do our homes exceed the basic requirements in terms of providing the context to live our lives? Are our homes enjoyable places to live? These are the differences between adequacy and quality, between 'house' and 'home'.

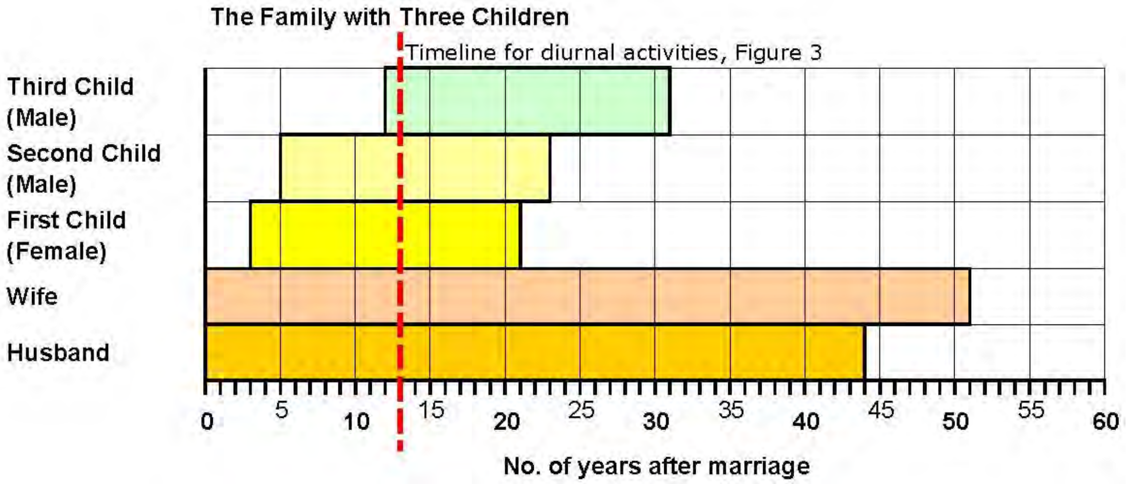
The idea of combining mass customisation, adaptable dwellings and end-user involvement in the design process may seem a utopian ideal. The fact is that all of these ideas are already being used in the industry, though not necessarily together. This chapter will suggest ways in which these ideas can be achieved in combination.

To explore the need for dwelling flexibility over time, Parker Morris (Ministry of Housing and Local Government, 1961) used a clear method of illustrating the change a family may go through during their development, using simple charts to demonstrate how household composition may change. Figure 2 illustrates this method for a family which has three children, and shows that the household might consist over the whole family cycle of one person for seven years, two people for sixteen years, of three people for ten years, of four people for nine years and of five people for nine years.

If we take this family from the stage of moving in as a young couple at the stage of having their first child, and staying until the last child left home, it would consist of its maximum of five occupants for less than half of its period of residence. Some design implications of these facts are that for at least eight years there will be a baby in the home, there will be at least one child under school age for about twelve years, and there will be four people having to et ready for work or school at the same time in the morning for about 10 years.

These charts will obviously vary from household to household, and significantly between household types due to changes in demographic and lifestyles, but nevertheless the approach taken is still particularly relevant. The purpose of these figures is to show how families expand and then contract over time. This means that at each stage the needs to be met by the dwelling are different, corresponding to changes in the size of family, to different demands on available space, and to varying patterns of life.

In addition to changes in the size of family, ways of life in the home will also change during the family cycle. There will be phases when all the family prefer to be together, for instance when a couple just have one baby. When there are several young children they will need play areas under supervision and the parents may sometimes want to shut off part of the house from the children. As the children get older they will need more privacy, rooms of their own and places to entertain their own friends. Living spaces are needed that can be left open for use together or closed off into separate rooms. The extra space available before or after the family is at its maximum, needs to be suitable for use as living space as well as for occasional use as a bedroom or other use. What this shows is that dwellings should be flexible to adapt to changing household types and their requirements.



The eldest child is a girl, the two others are boys
There is a child under 3 for 8 years
a child under 5 for 12 years
a teenager for 15 years
At least four go out to work or school for 10 years
The married couple are on their own for 18 years

Figure 2: Example household development chart

Across Europe at present there is a tendency towards increased number of single person households, or people living alone. In the UK for example the number of people living alone has more than doubled since 1971, an increase from 6.5% to 14% of the overall population (Shorrock and Utley, 2006). A similar trend can be found in most EU countries (National Statistical Institutes, 2006), with most of the growth amongst those of working age. The changing demographic towards smaller households has an impact on both energy efficiency and living space per person. For example, in England in 2001 the average floor space for a single person household across all tenures was 69m^2, compared with 44 m^2 for a two-person household and as little as 25 m^2 for a four-person household (ODPM, 2001). This gives an overall average living space per person of 43 m^2, up from 38 m^2 in 1991.

The reduction in average floor area from a one-person to a two-person household is significant, and is obviously partly explained by the sharing of facilities between occupants, such as cooking and washing facilities as well as living space. However, there are other factors that have an effect such as availability of accommodation for smaller households, the desire for a spare room for guests (although this need is also common within larger households), and the general desire for more space. The desire for more space (or the necessity as a household increases in size) can potentially be met within the same shell of a household's existing dwelling, with the reconfiguration of internal layouts, moving internal walls and services, avoiding the need to move to alternative, larger accommodation.

In the 1980s, under-occupation of larger homes was seen as a way of avoiding obsolescence for all but smallest of homes. This is partially true, but means that smaller households are not necessarily catered for, and may therefore be expected to move into dwellings that aren't suitable for them, using excess space they don't necessarily need or want because this is all that is available. This drives up the need for more accommodation for three or four-person households. As an example, if we take the average floor space for a single person household of 69m^2 given above, in principle this amount of space can comfortably house up to a four-person household if the dwelling is designed with the occupants in mind, and an activity-based approach taken instead of relying on standard room sizes per room. There will be less flexibility in the layout in achieving this, so for example there will be limited options to have guests overnight, but still the day-to-day accommodation can be more than comfortable. It is a case of understanding and appreciating priorities of the households and communities involved.

Although single person households are often living in apartments with areas suitable for larger numbers, they are commonly designed or constructed in ways that are not readily or economically adjustable to meet their needs. We are not looking here for smaller accommodation, but designing accommodation with real consideration for the activities that are likely to be undertaken in that space. In other words there is a difference between useable space and effective useable space: space that is readily available and accessible for comfortable use by the dwelling occupants. It is certainly not wrong to want more space than you require, but it needs to be weighed up with other considerations such as energy efficiency and cost.

> '*When dwellers control the major decisions and are free to make their own contribution to the design, construction or management of their housing, both this process and the environment produced stimulate individual and social well being. When people have no control over, nor responsibility for, key decisions in the housing process, on the other hand, then dwelling environments may instead become a barrier to personal fulfilment and a burden on the economy'* (Turner, 1974)

Taking an activity-based approach, whilst not necessarily providing user participation, allows us to develop spaces and inter-relations in a more sensitive way, more in-tune with the needs of the occupant. It relies on understanding in detail how activities are undertaken, and how these relate to other tasks, but also when tasks are likely to be undertaken in isolation or in groups. The focus is not purely on space dimensions, it includes greater understanding of the qualitative requirements and comfort aspired to for different activities.

Activity Spaces

> '*The right approach to the design of a space is, first define what activities are likely to take place in it, then to assess the furniture and equipment necessary for these activities, and design around these needs, plus others no less important such as aspect, prospect and communication with other parts of the home.*' (Ministry of Housing and Local Government, 1961)

It is important to differentiate between designing activity spaces and designing rooms. An activity space is the space and support systems required to undertake an activity, which potentially may be in a completely open environment. A room however is an enclosed space, which may successfully support activities or may be created with no real consideration of what will occur in that space.

With the design of a home for people, a good starting point is to understand the processes and activities that people want or need to carry out. What do they need and want from a dwelling? What activities do they carry out in living their lives, and how can their homes facilitate these? We also need to look at these activities in terms of frequency, timing and importance in terms of community, household and individual lives, but also what is needed to carry out these activities in a comfortable and reasonable way. Parker Morris (Ministry of Housing and Local Government, 1961) described the activity approach as being indirect. The arrangement of rooms and spaces should be the results, not the starting point of a design. The layout needs to grow from the inter-relations of activities: an appreciation of which activities can be carried out simultaneously or together, and which need to be separated. In this way, spaces develop from the needs of the occupants and evolve as a consequence of thought, not from bringing out the same standard (and often inappropriate) solutions used before.

Although the standardization of spaces in a dwelling may provide some benefits in terms of rationalizing supply and creating efficiency in production through repetition, it does potentially cause difficulties in the design and use of dwellings for households. The ManuBuild approach is not to standardize spaces, but to concentrate on creating the place for activities and facilitating this through ManuBuild, instead of concentrating on the development of product alone.

As an example of the issues surrounding space standardization, if a large space is available for an apartment, it can be broken down into a series of relatively small, cellular spaces. These spaces may be standardized rooms by type and feel compact in isolation; however walking between them is likely to give an appreciation of the overall size of the dwelling. It is the links between rooms here that achieves the overall sense of space. Alternatively, the same apartment may be completely open plan, and although immediately comprehensible as a vast space, may feel uncomfortable for residential use without some form of spatial definition. In other words, the links between activities and spaces are just as important as the spaces themselves. As Parker Morris put it (Ministry of Housing and Local Government, 1961), the design of homes is one of the most difficult tasks in the field of architecture, and standardization of spaces may not allow the flexibility to provide adequate solutions for a range of household types.

The Ministry of Housing and Local Government (1968) developed a valuable method of understanding and illustrating the processes and activities likely to form part of daily life. The process looks at diurnal cycles of a household to point out how activities coincide in the home at different times of the day, and in different locations. It suggests movement around the home, and where activities separate out or bring together members of the household. Figure 3 demonstrates this approach for the family illustrated in Figure 2, at a stage where there is one toddler and two young school children.

The illustrations indicate particular points of stress when the home is being most intensively used. The exact nature of these stresses, their location and the patterns of movement, will vary with the way of life of the household, but this kind of analysis based on local knowledge can be a useful way of guiding the designer to recognize that homes have to accommodate individual and group interests and activities, and the design must be such as to provide reasonable individual and group privacy as well as facilities for family life as part of a community of friends and relations. The analysis of the relationships between activities within a household is what will lead to an increased understanding, and finally definition of the multi-function that is needed within a dwelling, and within spaces that form part of the dwelling as a whole.

As the activities and timings will change between households, these illustrations are not intended as a definitive answer, nor are they attempting to define an ‘average’ family, but should be seen as a starting point for the architect or designer from which to move forward, developing their own assessments of the full range of activities likely to be encountered in the different types of household for whom they may be designing. At the same time it must not be forgotten that a home is more than a place full of activities. People also need to rest and relax, to enjoy their leisure time and bring up their children in attractive and comfortable surroundings.

0700 In the early morning rush, instant hot water and warmth is needed. 2 children getting ready for school and one parent getting ready for work.

0710 Breakfast has to be served quickly, the school children got ready and the youngest child looked after as he wakes up.

0800 One parent leaves for work and takes children to school. Other parent gives youngest child his breakfast and has something his/herself. A place where food can be eaten near a work area is useful.

0930 Toddler plays and wanders around the house and garden. Parent needs to be able to see the child easily while he/she works.

1030 Whilst the parent and child may be out of the home, there may be deliveries that need to be put in a safe place, or meters that need to be read.

1130 Coming back from shopping loaded up, parent needs space to put a pram and shopping, elbow room to take off child's outdoor clothes, and somewhere convenient to put them.

1200 Whilst the child plays indoors the parent needs to be able to see him from the kitchen, but he should be away from the kitchen equipment and not under the parent's feet.

1230 The parent eats, and feeds the child. The dining space should be conveniently reached from the preparation area.

1330 The child needs a place to play, where toys and other playthings are concentrated, so the parent is not constantly tidying up. There should also be a place where it is quiet to sleep.

1430 Space in the tidy area of the home is needed for adult visitors, while the children of both families play within sight but not too close to the teacups.

1600 When the children return from school they may spend time in the living room watching T.V. or individually on the computer, whilst the parent is preparing their evening meal.

1700 If people are watching T.V. whilst they are eating their meal, space for a low table may be needed to prevent accidents and stains.

1800 The working parent returns. People do not always want to watch T.V. when it is on or if they need to study, and need a place to sit away from it. The toddler needs quiet when he is being settled down to sleep.

1830 If one parent is working and making noise they need to be away from the other parent preparing their evening meal, and away from the sleeping child.

1930 Sometimes visitors are being entertained while a child is watching his favourite T.V. programme.

2130 One parent may wish to talk to the guests whilst preparing nibbles for them.

2330 Parents need to sleep near their young child, so they can attend to him easily.

0300

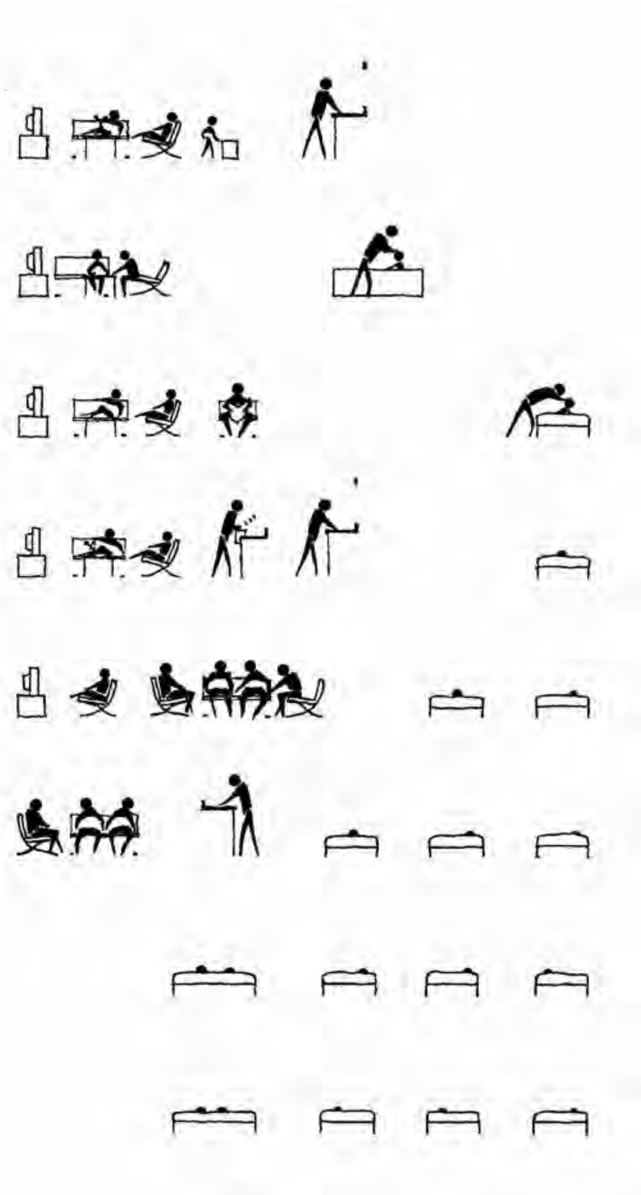


Figure 3: Example of time and place of daily activities for a family with three children

Activity Sequences

'*I see housing as a process that subsumes the physical objects produces, or as an ecosystem which can be understood only through the interrelationships between people, their actions and their environment.*' (Turner, 1974)

Once an understanding of daily cycles and the types of activities likely to be carried out have been developed (along with an appreciation that an activity will have different requirements for different participants such as the elderly or young), then the organization of activity spaces can be developed to ensure the dwelling can facilitate these events. One way of assessing activities and their spatial and environmental requirements is to look at activities as a sequence. Figure 4 illustrates how the activity of preparing a meal has been assessed in terms of the processes involved and what these processes require from the dwelling. The illustrations show that in assessing the activities and sequences in the example, activities 1 and 6 have similar requirements. As the two tasks do not typically occur simultaneously, they can therefore use the same space and facilities. The same can be achieved by combining activities from different processes, often completely unrelated activities. Overlapping activity spaces can be much more efficient when the time factor is considered to avoid clashes.

1	**2**	**3**	**4**	**5**	**6**
Prepare	**Mix**	**Cook**	**Serve**	**Eat**	**Wash-up**
Unwrapping Washing Peeling Chopping Mincing Adding Water	Weighing Measuring Mixing	Baking Boiling Frying Grilling Steaming	Keeping food and dishes hot Putting food onto dishes or plates	Table laying Eating Clearing away	Disposing of waste Stacking Washing Drying Putting away

Arrangement of activity zones

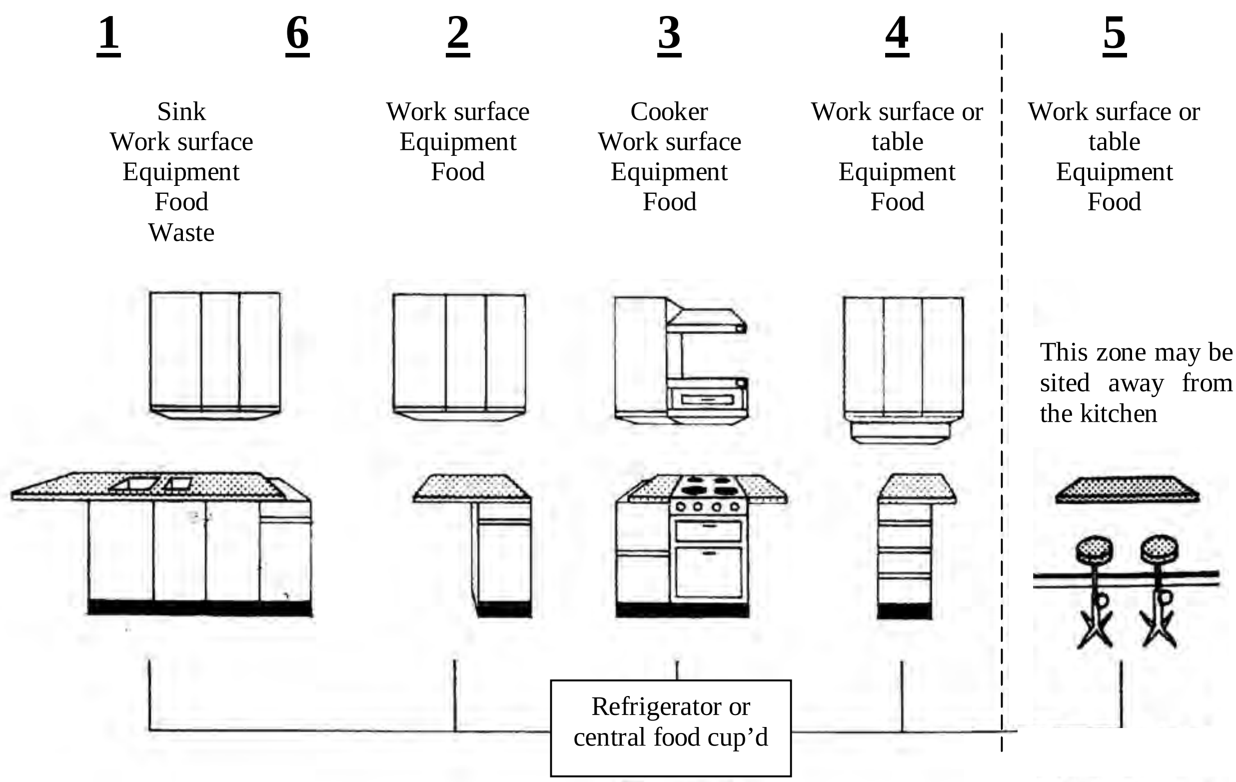


Figure 4: Example of activity sequences taken from Ministry of Housing and Local Government (1972)

When activity spaces have been developed for the relevant occupants, and there is an understanding of which are primary and secondary activities, it is important to consider links between activity spaces and how the design of the dwelling as a whole has an impact on each space. For example, the width, depth and aspect of a dwelling will affect the links with other spaces, and there will usually be some compromise needed in achieving the most suitable overall arrangements. It is a combination of user-focussed activity spaces, sequences and other factors such as aspect and interaction with the outside world amongst others that is likely to provide the most favourable solutions.

We have already covered the need to focus on the end-user and their requirements in the design of a dwelling. What has not been mentioned however is the potential of involving occupants in the design phase and making them aware of the capabilities of their dwellings. Making available end-user choice, but also ensuring the occupant is aware of how to get the most out of their home in terms of flexibility, adaptability, energy efficiency and maintenance and control.

Flexibility and Multi-function

Used in isolation, the activity space and sequence approach described earlier tends to be most beneficial in the design of a dwelling for a specific household or a specific point in time, rather than for changing occupant types or growing and contracting households. However, basic principles can be drawn from the approach to allow suitability for a range of households and situations.

It is highly unlikely that all activities that will be undertaken in a dwelling will be considered or catered for at the design stage, and this is where multi-functional space becomes useful. It can come in a number of forms: it can be neutral space that is capable of supporting a number of general activities (for example general living space), multi-functional activity space (where specific activities can be catered for at different times, such as a dining room / office where furniture remains in place, but the space needed to carry out activities overlap in such a way that activities can not be carried out simultaneously), or even re-configurable space (where a space may adapt from one use to another, for example by moving furniture to suit different activities).

To get the most out of the activity approach it is important to consider the timeline of a dwelling. How will the dwelling adapt to changes (growth and contraction) of a household over its lifecycle, and how can it adapt to suit different households or changes in external social and physical context? It is important to note that consideration of a dwelling's flexibility is not only about housing one family or group of occupants over their lifecycle, but also allowing new residents to adapt the dwelling to their needs, or to allow a suitable mix of dwellings in a development from the same kit of parts. We live in a rapidly changing world, and in many neighbourhoods the external environment changes at a greater rate than that in the home. It is therefore important to consider the impact the external environment may have in terms of requirements of dwelling design.

By combining the activity and timeline approach it allows us to consider the level of flexibility that is aspired to in the dwellings that we design, manufacture and assemble. The multi-function of space that is needed, and the flexibility in component and connection design.

In developing an open building system to achieve these levels of flexibility we need to consider and define the level of interaction an occupant may have, for example what or how can they change and adapt their environment as their circumstances change? If it is not easy for occupants to change their environment to suit their needs, they may not change it at all and either continue to live in an unsuitable environment (in some ways with their environment dictating they way they live their lives), or they may move. The consequences and suitability of different forms of multi-functional space are a key part of ManuBuild and residential developments in general.

Timing and ease of adaptability are important factors in considering the level of user intervention. If the internal configuration of a dwelling can be changed by one or two reasonably competent occupants, including safely lifting, moving and connecting elements including services over a short period of time (for example a weekend), then it is much more likely to occur in an effective and timely manner than if builders, electricians, plumbers or other professionals are required to carry out the same work. It may be that changes are desirable to allow different activities to take place, or to open up spaces to entertain guests. Allowing this level of flexibility can also facilitate seasonal changes in dwellings for improved comfort and efficiency, for example allowing the capacity to change between a relatively cellular arrangement in the cold winters and an open, airy arrangement in the summer.

Earlier in the chapter we mentioned the flexibility offered by Victorian and Edwardian housing in the UK, still being used up to the present day. The problem with this type of housing however is the expense, effort and time it can take to adapt such buildings. For example, to bring a home with solid walls up to current standards of energy efficiency and insulation is a major undertaking. To adapt layouts often means intrusive work to gain access to building services, and replacement of finishes. One of the main aims of ManuBuild is to make these changes easier, and to allow for future upgrades to meet changing standards. ManuBuild is not a physical building system, it is a methodology to allow design teams, suppliers and developers to combine and create sustainable open building manufacturing systems.

It is important that in developing components and connections for an open building system, and the level of multi-function that is required, we consider the lifecycle of different systems, components and services; how long will a component last before it is to be replaced? How often will it need maintenance or access (if it does at all)? We need to consider creating layers of accessibility in terms of allowing ease of access and maintenance or replacement for those components or services that require it, whilst minimising the need to disturb other elements such as structural components to achieve this. For example, to re-wire a dwelling constructed in traditional form may require extensive invasive work such as stripping back finishes or cutting into masonry to access and replace cabling.

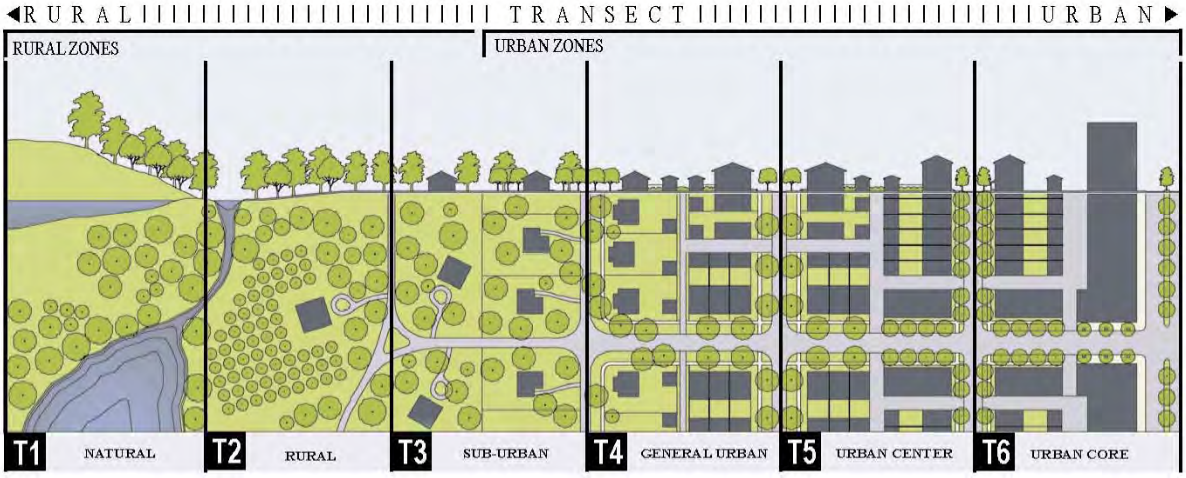
This holistic and user-focussed approach to design will create flexible dwellings. Following on from an understanding of the occupant and activity based approach to design, and the technical flexibility and integration required, we need to look at how a place can be successfully designed around people; how a dwelling sits within and interacts with its wider context. The aim is to concentrate on creating the place and facilitating this through dwelling and component design.

Dwellings in Context

Once the relationship between individual and dwelling is repaired, the relationship between community and housing environment can be addressed. Having covered the need for flexibility within the dwelling to allow choice and provide support for different households, we also need to look at the need for flexibility to adapt to external environments (physical, social and economic environments). The style and suitability of dwelling typologies changes significantly in different environments, between regions and countries, but also depending on whether the home is in a rural or urban environment, and even down to which block or street it is on. These differences combine with the activity approach to help define a dwelling’s suitability for use. At a community or city scale, the form of a building or development and its relationship to others may be equally or even more important than its function, as the form may be more permanent and affect a great deal more people. The specific characteristics of a site, building and household need to be considered together.

In environmental and ecological circles there is a common method of analysing natural ecologies known as the transect. It is a line showing varying characteristics through different zones such as shores, wetlands, plains and uplands, and can be used to represent the distribution of organisms within those areas. For human environments, Duany, Wright and Sorlien (2005) developed the rural-to-urban transect, based on this concept. This theoretical cross-section, illustrated in Figure 5, can be used to identify a set of habitats that vary by their level and intensity of urban character, a section that ranges from rural to urban. This range of environments can be seen through the organisation of buildings, plots, land use, streets and other physical elements that make up the human habitat. It is useful not only to help understand the local characteristics and identity around the dwelling, but also in enabling these characteristics to inform the design of the home to have a positive connection and integrate with its vicinity. Preserving the mix of architecture that makes our urban landscape a more humane and interesting place in which to live and work.

This approach is a simple tool that enables us to understand the differences in context between different areas of a region, and the suitability of different dwelling typologies in these areas. For example a high-rise apartment block may not to be suitable in a rural or suburban location, but may be in a more urban setting, whereas a detached farmhouse is unlikely to be suitable for an urban centre, but ideal for a rural area. Then based on regional or local practices the zones (and their dwellings and other components) can be locally refined. The approach is therefore not to standardise all developments and regions, but to demonstrate a basic understanding of the make-up of a region, which is then locally defined.



PRIVATE	LESS DENSITY	MORE DENSITY
	LARGER BLOCKS	SMALLER BLOCKS
	PRIMARILY RESIDENTIAL	PRIMARILY MIXED USE
	SMALLER BUILDINGS	LARGER BUILDINGS
	MORE GREENSCAPE	MORE HARDSCAPE
	DETATCHED BUILDINGS	ATTACHED BUILDINGS
	ROTATED FRONTAGES	ALLIGNED FRONTAGES
	YARDS & PORCHES	STOOPS AND SHOPFRONTS
	DEEP SETBACKS	SHALLOW SETBACKS
	ARTICULATED MASSING	SIMPLE MASSING
	GENERALLY PITCHED ROOFS	GENERALLY FLAT ROOFS
	SMALL SIGNAGE	LARGE BUILDING-MOUNTED SIGNAGE
	LIVESTOCK	DOMESTIC ANIMALS
PUBLIC	ROADS & LANES	STREETS & ALLEYS
	NARROW PATHS	WIDE PATHS
	OPPORTUNISTIC PARKING	DEDICATED PARKING
	LARGER KERB RADII	SMALLER KERB RADII
	OPEN SWALES	RAISED KERBS
	NIGHT SKY	BRIGHT LIGHTING
	MIXED TREE CLUSTERS	ALLIGNED STREET TREES
	MORE SILENCE REQUIRED	MORE NOISE ALLOWED
CIVIC	LOCAL GATHERING PLACES	REGIONAL INSTITUTIONS
	PARKS & GREENS	PLAZAS & SQUARES

Figure 5: Rural to urban transect from Duany, Wright and Sorlien (2005)

At first glance it may be difficult to see how the regional or urban context has an affect on the design of individual dwellings and their components. However the context, as illustrated in Figure 6, does have an affect on the design or suitability of its dwellings. Whether a dwelling is in a suburban or urban context for example, will affect the plot or block sizes, access points and parking or transport facilities. This will have an effect on the building forms, access and orientation, availability of view etc. This then directly influences the internal layout of dwellings in these areas in terms of planning for light, services, access and views in addition to external appearance. The internal arrangement and flexibility will determine the suitability and performance criteria of the components and connections that make up this dwelling. Affectively, this is a detail, or ManuBuild transect. In developing a dwelling design with this transect in mind, we then consider value to the wider community in addition to the individual dwelling occupants, who may eventually move and otherwise leave their dwelling (which was designed only with their specific needs in mind) behind. The focus is on designing for people.

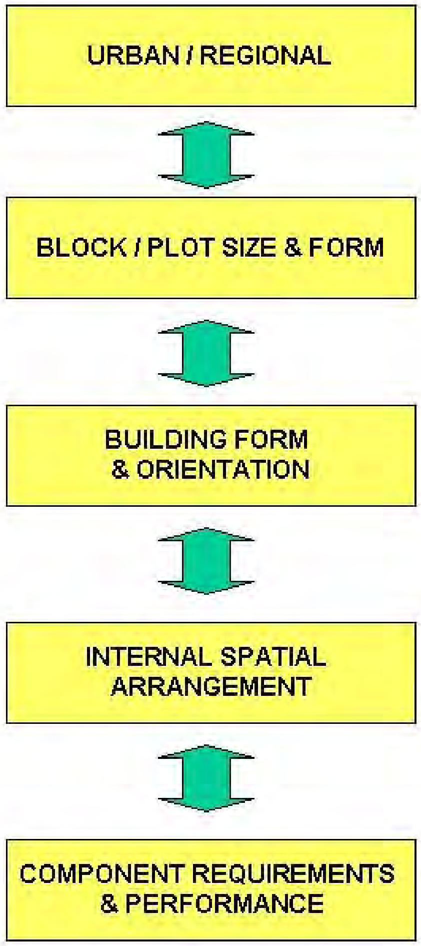


Figure 6: Links between dwelling context and component design

Open Building Manufacturing Solutions

'In a quality place, the components from which it is made are fully resolved. This requires fusion of all elements: the building, landscape, and the interface between them. All components need to have been designed with the overall scheme, and its character and quality in mind…. form a place where the elements belong seamlessly to each other.' (Llewelyn-Davies, 2004)

In this chapter we have extensively covered the need for flexibility to adapt to changing household and contextual requirements, and touched upon how these requirements begin to inform the design of systems and components to meet these needs. We are not looking at designing building components in isolation; we first need to consider what they need to do, how they need to perform and how they can be adapted in order to meet the needs of the occupant.

In the design of a successful, quality dwelling a range of factors need to be considered simultaneously. The design of an individual component affects the ability of other elements and the development as a whole to meet its goals. Taking a holistic approach allows the quality and integrity of a dwelling to be displayed through each component, and the significance of each component to be clearly understood. In considering the wider issues, greater flexibility is achieved which improves the ability for customisation, improving the suitability of a design to an increased range of situations.

Open building manufacturing meets these needs by combining the option for flexible, adaptable solutions and products with repetition in manufacturing through the standardisation of methodology and coordination, not standardisation of products. A key aspect of open building manufacturing systems is dimensional coordination to allow flexibility in forms of construction, and the capacity to deal with differences in dimensions and tolerances. Any building should be capable of being designed and built using the ManuBuild approach; ManuBuild should facilitate great architecture, not define it.

Previous attempts at open building systems have not always been successfully adopted because of outside influences such as regulatory requirements, development costs and scepticism that all of the aims of open building are achievable. The main strengths of ManuBuild are in the topics it covers and in its timing. The project not only looks at non-material specific building systems and components that are capable of being customised and assembled in a variety of ways, but is also developing detailed business processes, software and ICT support systems, manufacturing processes, training packages and regulatory impacts, all pulling together to provide realistic solutions to the problems now facing the housing industry across Europe.

Results and Business Impacts

Key Findings

At present there is a great need to reduce carbon emissions from the residential sector across Europe, and to develop or revive sustainable communities for the future. By taking a people-focussed approach at both household and community level, both now and in the future instead of concentrating on housing products in isolation, these goals can be met. With advances in technology over recent years and increased awareness of sustainability the timing for open building manufacturing approaches such as ManuBuild could not be better. The needs for flexibility and adaptability, for high performance dwellings and products, efficiency and continuity of supply in an expanding market have all come together to create the demand for a change in approach. There are barriers to these approaches, including often inflexibility of regulatory requirements and the image of manufactured housing left over from the 1960s. The challenge for ManuBuild is to overcome these challenges, through the depth and broad nature of the subjects it considers.

Business Impacts

The ManuBuild approach means a step-change in design thinking to consider buildings over their lifecycle, the need for flexibility and people-focussed approach. The aim is to demonstrating to architects and designers the benefits of an open building manufacturing and mass customisation, and enable clients to purchase high quality homes using manufactured components that have a high degree of flexibility both in initial design choices and future adaptability. This gives suppliers new opportunities for components and systems to be suitable for a larger market, by designing them to be flexible in the first place.

Conclusion

An improved understanding of end-users and their needs, flexibility and multi-functional requirements through consideration of activity spaces and integration with the public realm are key in developing sustainable homes and communities. Using this understanding we can begin to develop performance criteria for open building manufacturing systems, creating systems that are flexible to suit occupants' needs. The idea of combining mass-customisation, adaptable dwellings and end-user involvement may seem a utopian ideal. Think again. All of these ideas are being used in the industry today, though not necessarily together. The task of ManuBuild is to bring these together in a realistic way that can provide significant benefits for the future.

Key Lessons Learned:

The key lessons learnt in the work covered in this chapter are:

- Design for flexibility of use, both now and in the future
- Consider a dwelling through its lifecycle, not only until assembled on site
- The most sustainable way to dwelling design is a people-focussed, not product-focussed approach, both on an individual and community level
- Consider components, systems and dwellings together in their context, not in isolation

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Author's Biography

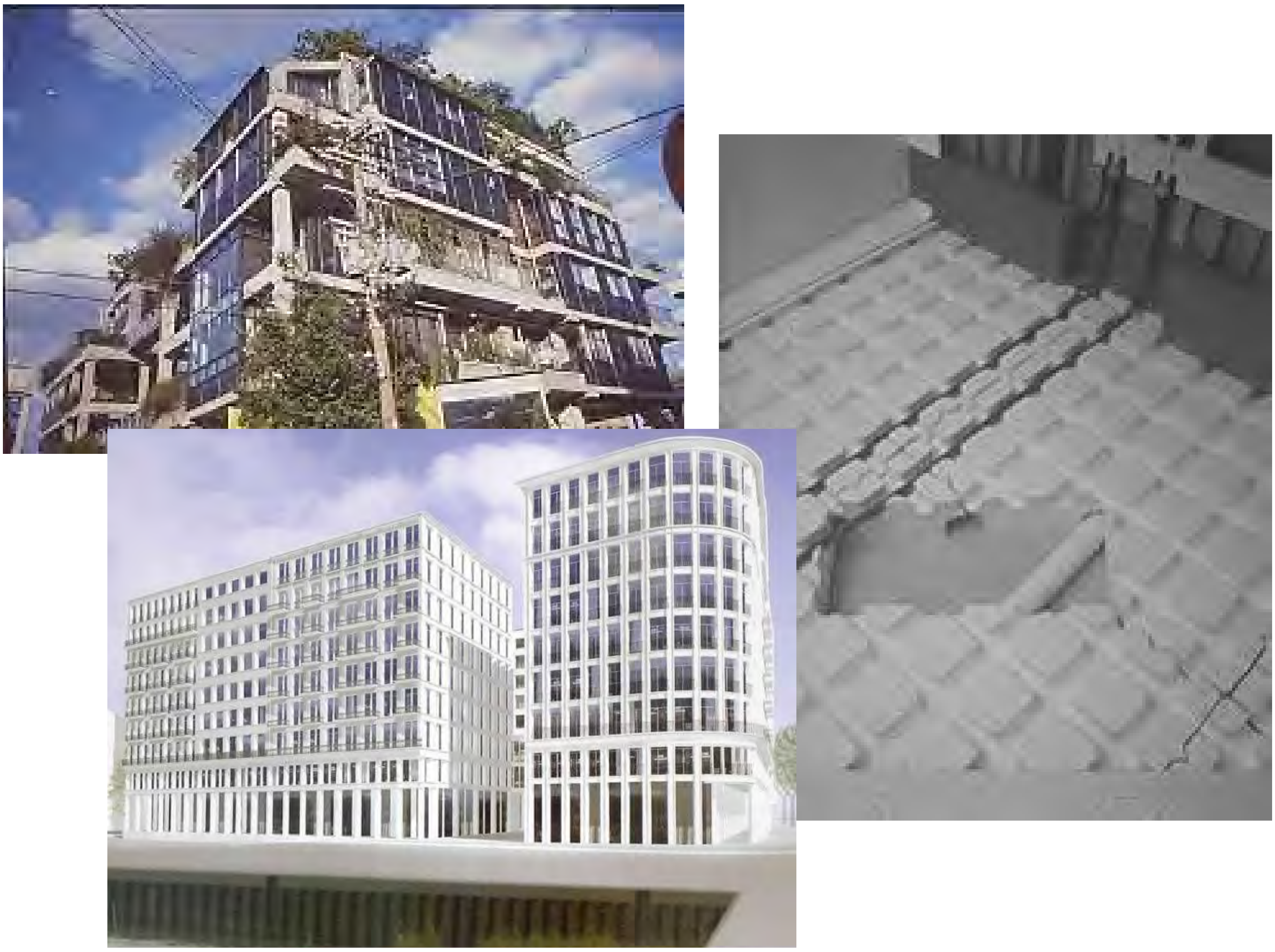
Steve Thompson works as a senior architect for Corus. His background is from private practice, working on and leading residential, commercial, education and transport projects. He joined Corus in 2000 to work on rail and transport architecture, and has been involved in a number of high profile projects across the UK. As part of Corus, RED Architects were formed in 2002, and Steve diversified to work on residential, commercial, leisure and educational projects developing and using off-site construction systems.

In his current position, Steve strongly promotes best design practice across the construction industry, and advises on the effective use of steel in buildings.

5

Open, Lean and the Quality of the Built Environment

Ype Cuperus



Open, Lean and the Quality of the Built Environment

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Abstract

Any industry that does not satisfy its clients will not survive, except the housing industry, as it seems, so something must be basically different. Is this reassuring or is it a reason to worry? Will this sustain or is it time for a radical change? In order to find the answer, the differences and similarities between the manufacturing and building industry need to be identified. This is the heart of ManuBuild.

But who are we 'manu-building' for? If we don't know, it is hard-to-impossible to come up with strategies of which the outcomes can be measured. Is it the institutional client or is it the end –user? Or both and in that case how do we balance this?

This paper claims that the levels of intervention referred to are controlled by different parties in a decoupled and co-ordinated fashion and that they are served best by a construction industry that offers its services along the same lines. Consequently, the higher level (town fabric) is less 'manu' and more 'build', the lower level (fit out) can be more 'manu' and less 'build'. At all levels of intervention the optimum value needs to be created and as much waste as possible needs to be banished. In the final analysis it is concluded that 'manubuilding' the built environment needs a clear understanding of how to create value while with a built environment that can change over time. ManuBuild will succeed if it focuses on the client's demands, per level of intervention. The process to make this happen needs to be lean and without waste. The result will be a built environment that outlasts fashion and will get better as it gets older.

Keywords: Open Building, Lean Construction, Connections, Co-ordination, Decoupling

Background

We add to the build environment by erecting buildings of all sorts. The concept of Open Building accepts control as a guiding force in design, construct and usage of the built environment. Whether we look at private space, such as the interior of our house of public space, streets of residential areas, inner cities or industrial areas, it has to be clear who controls what. If this is not clear, the house will not be maintained, the street will be vandalized and becomes a place in which we feel uncomfortable and unsafe. The built environment is the product of the construction industry that like any other industry cannot survive without making profit. Cutting costs contributes to increasing profit. As long as wanted value can be cut off, thus adding to the profit, it is hard to get it realised. Lean construction explores how the construction industry can raise its profit by creating value, rather than by axing it. In order to develop thoughts for ManuBuild, the industrial context needs to be characterised, before we can identify the problem and the research approach.

Industrial Context

Why did the construction industry never make the quality jump by 'industrialising' its own practice, like most of the other industries did? It is obvious that an industry does not change unless there is a profitable reason, such as survival, to change. This in turn raises the question 'Why has the construction industry managed to survive so far without dramatic changes?' The reason is simple: there was never the need to change. Poor as well as affluent societies tend to sustain housing shortage, in which the construction industry has to deliver in a supply market, a market with no alternatives for buyers.

Protection against the climate is one of the first basic demands of any species. Creating shelter is one of the first needs of mankind. This makes the construction industry one of the oldest professions, based on strong local conditions and traditions. Although it may sound logical, it is not. Another old profession that of weaving fabric was one of the first new industries of the industrial revolution and left its history of a cottage industry behind. The textile industry became the crystallisation point of new cities and in line with the efficiency of mass production housing was built, that turned out to become slum cities. They are the construction output equivalent of the industrial revolution, the way they were built remained very traditional: manually laid brick combined with manually laboured timber. Working conditions were similar to those in the manufacturing industry: long days, heavy work, badly paid with very low lifetime expectancy. Whereas it may be presumed that the textile industry optimized on the quality of its product, competition would move bad performers out of business and driving costs down by underpaying the labourers, the construction industry optimized on reducing cost only. The main concern of the first clients of mass housing were note really concerned with the value they created for their personnel, but with creating housing at minimal costs. Although they had their architects to produce plans and specifications, the construction was then tendered to contract the builder who delivers the minimum required quality at the lowest price. The traditional building industry always lacked the incentive to create value. In addition, the housing industry by its own nature has always built in a sellers market. Poor societies need large families as insurance for the old age. Affluent societies have smaller households, however higher lifetime expectancy. Better healthcare extends our life, thus adding to the population figure and housing shortage. Improved healthcare in developing countries drops the child death figure thus boosting the population size. Affluent societies in turn see their low birth rates compensated by unwanted immigration by people who look for a better life or wanted immigration to supply our reducing workforce. In short, the housing industry is not used to build for a buyers market and can afford itself to optimise on price rather than value for the end user.

Problem

The self-sustaining shortage of housing is at first glance an attractive condition for the construction industry. At the same time the construction industry continues to have high failure repair costs and low profit margins. And there is no guarantee that it delivers a sustainable built environment we all love and wish to defend and maintain. ManuBuild's presumes that the combination of manufacturing and building offers a perspective for improvement.

Any industry that does not satisfy its clients will not survive, except the housing industry, as it seems, so something must be basically different. Is this reassuring or is it a reason to worry? Will this sustain or is it time for a radical change? In order to find the answer, the differences and similarities between the manufacturing and building industry need to be identified. This is the heart of ManuBuild.

But whom are we 'manu-building' for? For who are we crating value? If we don't know, it is hard-to-impossible to come up with strategies of which the outcomes can be measured. Is it the institutional client or is it the end –user? Or both and in that case how do we balance this?

Learning Objectives:

- Open Building provides the framework for organizing the process of constructing the built environment along lines of decision making rather than being dictated by the subdivisions of the construction industry.
- Lean Construction teaches us how to create value by introducing flow in the construction process and how to banish waste from the process. Minimizing the failure repair costs improves the profit and reduces the environmental load.
- Combining the Open and Lean vision help us to better understand and improve the performance of the construction industry resulting in a better built environment and to connect ManuBuild to the built environment rather than to the construction industry only.

Approach

The line of thought of this chapter is based on a series of observations with regard to demography (a growing population, whether in number or demand needs more buildings) and presumptions with regard to the construction industry. This results in two research questions. The search for answers gives food for thought for ManuBuild.

Presumptions

Open Building: a concept to build for an unknown demand, resulting in a built environment that adapts to changing needs and gets better as it gets older.

Lean Construction aims 'develop new principles and methods for product development and production management specifically tailored to the AEC industry, but akin to those defining lean production that proved so successful in manufacturing' (www.iglc.net) other to words: create value, banish waste.

This results in two research questions.

Research Questions

- Who are we building for? This question is used to look into the history of the Open Building concept, its concern for customers of the built environment and their respective levels of decision-making. This has resulted in guidelines for design, construction and use of the built environment. This is illustrated with three cases.

- What and how are we building? What value is needed and how is it created? The lean production mantra: create value, banish waste is too limited to answer this question. Koskela adds an interesting perspective to this subject: construction is a way of production that has to balance transformation of material, flow of the process and value specified for the customer.

The search for answers is based on two assumptions:

- In order to maintain and sustain the built environment it has to be clear who is in control about what. This works best if these levels of intervention are technically decoupled yet coordinated and the construction industry can offer its services separated along the same lines.

- The construction industry needs to optimize on creating value, rather than on reducing costs. It can learn from lean production.

Analysis

Who are we building for? Open Building to control the forces at work

The built environment is the result of many forces. Hard economics play an all-encompassing role in constructing and running buildings and their environments. At the same time there are many 'soft' forces that influence the built environment. The weight of aspects such as safety, clean air, comfort, energy consumption, and concern for global sustainability has grown and now also influence the way buildings are built, used and maintained. All at its own cost and economic consequences. With sufficient political consensus, soft forces become cemented in regulations and can be as tough as the hard ones. Open Building always has had an open eye for the forces at work that determine the built environment. This originates from the presumption that a built environment only works well over time if its users can control their own territory. The dweller controls the house, the neighbourhood the street and the municipality the city. If the connections of individuals or groups and their territories do not substantiate, they will live in an environment they are not willing to defend, to maintain, decorate and belong to. When the results of post WWII mass housing, inspired by mass production methods from the manufacturing industries, became visible, it was clear that since it was built on optimizing economics rather than reflecting the control structure of its intended users, it would not result in lovable environments. In 1961 it was suggested to make a clear distinction between 'support' and 'infill', between base building and fit-out. This would create conditions for the dweller to control his territory, at the same time being very clear about those elements that are not controlled by the individual dweller but by a higher order, such as a collective of dwellers, the land lord or municipality. There is a parallel between the level of intervention and the life span of its related building parts. The infill has a shorter life span than the base building, which in turn has a shorter life span than the surrounding urban fabric. Based on these observations it was advocated to organize the construction industry (from design to construction, use and adaptation) that reflects these levels of intervention, with separate industries for base buildings and fit-outs (Habraken, 1961). In the early sixties of the twentieth century the Netherlands SAR, Foundation for Architects Research, translated these ideas in design guidelines for architects, based on an internationally accepted 10 cm module and a preferred 30 cm multi-module modular system to dimension and position building parts. Although embraced by some, many others opposed it. In the community of established architects they felt threatened in their design freedom and amongst a influential group of politically active students it was rejected on Marxist arguments: 'The vision of the technocrat with regard to the housing industry results in an increasing dehumanization of the individual. Humankind has become object of manipulation at the least. Deceptive necessities are cultivated in order to sustain the production system and to increase production. Thus the construction industry also conforms itself to the development of contemporary capitalism' (Stielos 1970, p. 91). In the mean time SAR became open for contractors and manufacturers in the housing industry. In the seventies the SAR ideas were translated into guidelines for the construction industry. Until then, modular coordination was seen as a means to streamline the production of building parts. A limited set of dimensions would reduce the number of different sizes to have in stock. Based on the 30 cm grid with an embedded 10-20 cm tartan grid a new experimental code for subsidized housing was introduced. This was a unique building code that described a complex system of modular coordination. It differed form all other MC exercises in other countries, because it did not aim at modularizing dimensions of building parts for a more efficient manufacturing process, rather than on creating conditions to decouple building parts by coordinating their positions on the 10-20 cm tartan grid. Positional and dimensional coordination of building parts created guidelines for project independent product design, it allowed designers to postpone decisions about the choice of materials, for example in situ poured or a range of pre-cast floors, as well as the positions of materials: customers wanting different lay-outs. This modular coordination was intended to take the ripple effect out of the building design and the construction process, thus decoupling decision-making. This had implications for the way drawings were made and had to be read on the building site. To illustrate this point, for details, scale 1 : 5 pre-printed transparencies, with a smallest grain of 2.5 mm could be used. Since this was a disruption of the existing routine it got a lot of resistance from draftspersons and tradesmen who had to build from these drawings. By making it attractive to use building parts of modular sizes it was thought to be an incentive for the building material manufacturers to switch to modular product series. When in the early eighties the economy got into a depression, the building material industry did not want to invest in changing their production lines and from the view point of fair trade a set of dimension and position rules was never made compulsory. In retrospect it needs to be said that the introduction a sophisticated set of modular coordination rules failed, because it never got the status of a building code and it lacked the user friendliness, needed to sell itself. Flexible computer aided production techniques and logistics support became the nineties answer to reduce inventory. It may have resulted in cost reduction during construction; there is no evidence however that this has resulted in better and safer cities and a more sustainable environment.

It seemed that modular coordination and Open Building type innovations in construction had timed out. Still, three developments illustrated by cases deserve to be mentioned.

Case 1: Next21

Figure 1: Next 21, Osaka: super structure with super modular coordination.

In the early nineties the Osaka Gas Company in Japan initiated the construction of a apartment block with a strict technical division of base building and fit out. It is a super structure that includes eighteen different units. In addition it offered the environment for all kinds of advanced technological experiments about energy saving. It was also the test ground for applying and studying a set of modular co-ordination rules. In comparison with the experiments in the Netherlands it had an even finer grain and in that respect it was an exploration of a super modular coordination. The bursting of the Japanese bubble economy in the mid nineties made an end to these large-scale experiments. Nevertheless, Open Building type research and development continues, be it on smaller pilot projects.

Case 2 Matura Infill System

Based on Open Building principles and extensive knowledge of modular coordination, the Matura Infill System was developed in the Netherlands. It consisted of a raised floor of polystyrene tiles with grooves that accommodate space for ducts and L-shaped base-boards to run wiring in and to be the base for any type of inner partition wall. Since it catered for the horizontal distribution of ducts and services, the result of customer preferences, it freed the load bearing construction from embedding pipes and conduits.

Figure 2: Matura Infill System
(space reservations for ducts and services, based on modular coordination.)

It had the potential to simplify the base building and to be the basis for two separate industries: one that constructs base buildings without plumbing and cabling, the other fitting the support out with a complete working interior according to the customer's demands. It is beyond the scope of this chapter to analyse why the Matura system was terminated after having been applied on a small scale. It is obvious and possibly an understatement to say that the traditional construction industry did not see any reason to embrace this type of product and management innovation. "Clean' supports, without plumbing and cabling are cheaper and easier to construct. The builder's profit is related to its turn over and his speciality is to coordinate complex processes and fire fighting if needed. The traditional builders gain less with simpler and cheaper. Simplicity is an excellent condition to reduce failure repair costs. Since it also reduces complexity and risk there is little incentive for the traditional builder to go this way.

Case 3: Solids

The Amsterdam based housing corporation 'Het Oosten' has given their own interpretation of the Open Building concept. They emphasize the aesthetic and cultural quality of buildings. They have learned from observations in Amsterdam where old buildings are refurbished over and over again and are more appreciated, as they get older. They have invited an architect to design a base building as an empty shell. The floors or parts of floors can be sold or let according to the space requirements of the dweller. They then have to organize the fitting out themselves. It was in the client's interest to build an empty shell as a base building; they therefore decided to make it a support infill project. The construction industry happily follows.

Figure 3: Solids, Amsterdam: aesthetic and cultural values sustain.

In the final analysis it can be concluded that although many aspects of the Open Building concept have been accepted and are implemented in the construction industry, there is still a lot of resistance to overcome. Habraken's observations with regard to the quality of mass housing laid the groundwork for the Open Building concept. In many other production processes the application of mass production resulted in highly appreciated products. Unlike the construction industry, manufacturing has changed considerably from cottage industry to mass production to customized single piece production. Why did these radical changes not take place in the construction industry so far? This is subject of exploration in the next paragraph.

What and how are we building?
Lean Construction: Create Value, Banish Waste

When the negative side effects of mass production became clear, manufacturing processes were adjusted. This process is well described by Womack et al. in their best selling book, 'The Machine that Changed the World'. It tells the story how Toyota learned from Ford how to build cars in an efficient way, how they had to translate it to the post war Japanese market and how they developed the TPS, Toyota Production System. Unlike the traditional car manufacturers in the US and Europe, Toyota first determined the customer desired value and then build the cars the customer wants in a process that creates value while banishing all kinds of waste from the production process. TPS applied to other manufacturing industries was named lean production. In order to understand the meaning of lean we have to go back to when it was first used in the context of production. It was offset against craft production and mass production 'the two other methods humans have devised to make things'. 'The lean producer (...) combines the advantages of craft and mass production, while avoiding the high cost of the former and the rigidity of the latter. (...) Lean production (...) is called "lean" because it uses less of everything compared with mass production. – half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products." (Womack et al 1990, p.12-13). The IGLC, International Group for Lean Construction first met in 1991. Their goal is '(...) to better meet customer demands and dramatically improve the AEC process as well as product. To achieve this, we are developing new principles and methods for product development and production management specifically tailored to the AEC industry, but akin to those defining lean production that proved to be so successful in manufacturing' (www.iglc.net).

People from the construction industry ask themselves why they cannot build the way cars are built. They pride themselves or resign to the idea that construction is so different from manufacturing. Koskela who was intrigued by the virtues of lean production from its beginning started an extensive analysis on this subject presuming to find the differences to learn from. He asked himself two questions. First, 'is it possible to formulate a theory of production?' Secondly, 'Does such a theory add to our understanding and lead to improved performance when applied to constructions? His answer was a double yes. It was a PhD thesis after all. He characterises the construction industry and is not optimistic about the achievements of industrialisation: 'Construction productivity lags behind that of manufacturing. Occupational safety is notoriously worse than in other industries. The quality of construction is considered to be insufficient. A number of solutions or visions have been offered to relieve the chronic problems in construction. Industrialization (i.e. prefabrication and modularization) has for a long time been viewed as one direction of progress. Currently, computer integrated construction is seen as an important way to reduce fragmentation in construction, which is considered to be a major cause of existing problems. Robotized and automated construction, closely associated with computer integrated construction, is another solution promoted by researchers. However, at least up till now, there have been no signs of major improvements resulting from these envisioned solutions.' (Koskela 2000, p. 13) He came to the conclusion that lean production should be looked at as a production process like so many other manufacturing processes and that construction is not all that different. It is just that the construction industry, although catching up, still lagging behind with regard to other industries: 'Thus, construction is now in an analogous situation to manufacturing in the 1980s, when JIT methods started to diffuse and led, together with ideas from the quality movement, to a re-evaluation of the most aspects of production management' Nevertheless, there is hope: '(...), construction is in one respect in a better position than manufacturing, the new foundation is not implicit anymore, but can be made explicit and accessible to practitioners through the doctrine of construction management'. (Koskela 2000, p. 250). His contribution to the doctrine is the TFV concept and is worth taking note of for ManuBuild. In his analysis off the production process he demonstrates that the emphasis has changed in time from a transformation of material to the flow of the process to creating value for the customer. Almost form the outset, going back to the late ninetheenth century, industrialised production was seen as a process of transformation.

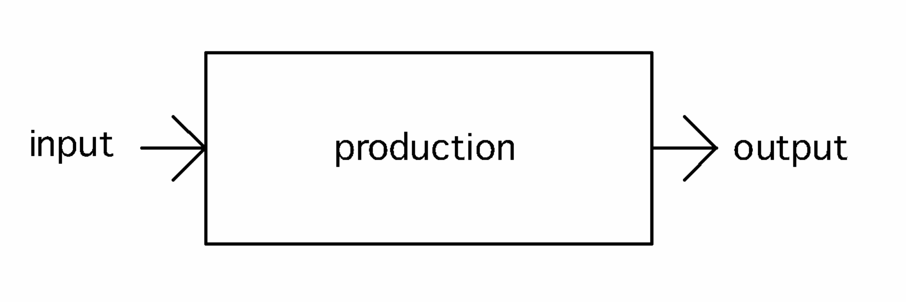

Figure 4: production as transformation.

It was thing-based, its focus was on transforming material into a product. We had to wait until the eighties for flow as a new approach emerged. JIT, just in time delivery became popular to make the transformation based production more productive. Koskela quotes Shingo: 'Flow along the y axis represents the change taking place in the material being worked on, that is, the *object* of production. Flow along the x axis represents the operations being performed on the material by workers and machines, that is, the *subject* of production'.

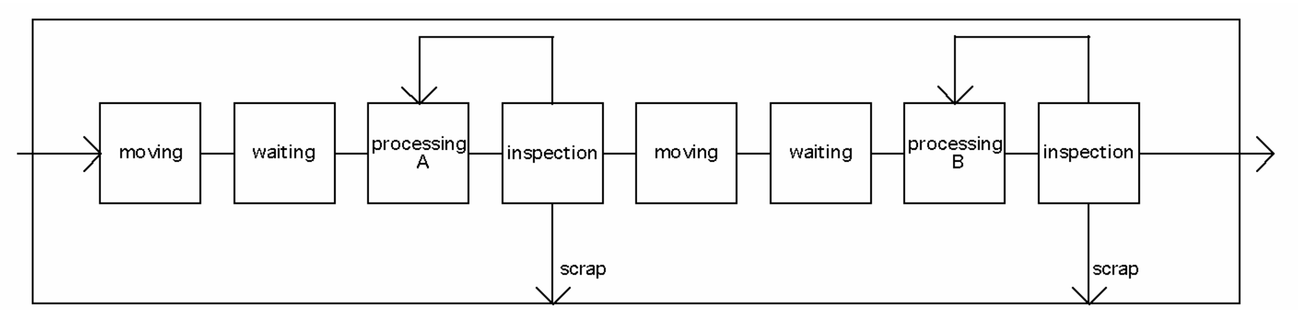

Figure 5: production as flow.

When looking at the production process in terms of flow, it immediately becomes clear that there are many activities that do not add value. They were identified by Taiichi Ohno of Toyta as: waste of overproduction, correction, material movement, waste of processing, waste of inventory, waste of waiting, waste of motion (Ohno 1988). Koskala warns: '[eliminating waste] cannot be used simplistically. Some non-value-adding activities produce value for internal customers, like planning, accounting and accident prevention. Such activities should not be suppressed without considering whether more non-value-adding activities would result in other parts of the process. Needless to say that eliminating waste from the process reduces the lead time, the time, 'the time required for a particular piece of material to traverse the flow' (Koskela 2000, p.54-58). Was transformation material oriented, and flow process oriented, both still leave out the customer. This observation resulted in the conclusion that 'the value of a product can be determined only in reference to the customer, and the goal of production is satisfying customer needs (Koskela 2000, p.74).

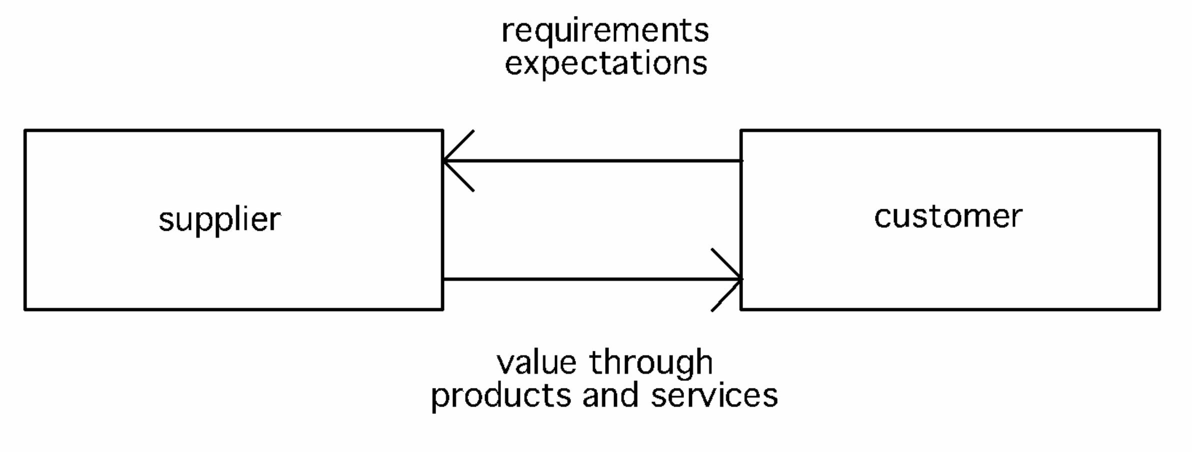

Figure 6: production to generate value.

Concluding, Koskela identifies transformation, flow and value as three successive guiding principles in production. T, F and V should be applied in a balanced way while the meaning of the value concept has not crystallised yet. The TFV concept can be applied at manufacturing as well as construction. Therefore it is similar to the Open Building concept an important consideration for ManuBuild.

Results and Business Impacts

Key Findings

Manufacturing is making in the factory and building is making on the building site, both having their own peculiarities. How can ManuBuild profit form the best of these worlds?

The urban fabric, base building and fit out are products of the construction industry, they are the result of their respective spheres of influence and all levels of decision making have their own (combination of) customers. Open Building awareness how to build for an unknown future offers us the framework to differentiate between different types of clients and connect them to different levels of intervention and their respective cycles of change. The consumer consumes the fit out of the building, after a while it has gone. The owner maintains the base building and in general sees the value of its property rise more than the value of the local currency. If the location of the property turns out to be right he has hit a goldmine. The Open Building concept was a designers initiative that began in the early sixties and includes an extensive set of guidelines how to decouple the dependencies of decision making by coordinating position, dimension, interfacing and design of building parts. Although it had the potential to improve the productivity of the construction industry and although aspects are applied, it has never been totally implemented except in experimental projects such as Next21, having left a lot of accumulated knowledge underused.

Lean Construction, born 1991, is a construction management concept and has provided us with a powerful set of definitions. Its mantra is 'Create value, banish waste'. Any activity that does not create value for the customer is waste. In that sense, large inventories, large buffers, waiting and redoing are a waste, since they do not add value. The TFV concept has made clear that understanding value, what kind of value are we creating for whom, is still subject of thought.

Open Building suggests a better construction process and a better-built environment. This makes it possibly harder to get implemented than Lean Construction that is much easier to connect to profit for the construction industry.

Business Impacts

Open Building and Lean Construction can complement each other. OB identifies customers per level of decision-making and describes value in terms of quality of the built environment. LC provides the tools to optimize value generation by banishing waste. Both on-site as well as off-site production can benefit form combining, developing and applying these concepts, since they support creating well defined value for well-defined parties and optimising the process by banishing waste.

Conclusions

This paper claims that the levels of intervention referred to are controlled by different parties in a decoupled and co-ordinated fashion and that they are served best by a construction industry that offers its services along the same lines. Consequently, the higher level (town fabric) is less 'manu' and more 'build', the lower level (fit out) can be more 'manu' and less 'build'. At all levels of intervention the optimum value needs to be created and as much waste as possible needs to be banished. In the final analysis it is concluded that 'manubuilding' the built environment needs a clear understanding of how to create value while with a built environment that can change over time. ManuBuild will succeed if it focuses on the client's demands, per level of intervention. The process to make this happen needs to be lean and without waste. The result will be a built environment that outlasts fashion and will get better as it gets older.

Key Lessons Learned:

- The built environment, the way it is built and can be changed, is the result of decisions by individuals and parties. Therefore building parts, belonging to different levels of decision-making should be de-coupled, yet coordinated along these lines.
- In order to de-couple yet coordinate building parts, position, dimension and interface need to be well designed.
- Lean is: Create value, banish waste.
- Production emphasis has evolved from transformation to flow to value, from material to process to customer. FT and V should be applied to construction in a balanced way.

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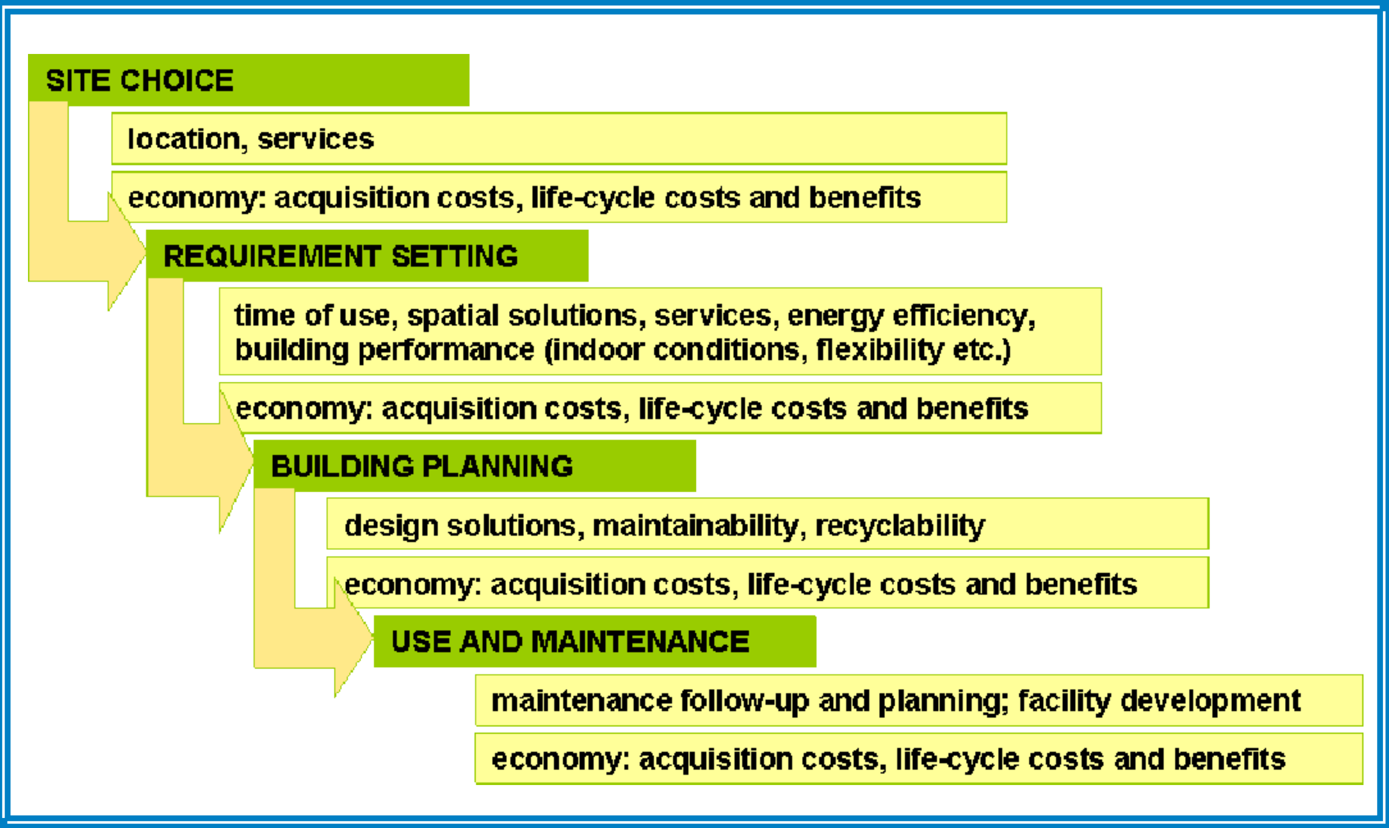
6

Use of LC Guides in Open Building Manufacturing

Tarja Häkkinen & Sakari Pulakka



Use of LC Guides in Open Building Manufacturing

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Abstract

The Chapter discusses the availability of Life Cycle (LC) guides and assesses the usability of LC guides, methods and tools from the view point of open building manufacturing. LC guides include standards, national voluntary methodologies and different kinds of methods developed in national and international research projects. Open building manufacturing needs LC methods in order to be able to state LC requirements and consider user needs, to be able to design for required performance and life cycle, and to be able to make decisions between alternative options. The general and building related principles of LC methods have been agreed upon and made public with help of standardisation.

The Chapter discusses the compatibility of LC methods with EU policies and states that the emphasis on life cycle approach issues from the principles of sustainable development; the adoption of life cycle approach as a basic principle for sustainable building methodologies is consistent with the EU policies.

The Chapter describes the role of LC methods. Sustainable construction is tried to be promoted with help of developing LC methods. It is believed that sustainable building can be promoted if there are methods and tools that help to set targets for sustainable construction, assess the results and show the achievements for clients. The role of public actors in building sector is important with this respect.

Environmental classification systems support the consideration of LC aspects in early stages of building process. However, the usability of LC guides and methods still needs improvement. The basic LC methods support rather subsequent assessment than advance evaluation. Design phase still lacks efficient LC tools, and there is a clear need for integrated methods. Product model based building will probably bring useful solutions.

Keywords: life cycle assessment, environmental declaration, life cycle cost, sustainability indicator, building product

Introduction

Open building manufacturing needs life cycle assessment methods and sustainability indicators in order to be able to state life cycle requirements, to be able to design for required performance and life cycle, and to be able to make decisions between alternative options. An important challenge is that these methods should be able to assess different kinds of systems with help of generally accepted indicators without favouring any specific solutions and be able to support the consideration of user needs and requirements.

This Chapter discusses the problematics of sustainable construction from the viewpoint of guidelines, methodologies and tools. The Chapter discusses the compliance of sustainable construction assessment methods and life cycle methods with the EU sustainable development policies, presents an overview of the existing LC methods and finally discusses the usability and restrictions of the existing methods from the view point of open building manufacturing.

Sustainable Development and Sustainable Building from the Viewpoint of EU Policies

Sustainable Development Strategies

The implementation of the principles of sustainable development is a fundamental goal of EU policies. The European Council of June 2006 adopted a comprehensive renewed Sustainable Development Strategy for an enlarged EU (EU 2006). The renewed strategy builds on the Gothenburg strategy of 2001 (EU 2001) and is based on the results of an extensive review process. The renewed strategy recognises the need to gradually change the current unsustainable consumption and production patterns and move towards a better integrated approach in policy-making.

The overall aim of the renewed EU Sustainable Development Strategy is to identify and develop actions, which enable the EU to achieve continuous improvement of quality of life both for current and for future generations, through the creation of sustainable communities. Sustainable communities should be able to manage and use resources efficiently and to make use of the innovation potential of the economy, ensuring prosperity, environmental protection and social cohesion.

In principle, the emphasis on life cycle approach issues from the principles of sustainable development. As stated in the renewed Sustainable Development Strategy for an enlarged EU (EU 2006) "Sustainable Development stands for meeting the needs of present generations without jeopardizing the needs of futures generations - a better quality of life for everyone, now and for generations to come. It offers a vision of progress that integrates immediate and longer-term needs, local and global needs, and regards social, economic and environmental needs as inseparable and interdependent components of human progress." The adoption of life cycle approach as a basic principle for sustainable building methodologies is consistent with the EU policies on sustainable development.

Significance of Building and the Role Steering Mechanisms

The construction sector is one of Europe’s largest industries and of major strategic importance as it provides the built environment, on which all other industries and sectors of the economy depend (Lorenz et al. 2005). Built environment significantly affects the environmental quality and environmental impacts in Europe: Buildings are responsible for about 40 % of Europe’s total primary energy consumption and generate more than 35 % of all greenhouse gas emissions in Europe (Petersdorff et al. 2004). The overall environmental management of buildings is important for the European Union in order to reach targets required by the Kyoto Agreement; the EU is committed to reduce the CO_2 emissions by 8 % by 2010 in relation to the base year of 1990 (EC 2006).

The communication “Towards a Thematic Strategy on Urban Environment” (TSUE 2005) explains the priority theme Sustainable Construction by stating that “buildings and the built environment are the defining elements of the urban environment. They give a town and city its character and landmarks that create a sense of place and identity, and can make towns and cities attractive places where people like to live and work. The quality of the built environment therefore has a strong influence on the quality of the urban environment but this influence is much deeper than purely aesthetic considerations.”

Within the TSUE process the WG on Sustainable Construction (Sustainable Construction 2004) summarised that

– The built environment represents a substantial and relatively stable environmental resource. Most buildings survive for several decades, and very many survive for centuries. As the community's principal physical asset, getting good value requires that the building's full life cycle is considered, avoiding short-sighted attempts to merely minimise initial cost. A strategy on sustainable development will seek to prolong the life of existing structures, and indeed to prolong the utilisation of the materials with which they were originally constructed. Adaptation is usually preferable to new building, and upgrading of performance often represents an efficient deployment of resources.

In order to ensure sustainable building European countries and the Community have put great efforts on the development of methodologies and tools for the management of sustainable building with help of national and European research programmes. It is believed that sustainable building can be promoted if there are methodologies that help to set targets for sustainable construction, assess the results, and show the achievements for clients. Methodologies as such do not improve the sustainability of built environment, but the strategic impact will depend on the implementation of methodologies. The eventual impact of sustainable construction methodologies may be based on (Figure 1)

– informative support
  If there is knowledge available about the sustainability aspects of buildings, this helps owners and investors to voluntarily consider these aspects. If there are voluntary labelling methods available, leading actors make use of those and improve the sustainability aspects of their products and thus possibly increase the market value of the products and achieve competitive advantages.

– economic incentives
  If certain economic incentives (through for example taxation) are combined with sustainable classification of buildings this may encourage owners, developers, contractors and/or designers of buildings to consider sustainability issues and to develop more sustainable building solutions.

– normative regulations
  If environmental classification of new buildings and building renovations was mandatory and if certain minimum levels were required, this would improve the sustainability of construction. The degree of impact would depend on the stated minimum levels and on the range of the requirements.

Normative regulations may be an effective way to achieve results but because it calls for societal agreement either on national or EU level it may be a time-consuming process.

The role of public actors may also be important when encouraging sustainable building. The state and municipal organisations that own and develop public buildings affect significantly the development of sustainable building as a whole, if they decide to make use of sustainable building methodologies in new building and in renovations. This is not only based on the share of public buildings compared to the whole building stock, but also on the strength of example and on the effect of cooperation. By setting sustainability targets, public building processes may initiate private construction and design companies into sustainable building methodologies.

Sustainable entrepreneurship can be defined from different viewpoints. Interpretations of sustainable entrepreneurship often introduced include (Gerlach 2000):

- commitment of the organisation with environmental targets
- organisations aim at achieving competitive advantage with help of ecological / sustainable innovations
- organisations actually aim at societal changes which are in accordance with sustainable development.

Sustainable entrepreneurship needs and benefits from information, knowledge, methods and tools that they can make use of in setting targets, monitoring results and in declaring and claiming the sustainable characteristics of the products for public.

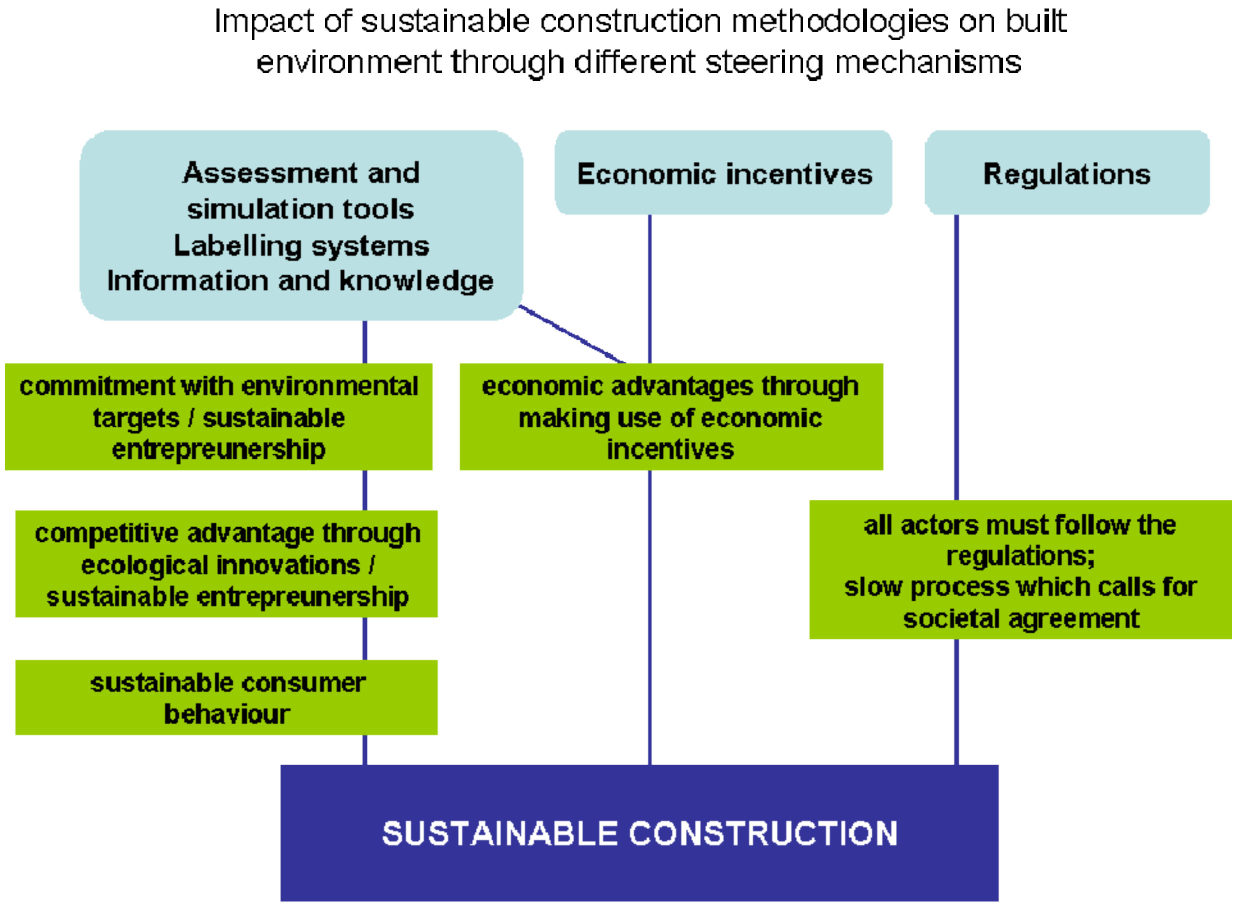

Figure 1. Impact of sustainable construction methodologies on built environment through different steering mechanisms.

Building construction and the use of buildings have a significant effect on the sustainable development of European societies. Sustainable building construction affects the environment as well as cultural and socio-economic issues. In order to aid target setting and design for sustainable new buildings and renovations several European organisations and countries have developed assessment and classification methods. The structures of these methods often resemble each other. It is typical that the methods include certain main categories with regard to which buildings are assessed with help of indicators. The methods typically focus on environmental issues and have a life cycle approach. There is a clear need for common development and harmonization of these methods. Although Europe is one community, it is not homogeneous. For example:

- legislation
- climate conditions
- cultural aspects

- social behaviour
- building types, building processes and building materials

are not the same along all Europe. For this reason the development of common methodologies will require the definition of a common framework but taking into account the specific features of different regions. This requirement is consistent with the requirements of open building manufacturing.

Integrated Product Policy

Life cycle approach is emphasised in EU policies and legislation. As stated in the Communication on Integrated Product Policy (IPP 2003), sustainable development is one of the fundamental objectives of the European Union. Integrated product policy has a clear role to play in contributing to sustainable development. All products and services have environmental impacts during their production, use and/or disposal. IPP (2003) emphasises that the challenge is to combine improving life styles and well-being – which are often directly influenced by products – with environmental protection. It is important to ensure that environmental impacts are addressed throughout the life-cycle in an integrated way. It is also important that environmental impacts are addressed at the point of life-cycle where they will best and most cost-effectively reduce the overall environmental impacts and resource use. It is and it will be more and more important for industry to understand the meaning of the LC approach and the importance to adopt the approach.

LC guides have been developed nationally and in international level for life cycle assessment and declaration of building products, services and buildings. The general principles on life cycle assessment of products and services have been agreed upon and made public with help of standardisation. There are international standards available on the formats, contents and processes of environmental declarations of products. In addition to general methodologies, applied methods for building products have been standardised by ISO. There is also a European process going on, which aims at the development of harmonised life-cycle standards for buildings and building products as described in the next section of this Chapter.

EU Directives

The life cycle approach can be distinguished in the two essential directives, which direct the building product and energy regulations of building, namely CPD and EPD; both of these emphasise the importance of use phase of buildings.

Construction Product Directive

The European Union adopted the Construction Product Directive (CPD 1988) in 1988. The Directive aims to complete the internal market for construction products through removal of barriers for trade by means of technical harmonisation.

The CPD defines the so-called essential requirements concerning safety and health aspects in construction works. According to the Annex 1 "the products must be suitable for construction works which (as a whole and in their separate parts) are fit for their intended use, account being taken of economy, and in this connection satisfy the essential requirements where the works are subject to regulations containing such requirements. Such requirements must, subject to normal maintenance, be satisfied for an economically reasonable working life." In contrast to earlier directives, the essential requirements stated in the CPD, are directed to construction works instead of building products. Therefore interpretative documents have been drawn up to the essential requirements. These should give concrete form to the essential requirements.

The essential requirement Number 3 is titled as "Hygiene, Health and the Environment". According to the interpretative document concerning the essential requirement Number 3, the environmental impact of building products shall be considered in all stages of life cycle including the extraction of raw materials, manufacture, construction, use, demolition, final disposal and reuse. However, being adapted to the limits of the CPD, the interpretative document is now related to the product "in use". For the present, the CPD mainly deals with the health issues, but the European Commission has noticed the need to take into account the environmental aspects and the need to provide the products with comprehensive environmental information. The development of the European standards on environmental performance of building products is the first step towards this.

Energy Performance of Buildings

The European Directive 2002/91/EC on Energy Performance of Buildings (EPB 2002) came into force 16 December 2002 in order to be implemented in the legislation of the member states in 2006. Four main elements define the requirements that were needed to be integrated into national legislation:

- Establishment of a methodology for an integrated calculation of the overall energy performance of buildings;
- Definition of minimum energy efficiency requirements per member state based on this methodology;
- Energy efficiency certification of new and existing buildings;
- Regular inspection of heating and air conditioning systems.

On the basis of the EC standardisation mandate M/330 EN CEN is developing methodologies for the calculation of the energy uses and losses for heating and cooling, ventilation, domestic hot water, lighting, natural lighting, passive solar systems, passive cooling, position and orientation, automation and controls of buildings, and auxiliary installations necessary for maintaining a comfortable indoor environment of buildings.

Obviously, the EPB directive emphasises the life-cycle approach. The directive highlights the consideration of use phase of buildings and aims at supporting owners and users of buildings to take into account the expected energy flows and related life cycle costs when making choices.

An Overview of the Life-cycle Guides for Building

Sustainability Indicators for Building

ISO TS 21929 (ISO 2006a) defines a framework for sustainability indicators of buildings. The framework is based on the premise that sustainable construction brings about the required performance with the least unfavourable environmental impact, while encouraging economic, social and cultural improvement at a local, regional and global level.

Environmental indicators address environmental aspects in terms of environmental loadings or impacts assessed on the basis of life cycle inventory or assessment. Environmental loadings are the use of resources and the production of waste, odours, noise and harmful emissions to land, water and air. However, consequential environmental indicators are also needed and used in requirements setting, design and selection of products for sustainable building. Consequential environmental indicators express environmental impacts in terms of building performance or location either quantitatively or qualitatively. These kinds of indicators have been developed for cities, built environment, buildings and other constructive assets and building products in various research projects like in the European CRISP (Häkkinen et al. 2002) and TISSUE (2004) projects.

According to ISO TS 21929 the following economic flows are related to the life cycle of a building:

- investment: site, design, product manufacturing, construction,
- use: energy consumption, water consumption, waste management etc.,
- maintenance and repair,
- deconstruction and waste treatment,
- development of the economic value of a building, and
- revenue generated by the building and its services.

The economic indicators indicate monetary flows connected to the building life cycle. Social indicators of buildings are used to describe how buildings interact with issues of concern related to sustainability at the community level. Community level issues that may be relevant are for example urban sprawl, mixed land use, access to basic, availability of green and open space, attractiveness of city centres, development of brown-fields, availability of housing, social segregation, cultural quality and protection of cultural heritage, safety, noise and air quality. Social aspects can also be addressed on the building level like for example (ISO 2006a):

- quality of buildings as a place to live and work,
- building-related effects on health and safety of users,
- barrier-free use of buildings,
- access to services needed by users of a building,
- user satisfaction,
- architectural quality of buildings and
- protection of cultural heritage.

In the discussions on sustainable building the link of sustainable building with building performance has been emphasised lately (Trinius and Sjöström 2005). Though environmental impacts and life cycle costs indicate aspects of sustainability, the quantifying is meaningless without a common reference. When comparing different design options, performance aspects are the underlying factor. Building performance is gaining stronger consideration in the connection of sustainable building, and thus also the management of building performance can be seen as an important part of sustainable building process.

Standards for Life-cycle Assessment and Service Life design of Buildings

There is an active process going on aiming at the formulation of international and European standards for the assessment and declaration methods of environmental aspects of buildings and building products.

CEN/TC 350 will develop voluntary horizontal standardised methods for the assessment of the environmental performance of new and existing buildings and for standards for the environmental product declaration of construction products, in the framework of the integrated performance of buildings. The becoming standards will be applicable (horizontal) and relevant for the assessment of buildings over its life cycle. The results from the standards mandated by the M/330 (energy performance directive) are integrated into the assessment of the environmental performance of buildings in the framework of integrated performance of buildings.

The standards that will be developed by CEN/TC 350 will describe a harmonized methodology for the assessment of environmental performance of buildings and life cycle cost performance of buildings as well as the quantifiable performance aspects of health and comfort of buildings. The agreed basic principles for the development of the becoming standards support the EU environmental policies, such as Integrated Product Policy (IPP 2003), the Sixth Community

Environment Action Programme (6EAP) (Sixth EAP 2002) and several thematic strategies derived from the 6EAP.

The stakeholders in the building sector should come from all sectors of the construction industry and building management and include building owners and users, investors, insurance companies as well as manufacturers, designers and contractors.

ISO / TC 59 "Building construction" / SC 17 "Sustainability in building construction" makes standardisation in the field of sustainability of the built environment. The environmental, economic, and social aspects of sustainability are included as appropriate. The work is carried out by four working groups:

- WG 1: General Principles and Terminology
- WG 2: Sustainability Indicators
- WG 3: Environmental Declarations of Building Products
- WG 4: Framework for Assessment of Environmental Performance of Buildings

The work of WG 3 has resulted in the development of ISO/DIS 21930 (Building construction - Sustainability in building construction – Environmental declaration of building products) (ISO 2006b). ISO/DIS 21930 provides the principles and requirements for conducting Type III environmental declarations of building products. It gives guidelines for the development and implementation of such declarations based on the Life Cycle Assessment, LCA. Thus ISO/DIS 21930 complements the general provisions for such declarations contained in ISO 14025 (ISO 2006c). ISO/DIS 21930 also provides a general framework for Product Category Rules, PCR, as defined in ISO 14025, for Environmental Product Declarations of building products.

ISO has also leaded the process of developing standards for service life planning. ISO 15686-1 (ISO 2000), ISO 15686-2 (ISO 2001) and ISO/DIS 15686-8.2 (ISO 2006e) give general principles for service life planning, describe service life prediction procedures and give guidelines for reference service life.

Standard ISO 15686-1 presents a valuable basic methodology in the area of service life design, but the methodology requires considerable knowledge about the degradation of components and materials (Marteinsson 2003). The service life and environmental assessment and prediction methodologies standardised by ISO provide a framework for the assessment procedure. Tools and practical guidelines have to be developed to make the methods easy to use for practitioners.

Life-cycle Assessment (LCA)

LCA is a technique for assessing the environmental aspects and potential impacts with a product by (ISO 14040):

- compiling an inventory of relevant inputs and outputs of a product system;
- evaluating the potential environmental impacts associated with those inputs and outputs;
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

ISO standards 14040 (ISO 2006d) and 14044 (ISO 2006f) describe the methodology and give principles and guidelines for Life Cycle Assessment. LCA studies the environmental aspects and potential impacts throughout a product's life from raw material acquisition through production, use and disposal. According to ISO 14040, LCA can assist in

- identifying opportunities to improve the environmental aspects of products at various points in their life cycle;
- decision-making in industry, governmental or non-governmental organisations;

– selection of relevant indicators of environmental performance, including measurement techniques; and
– marketing (e.g. environmental claim, eco-labelling scheme, including environmental product declaration).

As sated by Cole (2004) the notion of life cycle assessment has been generally accepted within the environmental research community as the only legitimate basis on which to compare alternative products and services; the approach is firmly adopted for the European assessment tools.

Life-cycle Costing (LCC)

Life cycle costing (LCC) is a technique for estimating the cost of whole buildings, systems and/or building components and materials, and for monitoring the occurred throughout the lifecycle. The technique can assist decision-making in building investment projects. LCC is used to evaluate the cost performance of a building throughout its lifecycle, including acquisition, development, operation, management, repair, disposal and decommissioning.

Although the basic principles of LCC are widely agreed upon and known, LCC is not commonly applied in Europe in practice.

ISO/DIS 15686-5 (ISO 2006g) is currently in preparation. This part of ISO 15686 aims at providing the procedures for performing LCC analyses of building and constructed assets and their parts, including cost or cash flows. The main content covers principles of life-cycle costing, instructions for LCC assessment with reference to

– design options/alternatives;
– investment options;
– decision variables and
– uncertainty and risk.

Nordtest standard (LCC for building trade (NORDTEST 2001), is a Nordic classification system for lifecycle costing. It doesn’t differ much from ISO15686-5 (Table 1). However it aims to increase knowledge and competence on LCC as a consequence of increasing demand and service life planning. The expressions and mathematics of Life Cycle costing have been developed nationally in different countries. The basic principles adopted by those standards are quite alike. However, practical use of life cycle costing methodologies is not quite clarified. The analysis model has to be directed and customised for different types of use; for example facility economics, effects of certain types of buildings, choice of technical systems, and comparison of providers of maintenance services are issues, which need further discussion.

Table 1. Classification of life-cycle cost according to ISO15686-5 and NORDTEST.

Type of life-cycle cost	Description
Building cost or Capital Cost	Cost including all material, labour and sub costs caused by construction of facility, product or material. If the length of life cycle is shorter than lifetime, the capital cost includes only the pre-paid share.
Funding cost	Price of money within chosen life-cycle. Real rate (nominal rate – inflation) is based on real need and price of money.
Facility management	Price of money within chosen life-cycle. Real rate (nominal rate – inflation) is based on real need and price of money.
Operating cost	Continual cost caused by the use of building including energy, water, waste, cleaning, other space services etc.
Maintenance cost	Time-planned maintenance and renewing of components.
Modification cost	Cost of spatial modifications.
Development cost	Improvement of technical systems, building parts and/or environment through demand management and building condition charting.
Environmental costs.	Possible needs for soil refreshment and sheltering, use of raw material, cost of demolition and recycling etc.

With regard to open building the LCC calculations can be divided to deal with the basic elements of building (longer lifecycle) and user elements (supplementary structures and furnishing with shorter lifecycle). The following list shows examples of issues that can be taken into account in life cycle costing and which bring essential benefits in open building:

- work safety → lower construction cost
- energy performance → lower maintenance cost
- life cycle quality → lower renovation cost
- flexibility → lower modification cost
- easy change of building parts → lower renovation cost and higher rate of recyclability

Because of the predictive nature of life cycle costing methods, sensitivity analyses are often important in the connection of LCC. Sensitivity analysis may be based on classification including for example the three steps: optimistic – probable – pessimistic. Possible economical risks on different levels include the following:

- Advancement of resale value, permanence of characteristics, maintainability and chances of valuation and adaptability of systems with needs for facility management;
- Mistakes concerning building planning, accessibility of building products, operative experiences, damage risks and way of use;
- In production process insufficiency of professionals, problems with acquisitions, actions and transfer of project start towards winter time or other unfavourable conditions;
- In use and maintenance under-prising in planning phase, defaults of use and maintenance directions, unexpected rises of prises, larger and careless use of systems, unexpected damages and problems with usability in case of user changes and faults and lacks of maintenance actions;
- In case of facility management a failed consolidation of actions, unexpected damages revealed by demolition and disturbances caused to users.

National Environmental Assessment Methods for Buildings and Building Products

In addition to internationally agreed standards and guidelines, there are a number of national methodologies based on life cycle approach. For example VTT together with the actors of the Finnish building and real estate sector has developed national methods for environmental management of buildings and building products. These include

– the EKA method for the environmental assessment and environmental declarations of building products (Häkkinen et al. 2004)
– the environmental classification method for buildings PromisE (Table 2) (described in Huovila and Häkkinen 2005),
– the environmental assessment and life cycle cost assessment tool to support consideration of life cycle aspects in building design (BECOST 2005)
– building performance requirement management tool, EcoProP, to support requirement setting (EcoProP 2006)

Table 2. Categories and weight values (in %) of environmental indicators in the Finnish PromisE tool.

	Weighted value of the indicator		
	Office buildings	***Residential buildings***	***Retail buildings***
HEALTH OF USERS	**25**	**25**	**20**
Management of indoor climate	35	40	40
Setting of requirements and level of requirements	35	35	30
Quality of design	25	30	35
Quality of supervision and documentation	20	20	15
Quality of facility management contract	20	15	20
Indoor air quality	30	30	30
Volume of air ventilation	40	25	20
Purity of incoming air	30	30	25
Surface materials emissions	30	45	55
Management of moist damages	30	30	30
Quality of building-physical design	40	30	25
Quality of moist control on site	45	55	65
Quality of building maintenance manual	15	15	10
Illumination	5	0	0
Intensity and uniformity	55	0	0
Prevention of reflections and glare	45	0	0
CONSUMPTION OF NATURAL RESOURCES	**30**	**30**	**35**
Energy consumption	45	40	45
Setting of requirements for energy consumption	15	15	15
Heat consumption	25	40	25
Use of real estate electricity	35	20	35
Energy consumption management	15	15	15
Quality of approval inspection	10	10	10
Water consumption	5	10	5
Quality of water distribution system	100	40	100
Water consumption monitoring facilities	0	60	0
Land use	10	10	10
Utilization of existing built environment	55	55	55

	Weighted value of the indicator		
	Office buildings	***Residential buildings***	***Retail buildings***
Utilization of existing networks	45	45	45
Materials consumption	20	20	20
Total use of raw materials (excluding by-products)	70	55	70
Recycling rate of building materials	30	20	30
Savings in space areas with help of common spaces	0	25	0
Service life	20	20	20
Design service life	20	25	20
Level of carefulness and detail of service life design	30	50	30
Level of adaptability	50	25	50
ENVIRONMENTAL LOADINGS	**35**	**35**	**35**
Emissions into air	50	50	45
Environmental impact of building products	25	25	25
Environmental impact from energy use	75	75	75
Wastes	20	20	20
Quality of waste management of building	50	50	50
Quality of waste management on building site	50	50	50
Sewage	0	5	0
Utilization of rain water	0	100	0
Bio-diversity	10	10	10
Soil sealing	30	30	30
Removal of soil materials on site	30	30	30
Value of building lot with regard to nature protection	30	30	30
Appearance of rare species on site	10	10	10
Environmental loadings from traffic	20	15	25
Level of public transportation services	50	45	60
Vicinity of pedestrian and bicycle routes	35	25	30
Level of other services needed by users	15	30	10
ENVIRONMENTAL RISKS	**10**	**10**	**10**
Environmental risks of building site	35	35	35
Level of purity of building site	100	100	100
Environmental risks of building	65	65	65
Building materials' risks	40	40	25
Risks of refrigerants	0	0	25
Level of environmental risk management on building site	30	30	25
Level of health risk management on building site	30	30	25

EKA is a Finnish national, voluntary method for environmental assessment of building products. VTT formulated the method on the request by The Confederation of Finnish Construction Industries RT. The method describes the principles that should be followed in the environmental assessment of building products and introduces the format of environmental declarations. The procedure for environmental assessment and declaration of building products includes the following issues:

- principles for data collection and data handling;
- generic environmental profiles for energy and transportation;
- the declaration format;
- procedure of environmental assessment; auditing, approval and publication of declarations

– principles that one should follow when using the environmental profiles of building products within building design and environmental assessment of buildings.

Corresponding national methods and tools have been developed in a number of countries as presented for example in the Sustainable Building Conference in Tokyo (see Cole et al. 2005). The connective features include the life-cycle approach and making use of sustainability indicators for the classification of buildings.

Usability and Restrictions of LC guides

Open building manufacturing needs life cycle guides and sustainable construction methods for

– requirement setting;
– design for required performance and life-cycle;
– declaration of life-cycle quality of final products.

An important challenge is that these methods should be able to assess different kinds of systems with help of generally accepted indicators without favouring any specific solutions. In addition, those should be able to support the consideration of user needs and user requirements in building processes.

As stated by Shelbourn et al. (2006) one of the key issues in making construction projects more sustainable is overcoming the obstacles of capturing and managing the knowledge needed by project teams to affect such change. Although indicators, checklists and assessment tools for sustainability in construction are available, there is still a need for a structured approach for the implementation of sustainability practices and methods within construction projects.

Requirement Setting

With regard to building process, the life cycle methodologies support rather assessment ex post facto than advance evaluation. LCA based assessment can only be performed after specifying the solutions. After identifying the products and systems, the product specific life cycle assessment data can be collected and combined as building specific results. Of course this might be done in before hand for specified alternative solutions though the procedure would be toilsome.

To be able to consider life cycle aspects in the stage of requirement setting, classification systems like the before mentioned PromisE system for new buildings can be made use of. These systems classify building process, building location and building performance related issues from the view point of sustainability and life cycle advantages. As far as the indicators are not based on technical solutions, this approach is highly useful from the point of view of open building manufacturing.

Design for Required Performance

From the viewpoint of the usability of LC guides and tools, the most problematic field seem to be the building design phase. Classification systems of sustainable buildings may support designers to consider life cycle aspects. Energy efficiency and life cycle assessment tools support designers to compare alternative solutions. Energy consumption estimation methods and service life prediction methods support designers to identify and consider parameters and aspects that affect energy efficiency and service life of design options. However, the classification methods only support designers with help of basic guidelines and the assessment methods bring much extra work for the design process. Design for sustainable buildings needs integrated methods which should provide the process with

- easy-to-use and comprehensive product information
- integrated calculation and simulation facilities that enable the comparison of design options and the effect of changes automatically or with reasonable extra work.

Product model based building will probably solve these problems as illustrated for example in Häkkinen (2006) from the view point of product information and in Lam et al. (2004) from the view point of simulation. Product information should be able to be integrated with building information models (BIMs) and design software as illustrated in Figures 2 and 3.

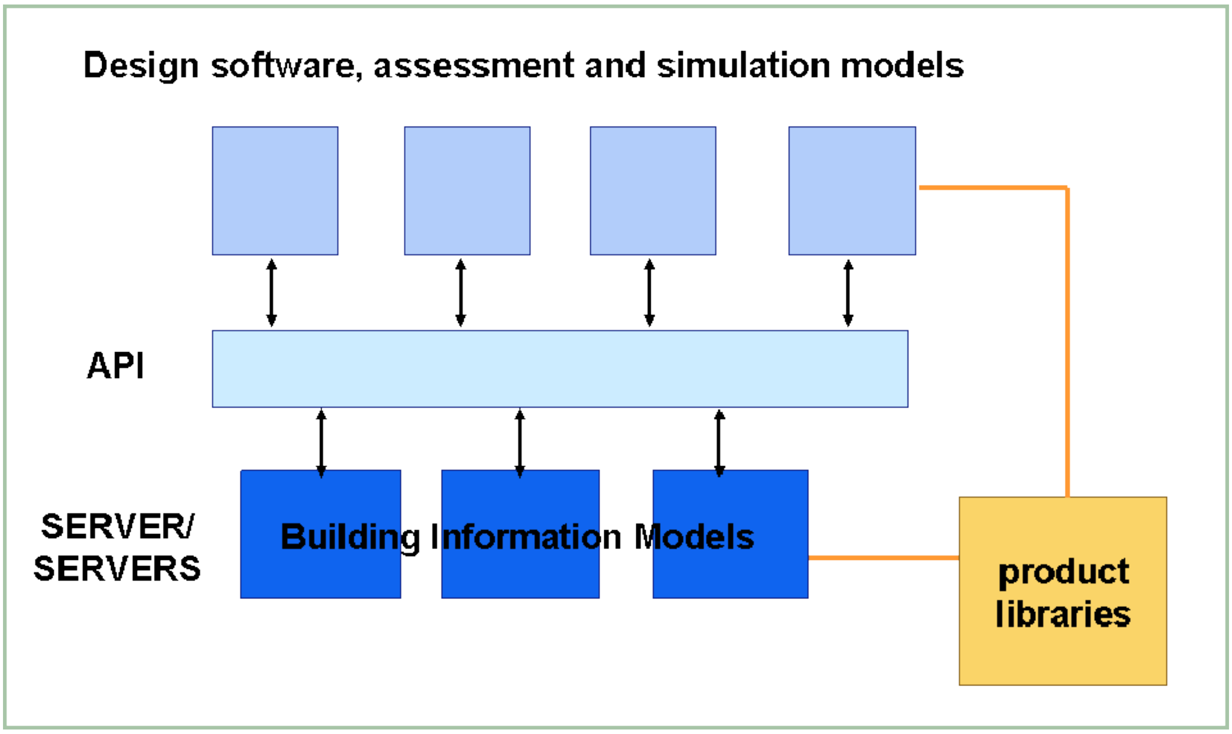

Figure 2. Illustration of the integration of product information with design software and building information models.

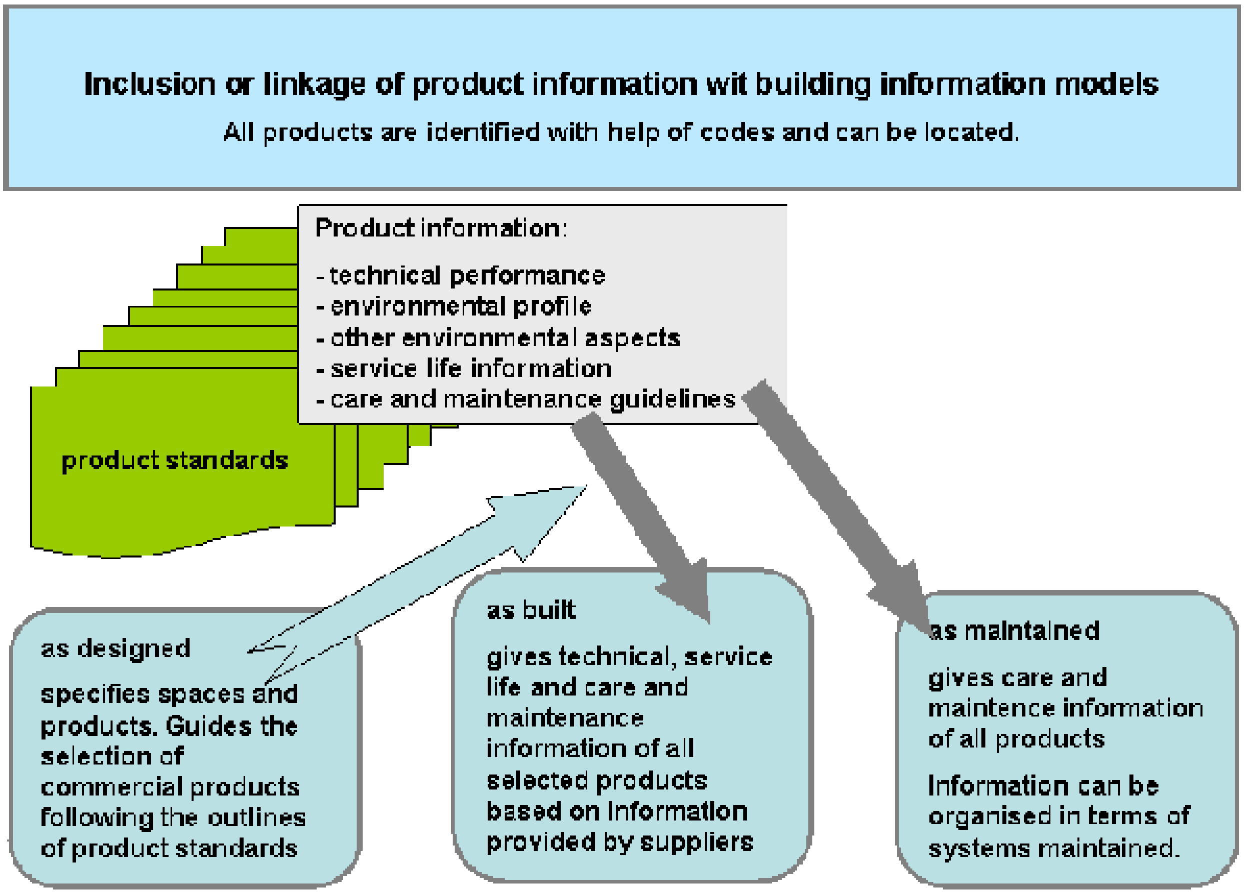

Figure 3. Illustration of the linkage of product information with BIMs in different stages of building process.

Declaration

The existing LC methods well support the formulation of life cycle based declarations for final products. These declarations can be used in from-business-to-business processes, which is the purpose of environmental building product declarations dealt with in ISO (2006b). However, declarations can also be worked out for buildings either based on life cycle assessment or with help of indicators. The latter is supported by the existing sustainable building classifications methods such as for example the before mentioned PromisE system for new and existing buildings.

At present, the existing methods can be used in national level. The completion of the European and the international standards and methods will in future enable the LC information of buildings and building products valid internationally and/or in Europe.

Usability of LCC methods

Life cycle costing calculations can also be made use of in early stages of building design if there is information available on estimated energy efficiency and reference data on building related life cycle costs. Figure 4 outlines the possibilities to utilise life-cycle costing by different kinds of organisations in building and facility trades within life-cycle based decision making for example when comparing alternative technical solutions or when analysing cost-effectiveness, profit and cash flows.

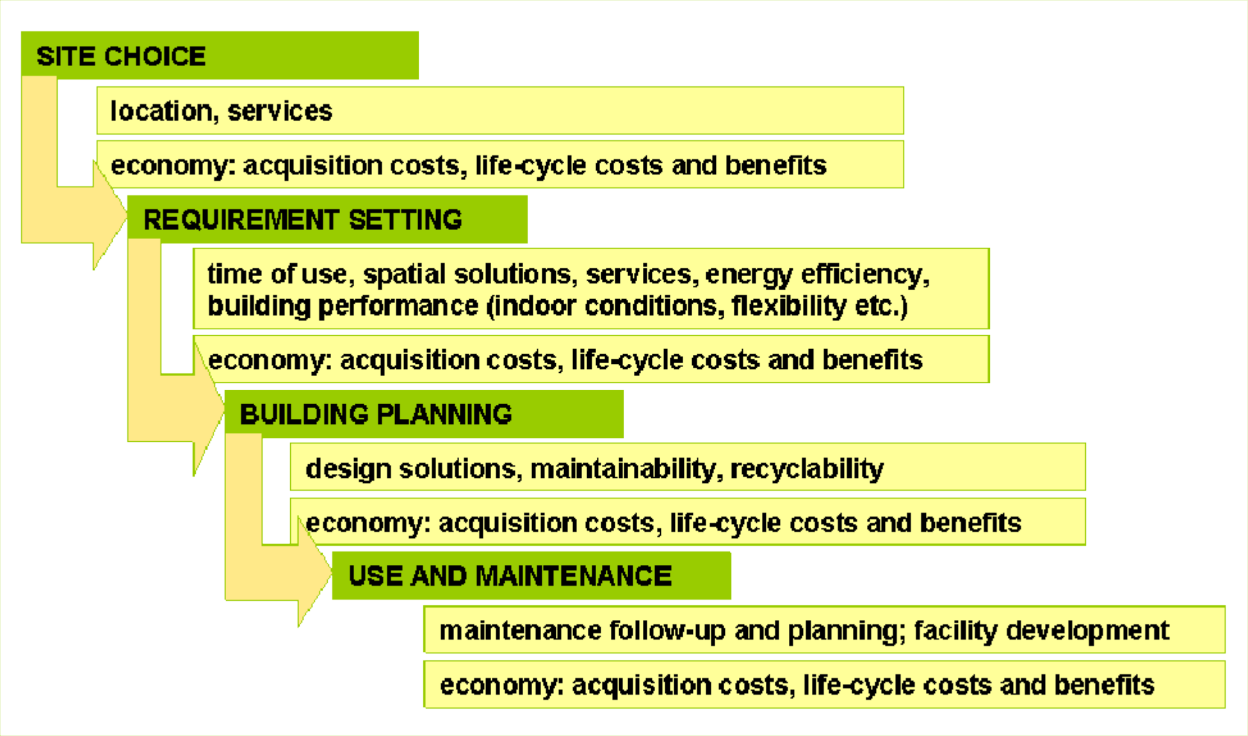

Figure 4. Life-cycle based decision making.

In facility investment and space acquisition the main interest is concentrated on location, use of spaces, time of use, energy economy and adaptability. LCC calculations can also be utilised in comparing life-cycle tenders. Based on the experiences of a big Finnish facility owner, Senate Properties, it is important in life-cycle based decision making to be able to direct the focus in each stage of the process. During the building process the LCC-based product selection should focus on facades and windows, base floors and roofs, separation walls, coatings, furniture, HVAC and electrical systems and routings as well as information systems. During the period of use and maintenance the important life-cycle areas are planning, use directions of ventilation and information technology and efficient maintenance methods. Facility development should be based on the following:

- Determination of the building condition
- Defining the suitable construction practises
- Definition of the wanted performance
- Definition of the eligibility with user's processes

The solutions are mainly based on the original state of the building: appearance, spaces, level of energy consumption, rate of flexibility and technical systems. The life-cycle advantageousness should be compared with a corresponding new building.

We can define different periods of life cycle: Functional life-cycle may be very short (1…3 years), economical life cycle being based on rent or funding time is longer (10…30 years), technical life-cycle is a period between construction and disposal (for example 50 - 100 years). The choice of life-cycle period looked at should be based on real needs of decision making; it has a remarkable influence on cost distribution. Classification of Life Cycle costs is very alike in different standards and solutions (Table 2), the important matters are that those cover all costs within the chosen period, those are estimated in a realistic way and the time correction has been made right.

Basic principles of life cycle costing are developed and widely agreed upon. However, the extensive practical use of life cycle costing methodologies has not realised. The models should be directed and customised for different types of use considering the different user needs and expected benefits. To promote life-cycle based decision making, the calculation models should be specified focusing on the most essential life-cycle characteristics on different levels of facility business. Adoption of life-cycle contracts should happen at the same time both in producing companies and client organisations.

The public sector has a central role in promoting life cycle advantageous solutions through its own production and its role in giving directions. When private sector applies these directions, it may seek for new areas of business through innovation processes. This would finally mean growing international value networking.

Conclusions

The implementation of the principles of sustainable development is a fundamental goal of EU policies. The adoption of life cycle approach as a basic principle for sustainable building methodologies is consistent with the EU policies on sustainable development; the emphasis on life cycle approach issues from the principles of sustainable development.

Life cycle assessment methods and sustainability indicators should be able to support open building manufacturing in requirement setting, design for required performance and life cycle, and in decision making. The methods should be able to support the consideration of user needs and those should be able to assess systems with help of generally accepted indicators without favouring any specific solutions.

There is a clear need for common development and harmonisation of LC methods. However, although Europe is a community, it is not a homogeneous but differences in cultural aspects, building types, climate conditions etc. exist. For this reason the development of common methodologies will require the definition of a common frameworks rather than detailed methods and tools.

The general principles on life cycle assessment of products and services have been agreed upon and made public with help of ISO standardisation. In addition to general methodologies, applied methods for building products have been standardised by ISO. There is also a European process going on, which aims at the development of harmonised life-cycle standards for buildings and building products.

The life cycle approach can also be distinguished in the two essential directives, which direct the building product and energy regulations of building, namely CPD and EPD; both of these emphasise the importance of use phase of buildings.

National sustainable building methods and tools have been developed in a number of countries. The connective features include the life-cycle approach and making use of sustainability indicators for the classification of buildings.

With regard to building process, life cycle methodologies support rather subsequent assessment than advance evaluation, because LCA based assessment requires knowledge on specified solutions. Evidently, LCAs might be done for specified alternative solutions though the procedure is toilsome.

Environmental classification systems support the consideration of life cycle aspects in requirement setting. Environmental classification systems classify building process, building location and building performance related issues from the view point of sustainability and life cycle advantages. As far as the indicators are not based on technical solutions, this approach is highly useful from the point of view of open building manufacturing.

Building design phase still lacks efficient LC guides and tools. Sustainable building classification systems certainly support designers to consider life cycle aspects; life cycle assessment tools may help designers to compare alternative solutions; energy assessment and service life prediction methods support designers to identify parameters that affect energy efficiency and service life of the design option. However, design for sustainable buildings needs integrated methods which should provide the process with easy use and comprehensive product information and integrated calculation facilities that enable the comparison of design options and the effect of changes automatically or with reasonable extra work. Product model based building will probably bring useful solutions for these problems.

Life cycle costing calculations can be made use of in early stages of building design if there are reference data available on energy consumptions and building structures related costs which can be used of in advance assessment of the new building.

The existing LC methods well support the formulation of life cycle based declarations for final products. These declarations can be used in processes from-business-to-business. That is the purpose of environmental building product declarations. Information that is needed in marketing and decision making can also be worked out for buildings either based on life cycle assessment or with help of indicators and sustainable building classification methods.

Key Lessons Learned:

- life cycle approach is a basic and overarching principle of sustainable building methodologies; life cycle approach issues from the principles of sustainable development;
- LC methods should be able to support open building manufacturing in requirement setting and considering user needs, in design for required performance and life cycle, and in making selections and decisions.
- LC methods support the assessment of building systems with help of generally accepted indicators without favouring any specific solutions.
- The general and building related general principles of LC methods have been agreed upon and made public with help standardisation. However, easy-use and integrated tools are needed for building processes.
- LC assessment methods support rather subsequent assessment than advance evaluation. Environmental classification systems support the consideration of LC aspects in early stages of building process.
- Building design phase still lacks efficient LC tools. There is a need for integrated methods that provide the process with easy use and comprehensive product information and calculation facilities that enable the comparison and simulation of design options. Product model based building will probably bring useful solutions.

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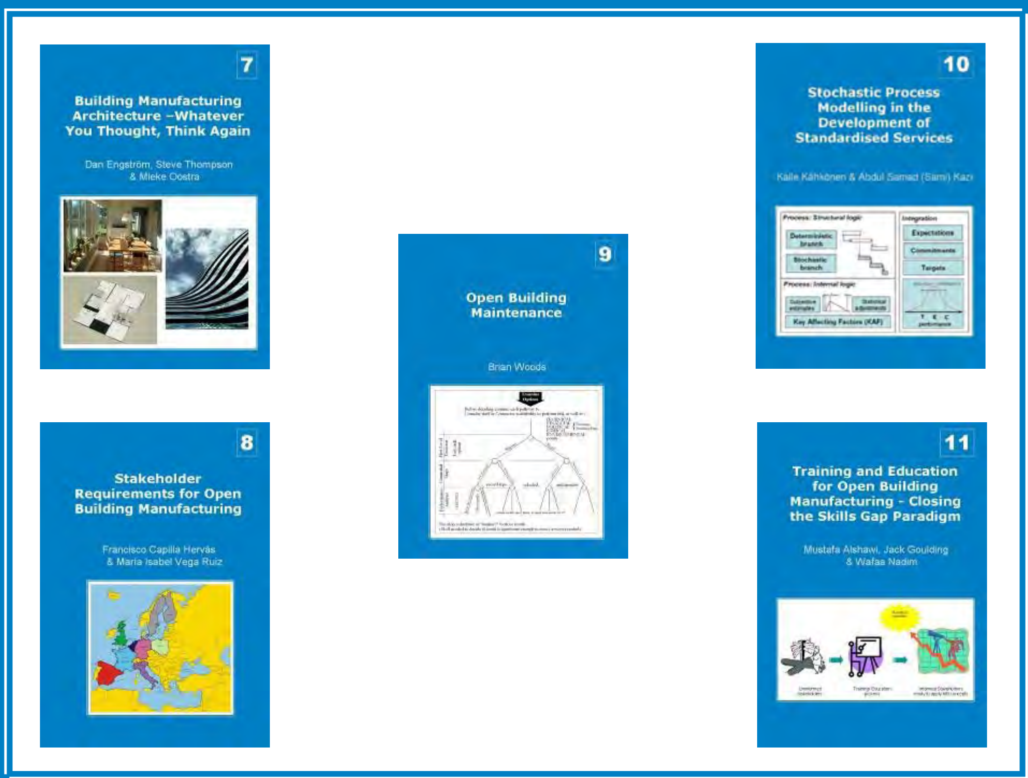
Mr **Sakari Pulakka**, M Sc, Special Research Scientist at VTT Materials and Building. His key expertise includes life cycle costing methodologies, sustainable building methods and life-cycle based co-operation procedures with facility owners.

Industrial Requirements



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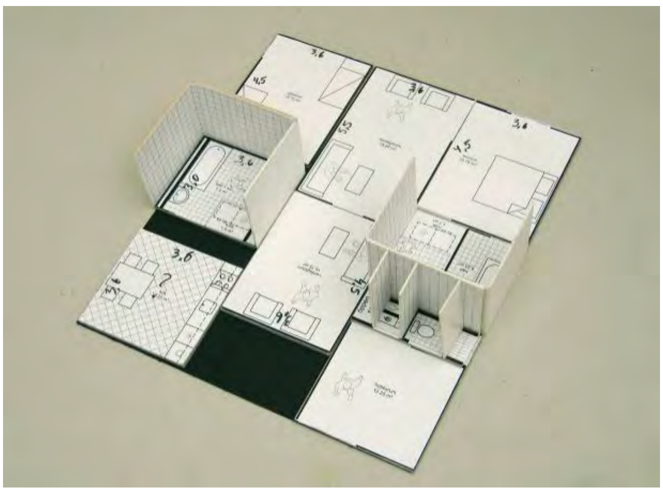
Building Manufacturing Architecture – Whatever You Thought, Think Again

Dan Engström, Steve Thompson
& Mieke Oostra



Building Manufacturing Architecture – Whatever You Thought, Think Again

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Abstract

In the eyes of the public, industrialisation as a concept brings with it images of the 1960s and the 70s, when we let construction methods and the disintegrating modern movement rule supreme the development of architectural expression. There is the definite risk that the current fast-paced development towards building manufacturing systems becomes highly product-orientated at the expense of the sustainability of the buildings.

Whatever you thought, think again. The overall aim of ManuBuild is to facilitate the industrial creation of contemporary state-of-the-art architecture. This chapter summarises the work done in ManuBuild on architectural quality and gives the principles and some examples of the brief for ManuBuild architecture.

The aim of this work is not to define manufacturing architecture but to help pinpoint qualities that it needs to exhibit. Without restricting users of the brief to a certain architectural style or language, the brief is written in the form of (1) a description of the key elements of the good home, (2) an analysis of the threats and opportunities of building manufacturing when it comes to architectural quality and finally (3) architectural checklists and performance criteria.

Having access to a detailed brief in a format useful for evaluation of design suggestions, it is possible for building owners and architects to work on the design of industrially produced buildings with confidence that important issues are not overlooked. The brief is open for anyone to use their own judgement and set their own standards for each project or system.

Before we get to the evaluation however, the principles given here for evaluation of architecture needs to be developed to suit architectural design, a task which needs to include the principles for the platforms used. This work remains to be done in ManuBuild in the months ahead.

Keywords: Architecture, Quality, Principles, Performance, Value-bearers

Background

Industrial Context

In the 60s and the 70s, we let construction methods and the disintegrating modern movement rule supreme the development of architectural expression. It is logical that in the eyes of the public, industrialisation as a concept brings with it images of this period in time. *Knowledge platforms* are becoming increasingly important, being sets of given technical solutions connected to purchasing and production methods, and the continuous monitoring and improvement of solutions and processes together with suppliers. There is the definite risk that this current fast-paced development is highly product-orientated at the expense of the sustainability of the buildings, both functionally, technically and aesthetically.

Whatever you thought, think again. The goals for the ManuBuild building manufacturing are set at achieving – and developing – contemporary state-of-the-art architecture. The line of reasoning is this. Today, we have the tools (ICT, CAD-CAM and flexible production techniques) to industrialise and yet create diversity. Through so-called *mass customization*, using platform thinking and modularisation, we can increase quality and rationalise dramatically – and still let classic architectural values in residential housing meet individual client requests. Knowledge platforms allow us to offer freedom of choice to the client, while we limit the number of components we use to create it. A choice of platform thinking and/or modularisation allows us to focus on design instead of starting each project with choosing building technology and collaboration forms. It thus makes it possible to end up in new and challenging places in the sphere of possible solutions. Arguably, building manufacturing can become an important tool for progressive architects who are seeking to develop contemporary architecture.

Learning Objectives:

The reader of this chapter can expect to learn:

- The main principles of the ManuBuild architectural brief
- Some key architectural value-bearers and criteria for providing them

Glimpses from Architectural History

Since the notion of architecture has changed its meaning during time, a short recap of history is in order.

In the Beaux Arts tradition buildings were composed in order to achieve harmonious proportions that integrated form, function and construction (or in Vitruvius' terms: venustas, utilitas and firmitas). Architecture was regarded to be of a higher standard than things created by engineers. It was art, and only used for certain kinds of buildings, namely the formal and representative ones (for example banks, schools, courts of justice, palaces etc.). The vernacular was not part of this, so ordinary homes were not regarded as architectural achievements.

This changed radically in the early 20th century. Established in 1907, the radical group *Deutsche Werkbund* (see Schwarz 1996) were pivotal in the interaction and overlap of economy (mass production) and art in buildings and everyday products. Pivotal was also the emerging *Neue Bauen* or New Architecture that had the ambition to change society. In order to achieve this goal, the discrepancy had to disappear between real Architecture with a capital A and construction of ordinary, day-to-day buildings. People like Ernst May (1926), Mart Stam (1929) and Hannes Meyer (1928) focussed on the issue of housing. On the second CIAM conference in 1929 in Frankfurt the issues concerning the homes of people on the *Existenzminimum*, the standard home for the not so well-to-do, were central. Architects in this movement adopted the engineer paradigm. The typical statement from Hannes Meyer: "building is not an aesthetic process" indicates this shift. Not by chance did the Dutch and the Germans call this movement *das Neue Bauen*. In the realm of *das Neue Bauen* the discrepancy between architecture and building did indeed disappear. Also in the Soviet Union Constructivists wanted to construct a new social state with a new technical architecture, and some banned the artist approach completely.

Fine examples of Das Neue Bauen. *Weissenhof, Stuttgart, 1927. Left: house 1-4, by Ludwig Mies van de Rohe. Right: detail from house 5-9, by Jacobus Johannes and Pieter Oud. Weissenhof is described in detail at www.weissenhof.de and www.weissenhof2002.de. Photos by Dan Engström.*

When Philip Johnson and Henry-Russell Hitchcock introduced modern architecture in America however, they deliberately neglected these arguments. They introduced it as a new style and differentiated in their discourse in different levels of aesthetic value within architecture. They thereby introduced again the distinction between building and architecture. They relied upon both the aesthetics and the technical efforts that were made to realize an architectural design.

After WWII it appeared as though the public for whom the housing efforts were made did not accept the products of *das Neue Bauen*. More and more they experienced the construction of these kinds of neighbourhoods as a patronizing act of municipalities and experts.

This criticism was a starting point for people like Turner (1968) to study how construction processes worked in the slums of Third World countries. According to Turner people there were much better off with their squatter elements, because they were in control over their own building process. These people could invest whenever their possibilities would allow them and they would get self-esteem and a feeling of accomplishment out of it. In addition, studies started of banal consumption architecture like the Las Vegas study of Venturi and Scott Brown (1968, 1971). It was also the start of experiments to include end-users in the design process of their homes and neighbourhoods. Johan Habraken (1969) stressed the importance of flexibility and looked for ways to combine structured urban development with substantial influence from the inhabitants on their surrounding. Others like Lucien Kroll involved end-users to participate in the design process.

Amos Rapoport (1969), a researcher of Rice University, pointed out a huge number of social-cultural influences that are easily forgotten by modern architects: religious influences, family & tribe connections, social structures, ways of making a living, and social relationships between individuals. He looked from an anthropological perspective on the architecture debate on living with attention to its cultural and symbolic aspects.

Kollhoff (1993) made a reference to the past and commented on modernism by claiming that there is a substantial difference between structure and finishings. The modernist would strive to show how the structure was made by the way finshings were applied. Kollhoff claims a real difference between structure and finishings and that finishings are meant to cover the structure and can tell their own story.

Nowadays different architectural styles can be (and indeed are) used for buildings, accompanied by different architectural theories. This means different styles can be used for a certain assignment, what could be seen as 'the end of great stories in architecture' in parallel with Lyotard's (1979) claims for philosophy. The era of the overall applicable truths seem to be over, at least for the time being. As a direct consequence, projects like ManuBuild that claim to be generic cannot prescribe an architectural style.

Architectural Quality

The ManuBuild Problem

With the possibilities of automation at hand today, we can produce more or less anything, even in construction. Many of these machined building parts will not be possible to separate from crafted items. For all practical purposes, the "Industry vs. Arts and Crafts" issue of applying true materials is a moot point, and instead the problem arises of industrially defining what a quality feature is – in order to be able to produce it instead of inferior products. The main problem in ManuBuild is that the project cannot prescribe a certain architectural style. Any principles that are given must be on a procedural or quality feature level, not on the level of design solutions. How does one facilitate quality architecture without defining it? How does one describe architectural standards without pointing to solutions or limiting the customer choice of quality level? The climate and the preferences in Scandinavia are also very different from the ones in Spain – regional preferences must be catered to. The suggested solution in ManuBuild is to provide description of key value-bearers for housing, but let the stakeholders in each project and/or system make their own priorities.

Construction must facilitate quality architecture without defining it. Left: one-off single family housing by Leonie Geisendorf (Strandvägen, Djursholm, Sweden, 1970, photo by Dan Engström). Right: contemporary multiple single-family housing development project (Uppsala, Sweden, photo by NCC).

A House or My Home?

In the information age, it is no longer the case that a dwelling's sole purpose is to provide shelter and a roof over one's head. With the increasing complexity of the world we live in and the technology available to us today, the appropriateness of where and how we live is much more complex, and draws on a number of other factors including social and physical context, the ability to facilitate our lives and activities, the flexibility to adapt and continue to do so over our lifecycle, and a wide range of other considerations.

To design, manufacture and construct a dwelling to meet the needs of occupants and communities, for today and for the future, requires a step-change in approach. A truly sustainable solution will not be achieved by continuing to push standardised house designs and layouts based on what was considered acceptable in the past, or aimed at what the housing industry envisages are ‘average’ or ‘typical’ households and dictate the way people live their lives through the constraints of the houses they live in. Nor can we design and construct houses in isolation, without regard for the wider context. There is a need to engage with the occupants, and increase the understanding of what they want, need and aspire to both at a household and community level.

The two main areas to consider therefore are: -

- Understanding the occupant requirements (both present and future), and
- Understanding the wider social and physical context, how these affect the design and success of a home and its components, and vice-versa. (For reasons of article length, this part is only briefly touched upon in this chapter.)

In understanding what is valuable to the end users and why, given the choice, they prefer one house to another, we can begin to explore the design of dwellings for these occupants to live in, and with, over their lifecycle. Designing homes and not houses; homes that adapt, grow and contract along with the household. This is a step-change in approach, from the common understanding that a building is static and complete when handed over to the client, to the notion that a building has a life to live, and is not complete until it is finally dismantled.

Fifteen years from now, what will our children ask from their homes? (Frösunda, Solna, NCC 2003)

We are not looking at designing building components in isolation; we first need to consider what they need to do, how they need to perform and how they can be adapted in order to meet the needs of the occupant. In the design of a successful, quality dwelling a range of factors need to be considered simultaneously. The design of an individual component affects the ability for other elements and the development as a whole to meet its goals. Taking a holistic approach allows the quality and integrity of a dwelling to be displayed through each component, and the significance of each component to be clearly understood. In considering the wider issues, greater flexibility is achieved which improves the ability for customisation, improving the suitability of a design to an increased range of situations.

The starting point for any successful project is development of the brief, and defining what the main objectives are: who is the project for? Who are the end client and end user? Is the client the end user? The main focus of this work is to appreciate value to the end user or occupant. In order to assess this value, we first need to have a good understanding of whom the occupant is, how they live and what they aspire to. This understanding needs to consider best practice, design principles and factors instead of concentrating on architectural style or taste, which is a more individual concern.

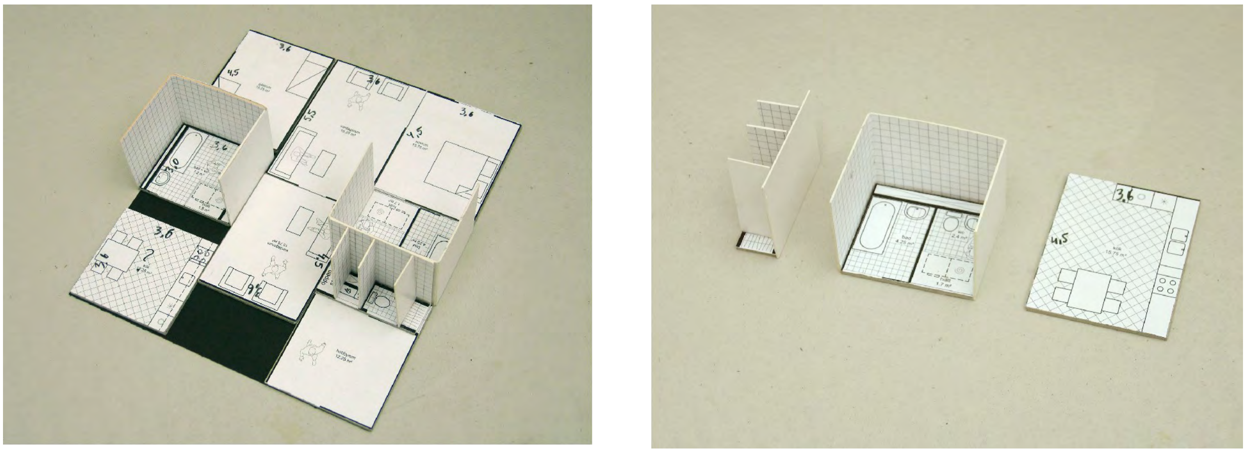
The Parker Morris Approach

In 1961 in the UK a seminal report was produced entitled 'Homes For Today And Tomorrow', otherwise known as the Parker Morris report (Anon 1961). This changed the approach to housing design in the UK, to:

> '*Evaluate the social and economic trends which are reshaping our lives; and to formulate recommendations, which while ensuring sound and well-designed homes, will encourage among architects and all concerned a creative response to the requirements of our age'* – *From 'Homes For Today And Tomorrow' (Anon. 1961)*

Prior to this report, housing standards and designs generally had focused on designing rooms for specific uses, with specific dimensional requirements. This approach can be constraining, and assumes to some extent that the house will always be used in a certain manner. Not only does it begin to dictate how people live, but also it wastes space. Excess space is often included in corners of oversized rooms. The approach taken by Parker Morris was to define space by the activities that were likely to be undertaken.

Over many parts of Europe, Modernism is the main influence of housing. This is characterized by its emphasis on function and its attempts to provide for specific needs – rooms are designed for specific uses, activities are separated from each other. The International Style (one of the versions of *das Neue Bauen*) is one of its main themes, where flat roofs, smooth façades and cubic shapes are predominant. The home is seen as a machine for living in, where the two main functions are the rest and hygiene of the worker and his family. ManuBuild architecture must necessarily meet many of the precedents set by Modernism: daylight, open spaces, well-planned functionality and quality equipment. However, there also needs to be other qualities in the home, since the information age requires more from the home than the industrial age did. A quality trait that Modernism underestimated (ignored) is the connection between the house and the surrounding environment. In general, one of the traits of ManuBuild architecture (in line with the Parker Morris report) is the design of the home as a 'creative response to the requirements of our age'. For example, housing now needs to cater in a sustainable way for telecommuting and varying family constellations. Housing needs to be prepared for changes over time. One of the practical upshots of this is that rooms should be designed and organised for adaptability and general use. For example, a dining room should easily be possible to use as a home office or bedroom when the occupants' needs change. This is a step-change from the modernist principles of functional separation.



We have a puzzle to lie: Developing quality contemporary apartment layouts with general functionality and flexibility, providing quality experience of home and a sense of context. The same apartment must also be designed for manufacture, assembly and future changes. (Working study-samples by Marie-Louise Greger, Chalmers University of Technology, Department of Architecture, 2006.)

Taking an activity-based approach – understanding in detail how activities are undertaken, and how these relate to other tasks, and when tasks are likely to be undertaken in isolation or in groups, allows us to develop spaces and inter-relations in a more sensitive way, more in-tune with the needs of the occupant. The focus is not purely on space sizes either, it includes a greater understanding of the qualitative requirements and comfort aspired to for different tasks. Parker Morris didn't focus on specific room size requirements. Instead he recommended areas for the dwelling as a whole, relating to the typology and number of occupants. Considering effective useable space in this way, instead of defined room sizes, allows far greater freedom, flexibility and less wastage. This activity-based approach is not used to create space standards for specific activities, but to highlight factors that need to be considered when designing a dwelling – an important task for ManuBuild.

The inter-relation of activities and spaces are key, and unfortunately often overlooked. The Parker Morris approach here was to demonstrate how people in different households (e.g. young family with children, elderly couple) were likely to interact with each other, and with the home, throughout the day. This simple tool and diagrams were used not to demonstrate how every such family lived, but to offer a basic understanding of how some activities are done in isolation, some are group activities, and some activities are undertaken simultaneously whereas some follow on from each other. It was not the results that were being emphasised, but the approach and need to consider these interactions.

Once we have gained an understanding of the needs and activities of a household, and the flexibility and multi-function that this brings, we need to consider household development and relocation over time. What affect does the growth and contraction of a household have on the suitability of the dwelling? How do we ensure the flexibility is available to adapt to support these changes, and changes to a new household? Again, Parker Morris used a simple demonstration tool to illustrate the development of families of different types over their lifecycle, and where there were likely to be the greatest number of occupants, where tasks were likely to be group or individual, etc.

Combining this timeline approach with the activity approach allows us to consider the level of flexibility that is aspired to in the dwellings that we design, manufacture and assemble. The multi-function of space that is needed and the flexibility in component and connection design.

Architectural Quality Check-lists

The essence of architecture is difficult to communicate, especially since it means different things to different people. For example, we often disagree with our spouses over which house we should buy, had we the opportunity to buy one. The *quantitative* architectural requirements are typically addressed in regulations and standards. Your national codes very likely give strong indications on sizes of a kitchen. It is equally likely that the code of another country gives different indications. However, we do have traits in common. Most people are a little below two metres tall, need to eat every day and sleep at night, and want to feel welcome and at home where we live. Consequently, it is possible to generically discuss architectural *qualities*. In order to set standards for ManuBuild architecture it is interesting to try to describe these qualities in a way that can be used to evaluate the architectural quality of buildings.

It is well known that quality architecture requires a holistic design approach. In architectural *design*, the methodology is very often that an inception form is made, considering a limited number of performance criteria. The form is tested against the remaining criteria, refined and tested again. In this chapter, the parts of the brief given are written mainly for the *analysis* of architecture, in the form of bullet-points and short summaries. Having access to a detailed brief in this format would make it possible for building owners and architects to work on the design of industrially produced buildings with confidence that important issues (for example threats or opportunities) are not overlooked. Below are given three types of tools for analyses: short and descriptive check-list, and performance criteria.

The need for a holistic approach: playing does not involve analyses of the place where you play. (NCC)

Straight to the Overall Point

A check-list is a crude but useful tool for testing design suggestions, and one which gives indications of whether a residential house or a housing development can be said to exhibit architectural quality. There are several lists available, each with its own merits, for example in *Building for Life – Delivering great places to live* (Anon 2005) and *Urban Design Compendium* (Anon 2000). Below can be found a short example which is to the point in general terms. It can be found in *Better Places To Live By Design - A Companion Guide To PPG3* (Anon 2001). Since it is very short, it would require extensive knowledge on the part of the reader to interpret the criteria. However, the point is easily argued that the shorter the criteria, the easier it is for a non-architect user or client to use them. Each of the points are covered in more detail in the main document, and aimed at the designer and client (governmental agency for example) alike. This list focuses on the building in its context and touches only briefly on the functionality of the building's interior.

- Character – A place with its own identity
- Continuity and enclosure – A place where public and private spaces are clearly distinguished
- Quality of the public realm – A place with attractive and successful outdoor areas

- Ease of movement – A place that is easy to get to and move through
- Legibility – A place that has a clear image and is easy to understand
- Adaptability – A place that can change easily
- Diversity – A place with variety and choice
- Layout: Urban structure – the framework of routes and spaces that connect locally and more widely, and the way developments, routes and open spaces relate to one another.
- Layout: Urban grain – the pattern of the arrangement of street blocks, plots and their buildings in a settlement
- Landscape – the character and appearance of land, including its shape, form, ecology, natural features, colours and elements, and the way these components combine
- Density and mix – the amount of development on a given piece of land and the range of uses. Density influences the intensity of development, and in combination with the mix of uses, can affect a place's vitality and viability
- Scale: Height – scale is the size of a building in relation to its surroundings, or the size of parts of a building or its details, particularly in relation to the size of a person. Height determines the impact of development of views, vistas and skylines.
- Scale: Massing – the combined effect of the arrangement, volume and shape of a building or groups of buildings in relation to other buildings and spaces
- Appearance: Details – the craftsmanship, building techniques, decoration, styles and lighting of a building or structure
- Appearance: Materials – the texture, colour, pattern and durability of materials, and how they are used.

Descriptive

The list below of key architectural value-bearers is based on the architectural evaluation method for housing, developed by Ola Nylander (Nylander 1999, 2002). This is more descriptive in character and thus more informative. Not even a long list, however comprehensive, can supplant the professional knowledge and skills on the part of the architect, but a more descriptive list can be useful as the foundation for discussions between user/client and architect, and as a backdrop for the interested user/client. This specific list focuses on the building as such and has only a single general bullet-point on the context.

The all-important window (photo by Ola Nylander).

- Materials and details are emotionally and physically close to the inhabitants and are very important as signs of authenticity and care in production. Their function is to help the inhabitants identify themselves through the territory they create in their home. The experience of care in production, well-made materials and details can raise the self-esteem of the inhabitants. This is especially true if care has been taken where eyes look and hands touch: window sills and sashes, door handles, mouldings, skirting-boards, doorsteps and so on.
- The experience of enclosed and open spaces is very important for the architecture of the home. Being able to feel both the safety of the nook and the freedom of the open and the light is an asset to the home. The balanced play between them gives rich experiences. We are fascinated by the enclosed character of the home, as made explicit by the proverb "My home is my castle". Window bars (transoms and mullions) in a brick wall gives a sense of safety in relation to the open spaces outside. We are also enthusiastic about openness in a home. It opens up views and connections between rooms and increases daylight. Just like the warmth inside a house is underpinned by the cold of the winter outside, the experience of a home is deepened by juxtaposition of open and enclosed spaces.
- Daylight is of fundamental importance for a rich experience of a room. It highlights and strengthens the different characters in different parts of the home. Plenty of light strengthens the public character of a sitting room, while soft, condensed light underpins the intimate and private character of the bedroom. Daylight is important also for the experience of the axiality, movement and openness of a home. The key to good light is careful design of the windows.
- Axiality (usually referred to in urban planning) in the home describes a line which connects two interesting points. An axis involves two or more rooms and can also create possibilities for sightlines, which increases the possibilities to read the home. There might be several axes in parallel or at angles from each other, sometimes there is a main axis, sometimes the axes are equally important. Factors important for the axial expression are: the length of the axis, the number of rooms involved, similarities, symmetries and repetitions in the rooms involved and the origins and the end of the axis.
- The proportions and size of spaces are important for their availability and usefulness. The general space (as opposed to the space dedicated to a specific purpose) is versatile and accommodates several different uses and furnishings. It is important to note that the generally useful room is a different species of room than the functionally specified room of the International Style which has been very influential over the years. The generally useful room would typically be slightly larger than the regular bedroom but smaller than the regular sitting room. In such a room, there is a long-term usefulness (e.g. for varying family sizes) which includes different needs and functions.
- Multiple movement choices, movement, rhythm and openings are prerequisites for experiencing architecture as a whole. Only by moving through a building can one bring one's intellectual assessment and bodily experiences into a synthesis. Movement acts together with other features of the home, and is important for the experience of for example axiality. Movement creates a sense of large volume and spatiality even in homes of limited sizes. It also makes it possible to experience the rooms both as singular units and as interacting units that create a whole. Rooms with many openings are useful tools for the generality of a home.
- The design of the interaction – the transitional rooms – between the home and the outer environment is an important part of living in a home. Through openness and light, the balcony, loggia and so on can transmit contact between outside and inside. Moving from outer to inner rooms with tapering degree of openness means that the inhabitants gradually can make themselves at home. One can also decide how far into one's private space to invite guests. Making ourselves comfortable in a spot and shaping our territory shapes our identity. The possibility to overlook one's territory, clear distinctions between what's private and what's public, and human scale are cornerstones to the comfortable home. In addition,

preserved historical imprints and patterns make it possible to make oneself at home in a new or remodelled block.

Window design giving quality daylight in a well designed transitional room – somewhere in between inside and outside (photo by Ola Nylander).

- The building and the urban space are always connected. The experience of the urban space follows the architectural principles of the experience of a room. The key is to use the individual houses as tools to create an attractive whole. The houses, together with other structures, create urban spaces of different character and meaning. The important features of an urban space are its size, proportions, their connections with each other, shapes, axialities, movements, contexts and demarcations – and the interaction of all these features. Like rooms in a house or apartment, urban spaces can be open and enclosed. In enclosed urban plans (as often in the classic town planning), the spaces are experienced as having been cut out of a homogenous mass of buildings. Open plans (as often used in the modernist town planning) make buildings stand out as artefacts (i.e. created by humans) in an otherwise empty area. In order to maintain population density and because of real estate prices, buildings in open plans close to major city centres need to be higher than in enclosed areas. The height of the buildings in contrast to the openness around them make these buildings stand out even more, which makes the scale used vital for the experience of the open urban space.

Performance Criteria for Beauty

General

To turn something useful, practical, functional into something beautiful, that is architecture's duty. – Karl Friedrich Schinkel
There are as many styles of beauty as there are visions of happiness. – Stendhal
Analogising architecture with ethics helps us to discern that there is unlikely ever to be a single source of beauty in a building, just as no one quality can ever underpin excellence in a person. – Alain de Botton

When working on a system or a specific building, check-lists are not sufficient – more specific criteria are needed. If check-lists are taken further in detail and focus, they may be formulated in the form of architectural performance criteria. They will inherently be extensive if they are to be useful and still cover all aspects of the building. Consequently, such criteria must be structured according to some principles. In ManuBuild, the principle is that design values that have bearing on the user/client should be used. Vitruvius stated three well-known such values: Beauty, Function and Durability. Below can be found the ManuBuild suggestion for architectural performance criteria for the first (and most elusive) of the Vitruvian architectural virtues in buildings – *Beauty*.

Beauty is not easy to grasp. It is a combination of qualities that delight the senses and the mind. It is strongly related to the question; what is architecture? Even thought the two are often mistaken for one another, architecture is not synonymous with beauty. Architects will not pose the question whether or not a building is beautiful, since this is a subjective question. But it is possible to hold a discourse professionally on the question: is it architecture? Criteria to assess this matter are not only limited to the building itself, but are also related to its environment. Therefore two scales will be taken into consideration while regarding beauty: the environment and the building.

Very nice. But is it beautiful? You tell me. Islands Brygge, Havnestad, Denmark (NCC).

In addition, decisions on beauty are made on different levels. The (environmental) context with its multiple actors will influence the outcome of the decision-making process, while choice is offered to customers. These decisions are made on different levels (city structure, tissue, support, house allocation, and infill) with different actors/parties (for example, customers, architects, builders, financers, municipalities, manufacturers, suppliers and distributors) on different times (during phase of design, the actual building and maintenance) about different elements (support system, envelope/roof/façade/shell systems, service systems, infill). A basic assumption for ManuBuild is to distinguish two separate levels in the decision-making regarding this design value on beauty; a high level where *professionals* determine the overall structure and the game rules, and the personal level where *end-users* decided what it is they like on the infill level of their home (Habraken 1961).

The Environment

Professional level

- Character of a place, regional identity
- A place with a clear image and easy to understand
- Variety for visual stimulation, for example a mix of dwelling types and functions
- Clearly distinguished public and private spaces
- Variation between open and enclosed areas
- Urban grain, or the patterns in a settlement: active frontage and animating the edge, block size, plot size, building width, block types and dwelling block layouts, building depth, designing for corners and mixed use of buildings
- Scale, the size of a building in relation to its surroundings and people.
- Massing – the combined effect of the arrangement, volume and shape of a building or group of buildings in relation to other buildings and spaces

- Materials and detailing used in the urban space – the texture, colour, pattern and durability of materials.
- The presence of green in the environment
- The integration of features of landscape in the building / area
- The character and appearance of landscape, including its shape, form, ecology, natural features, colours and elements, and the way these components combine and are integrated with the buildings in the area
- A place with attractive outdoor areas
- A place that is easy to get to and move through
- A place in which it is easy to orientate yourself and find your way around
- The framework of routes and spaces that connect locally and beyond, and the way developments, routes and open spaces relate to one another
- Adaptability
- Choice to facilitate different forms of use
- Participation of people living in the neighbourhood

End-user level

- Choice of location

The Building

Professional level

- A clear concept
- A clear style
- A clear identity
- Good proportions with well chosen order and dimensions
- Clever use of typology
- Spatial quality – an interesting layout of space organized in such a manner that it allows for best possible arrangements of furniture and equipment in relation to windows, circulation space, stairs, fixed elements etc
- A logical construction
- Materials & detailing - the texture, colour, pattern and durability of materials. Visible building material age with grace including the relation to the building concept.
- Relation with the location
- Relation with the social and cultural context
- Participation of the end-user
- Flexibility
- Variation - Differentiation of the shell and spaces, linear deviations, 2D/3D plasticity
- High performance, value for money
- Clever use of orientation & natural light
- Enjoyable place to live, that provides a feeling of:
    - home, with a personal connection
    - rest or liveliness according to my expectation as user
    - safety
    - comfort
    - beauty
    - control on the amount of interaction with the surroundings
    - space
    - quality
    - contentment with the way activities of its users are accommodated and facilitated

End-user level

- Extensive customer choice (amount of space, roof, façade, service systems, lay-out, infill, finishings)

SWOT- Analysis

Overall description

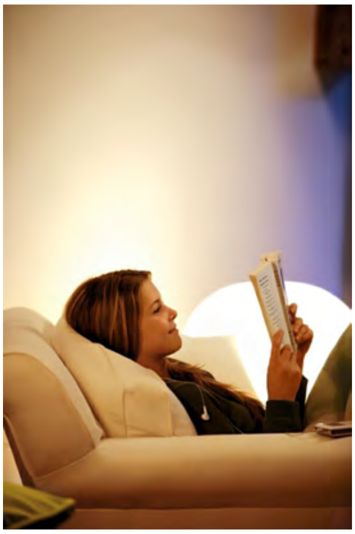
With the use of building manufacturing, will we likely be able to reach the standards we discussed above for architectural quality? Arguably, platform thinking, with carefully prepared component types and processes, will allow us to increase quality and rationalise dramatically and still let classic architectural values in residential housing meet individual client requests. However, there is a potential conflict in the explicit limitation of number of the components and configurations available. There are also inherent differences in designing variants of a product for a specific user (mass customization) than designing from a blank page for the "typical" user. As an approach to this type of problem, it is interesting to analyse the main *Strengths*, *Weaknesses*, *Opportunities* and *Threats* associated with building manufacturing for architecture, in terms of architectural quality, the work of the architect and what the architects and the new process can offer the client and user.

Client / User

Strengths

- The building as a whole will have industrial and predictable quality. One of the main drivers for the construction sector to turn to building manufacturing is the ability it offers of handing over building with zero defects. Arguably, the higher the percentage of offsite manufacture and assembly the more likely it is to achieve zero defects. Installers will be competent and trained. Unlike traditional construction, industrial processes do not have a stage, late in the process, where resources are used to fix mistakes that were produced earlier in the process. The aim is to make it right the first time. If something goes wrong, the process stops until it is fixed and the mistake is traced back to the source where it is then eliminated. This creates a platform for continuing improvements and prevents mistakes from being repeated.

- Real choice for clients will become available since consequence of their choices can be made explicit. Client involvement will increase, with well-designed interfaces between the client/user, the process and the product. Drag-and-drop design which visualises let's say an apartment will include performance predictions, costs estimates and consequences for future maintenance. The client/user can then interact with the platform behind the system and design an apartment that is to their own unique requirements without causing costly problems in the manufacturing, assembly and maintenance.



My home, my book, my choice (photo by NCC).

- The process will be transparent, quick and predictable. The process will be standardised – different products will be built but in the same way over and over. Manufacturing will take place in a factory environment and both transport and assembly on site will very likely take place under cover. This will make it possible for the contractor to open the process up for inspection by the client. It will also make it easy for contractors to reliably predict costs, schedules and levels of quality. In the more advanced systems, costs and schedules will likely be available simultaneously with the drag-and-drop design. And above all, compared to traditional construction, the process will be significantly quicker for the client from design to receiving the finished building with cost and performance certainty.

Weaknesses

- There is a negative overall image of industrial construction, inherited from the industrialisation of the 1960s and 70s. Because the current development also is known by the umbrella title *industrialization*, it is probably easy to mistake the current efforts to standardize *processes* for the earlier standardization of *products*. Then, the modernist effort to create a universally applicable architectural language coincided with a major lack of housing and a need to radically cut costs and time in order to quickly produce the housing so desperately requested. The most conspicuous results were major urban green-field areas of repetitive housing. Having forgotten the appalling conditions people in urban housing used to live under, we now see the quality of the apartments of 1960-75 being out-shadowed by the houses being completely out of human scale. Housing produced by the 21st century industrialization is a completely different matter. Processes are made for mass customization, i.e. using the same process, platform, modules and/or detailing principles to produce products uniquely adapted to client requests. Brown-fields are substituted for green-fields. The universally applicable aesthetics is not longer something that is sought after. But the image of universally applicable large-scale aesthetics might make it difficult for clients and their architects to approach the new industrialisation in an unbiased way. We must earn their trust.
- There are very limited possibilities for change after the starting-order has been given for different parts of the building. Unlike traditional construction, in industrial thinking all decisions are taken before production starts. Production, logistics and assembly are then planned in detail before they are executed. Visualization tools will help, but the clients will need to be sure of their decisions. Exception might be minor choices, like some car manufacturers offer the possibility to change the colour of the car you ordered until production week so-and-so (see below: Key decision milestones, under Opportunities).

At the end of the day, part of building manufacturing boils down to making hard choices before production starts of where bolts go.

Opportunities

- Key decision milestones for different activities or elements make it possible to establish a decision timetable to plan to. A building's shell can be in the process of detailed design and even manufacture whilst choice of internal finish or colour and fitted furniture may not be decided until later. This will give the clients more time to consider their choices. This may be even more important to them than quality architecture and interiors. That includes the development of some clever solutions in order to provide end-users with a decision timetable that is logical to them. Take for example the place of electrical sockets. This is now usually a decision that has to be taken very early in the process, before the production of the structure. For end-users is almost impossible to decide on the place of the sockets before they've made a decision on room sizes and their lay-outs.

- Life cycle-costs (LCC). The predictability of the process will make it possible to include the building performance, life-cycle costs, threats and opportunities, including environmental concerns. It will likely be easy to find out whether the house will need a heating system at all. It will be easy to find a combination of heating and ventilation system, window areas and insulation thickness which is economically optimised for economy during any given time-frame.
- Since the products used in the processes will be known beforehand, it will be easy for the client to get certificates, for example to make sure that no unwanted chemicals are used. Promotion of ethical aspects is facilitated.
- Thanks to the improved reliability of the built quality, contractors might use increased responsibility for the product as a business driver and give longer guarantees or use it as a means to build long term relationships with their clients and as a way to generate extra business.
- Possibilities to offer kitchen design, bathroom design, overall interior design and garden design, maintenance and other services (for example energy supply, window cleaning, adjustments to the house etc)
- Opportunity to offer clients the possibility to experience (parts) of the new home by 3D models, Virtual Reality, model houses or partial mock-ups.
- It will start to pay off to invest in:
  - Structural research on how houses can be made more practical in use or more practical to maintain or easier to adjust to future changes.
  - Feedback from all parties (including end-users) involved in build projects.

Threats

- It might be difficult to articulate early in the process what one's needs and requirements are. Until one sees the result, it is not easy to know what one is looking for or don't want. If the interactive design and visualisation tools are inadequate, the building or apartment that clients order might not be exactly what they actually wanted. This risk can be reduced by creating systems and products that are interchangeable, and by designing a building for life, not just as a one-off construction for one point in time. In addition, mock-ups, showrooms and model houses can help.
- Processes that do not have the ability to catch generic requirements. If the processes are inadequately designed, form will follow function and the metaphysical features of the home (a sense of safety, of homeliness and so on) might be overlooked. A related risk is that vaguely articulated requests are not included in the brief or design because there was no way to include the ambiguous "maybe" in the polarity of "yes" and "no". Consultation with architects or ManuBuild will help this.
- Too much effort is put in customer choices that are short-lived or not relevant to the client groups targeted.

Architecture and the Work of the Architect

Strengths

- There will be great possibilities for variations without high costs. There will be technology and economy platforms, where the tools and limits are given, and where new technologies and new materials can prove they have impact. If there is a new technology that is considered useful, it will not be used in only one project, the aim will be to use it in every project. Robots or manufacture benefit from repetition in terms of optimisation, time taken to adjust or reconfigure. But compared to manual production, a robot does not require additional resources for making a hundred different products compared to making a hundred identical products – it's only manual production that benefits greatly from repetition.
- The contact with the other players in the process will be significantly improved. Industrial processes are a team sport. Consequently, there will be good feedback from production and a working-climate positive for collaboration. *Design For Manufacture and Assembly* (designing things to fit the client's needs while still easy to cost-asses, make and put together) will be a pivotal feature of construction. It needs the input both from clients, architects, engineers and production which brings the players together.
- The possibilities will be good to have issues of quality, choices of materials and so on under control. Having all decisions taken before production starts requires a process where design gets sufficient resources and where changes after design do not take place. Architects will no longer have to consider the effects of materials or products being switched to "equal" alternatives. This will lead to performance certainty and comfort.

Weaknesses

- There is a lack of knowledge of design based on modular or platform thinking. It is clear that this type of design work will be different from the traditional work. Industrial thinking builds on that different projects have a certain number of features in common, whilst traditional architecture builds on the notion that each project needs to be designed in relation to the unique site (which often means a unique set of solutions). In the one type of thinking, a base of building blocks is configured to suit the features valid for this particular project. In the other, the design starts with a blank sheet of paper. In practice, there is always the balance between reuse of old knowledge and development of new knowledge. Less skilled architects would handle this balance poorly so that the results from platform thinking are poor designs.
- There are limits as to what the systems are able to economically offer. Industrialization builds on repetition, mainly in the processes but also in part in the products. Many systems will be able to meet the requirements for a very diverse range of buildings. But at the end of the day, modularization and building systems will be designed to cater for the most frequent needs and requirements. If there are requirements that the system was not specifically designed to meet, costs will increase.
- Processes will vary significantly using different approaches to construction (e.g. volumetric, panel, etc), using different percentages of offsite manufacture and assembly. Architectural firms often have a strategy for their work, either implicit or explicit. Some of theses typical strategies fit well with modular or platform thinking, some less so. There is the risk that the wrong design approach is adopted for the wrong system and thus reduces the effectiveness of manufacturing construction. This might also lead to the exclusion of some of the more artistically creative architectural firms from this type of construction.

- There is confusion in the professional role as architects. The issue is still very much open what the architects want when it comes to building manufacturing, which is a development being driven by the contractors. The lack of involvement of architects is obvious, both in the development of the systems and in the debate over industrialization.

Opportunities

- The role of the architect will likely become stronger with better control and more tools at hand (for example product models in 3D) to meet unique client requests with new designs which have suitable architectural qualities and meet the performance criteria aimed for in the project. Only the architect is able to create meaning and coherence in the plethora of possibilities that are open thanks to the tools of industrial processes. Only the architect is able to visualise to the clients/users the building or apartments that they have asked for.
- Modular and platform thinking will likely be a positive driver and challenge for progressive architects and for the development of contemporary architecture. Ever since the days of Viollet-le-Duc, architects have looked for a suitable expression of contemporary society and of the tools at hand. For almost a hundred years, architects (often inspired by Le Corbusier) have designed houses to look like they were made with industrial processes. Now, finally, we have the technology that fits these aesthetics. It would be very surprising if this did not affect the expression of the buildings.

In which direction do you wish to go?

Your architecture is your own, not construction's.Vertigo, a replica by Charlotte Gyllenhammar of her art studio – only upside down, inside a hill.
(photo by Dan Engström).

- Marketing research will get the design away from the "average client" and will make the design assignment more complex. (See for example the work of Lucien Kroll).
- There will be a differentiation between system, module and project architects.
- Integration of legislative information into the software in terms of performance, e.g. national Building Regulations, the software could easily include carbon emissions assessment calculations etc.

Threats

- There might be lack of involvement from architects, which might lead to the danger that designs chosen / selected by the client will not consider all criteria and may result in poor quality architecture.
- There might be lack of agreement in the construction sector on the concept of quality. For example, apartment layouts and meetings of materials are often more important for the architect than they are for other players in construction. Will we agree on their importance?
- There might be lack of acceptance from the client or the architect. Again, this is due to the erroneous image of industrial construction being about standardized products. As discussed

in this article, there will be a very persuasive number of positive effects of industrialization, but the negative image from earlier industrialization efforts might be an obstacle to positive collaboration. Demonstration and marketing of the flexibility and the performance of these systems will ease this.

- There might be transport limitations that affect the possible apartment layout negatively. For volume element construction, this is a very valid concern. Understanding and use of options including telescopic or folding technologies reduce the risk of transport limitations.
- The demarcations between what is the decision of the client/user and of the architect might be unclear. Who gets to decide what, and how are architects to take responsibility for the end-result as a whole if only parts of it are under their control? The client and users are part of the team!
- Variation might be economically viable only in high-cost segments. This is due to the fact that both buyer and producer might consider cheaper housing "good enough" without the producer investing in the automation equipment and processes necessary for varied products. In single-family housing lower degrees of variation have proven to be one of the most efficient ways of making money. This can be remedied in ManuBuild by properly formulated performance criteria – performance standards that include spatial as well as elemental performance, and procedures that give the occupant ways to choose and discriminate one quality level from the other.

Key Lessons Learned:

- The principles for a ManuBuild definition of architectural quality features without limiting the reader to a style, regional preference or quality level.
- A summary of key value-bearers in the home.
- Complementing the holistic approach needed in architectural *design*, the Taylorist division of features should be useful for the *evaluation* of buildings.

ManuBuild's Way Forward

In architectural design an inception form is often made, considering a limited number of performance criteria. The form is tested against the remaining criteria, refined and tested again. The methodology developed here for *evaluation* of architectural quality should now be developed to be suitable input for such *design* of architecture. The tools for design are processes, platforms and modules, of which we know nothing. In addition, the problem remains of ManuBuild working with illustrated principles, not solutions as such. We work to *facilitate* quality architecture (and its industrial production), not to *define* it. One possible way forward is working with scenarios for the organisation of the spaces needed for different activities. *Activity spaces* can be used as illustration both of typologies from different parts of Europe, and for different household types. In providing input on activity spaces, we support the ManuBuild work on principles for building templates, connection standards, components, manufacturing, ICT support and so on to meet the requirements set on them by architecture. Besides the illustration of the principles, this is perhaps the most important task at hand for the ManuBuild groups working on architecture.

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Steve Thompson works as a senior architect for Corus. His background is from private practice, working on and leading residential, commercial, education and transport projects. He joined Corus in 2000 to work on rail and transport architecture, and has been involved in a number of high profile projects across the UK. As part of Corus, RED Architects were formed in 2002, and Steve diversified to work on residential, commercial, leisure and educational projects developing and using off-site construction systems.
In his current position, Steve strongly promotes best design practice across the construction industry, and advises on the effective use of steel in buildings.

Mieke Oostra works for TNO as a senior researcher on building process innovation and leads a team of researchers working in this area. She graduaded as an architect at Delft University of Technology. After her study she became a researcher on innovation processes in construction at the department of Building Technology from the same university from 1994 to 2001. In 2001 she obtained her PhD on the role of architects in product innovation. After that theory was brought into practice in a four year period at Slavenburg's Bouwbedrijven, a Dutch contractor. Here she was responsible for the implementation of innovations that proved to be relevant for both clients and the firm.

8

Stakeholder Requirements for Open Building Manufacturing

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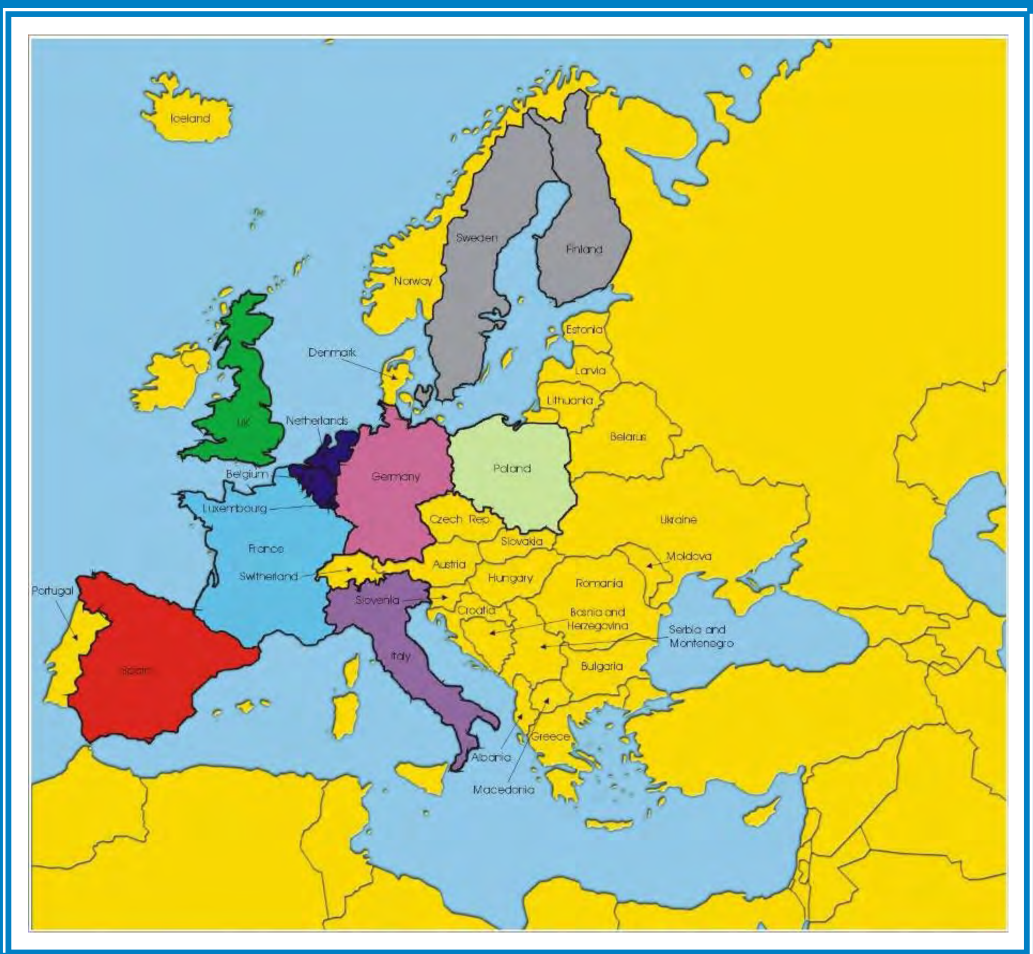

Stakeholder Requirements for Open Building Manufacturing

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Abstract

To assure the acceptance of Open Building Manufacturing in the construction sector, it is of vital importance to introduce the "voice of the stakeholder" into its development. This introduction is done through a development of the paradigm that takes the stakeholder requirements into account. This chapter deals with the gathering and analysing of the stakeholder requirements according to different geographical areas in Europe. It describes the methodology and documents that have been developed and presents the conclusions of the study undertaken.

The stakeholder requirements have been gathered via interviews that made use of an open questionnaire divided into 5 themes: General features of open building manufacturing, Specific questions about the concept of building and new technologies in information and communication, Specific questions for different stakeholder groups, General questions of the sector and Conclusions.

To assure that a balanced picture of the construction sector was obtained, a number of stakeholder profiles were defined and an estimation was made on the number of interviews to be done within every group and country.

The results of the 112 interviews that were done have be analysed and conclusions have been presented, signalling the main barriers and most efficient measures to success in the introduction of this new and revolutionary philosophy, as well as the main market requirements and trends. Finally a SWOT analysis for Open Building Manufacturing has been done.

Keywords: stakeholder, requirements, interview, geographical, area

Background

Industrial Context

The industrial goal to realise a radical breakthrough from the current 'craft and resource-based construction' to 'Open Building Manufacturing', combining ultra-efficient (ambient) manufacturing in factories and on sites with an open system for products and components offering diversity of supply in the market, is a new and revolutionary philosophy for the construction sector (ManuBuild Consortium, 2006).

Since the construction sector is known as a traditional sector that can be characterised as "reluctant" or even "resistant" to changes, it is of vital importance to take away as many of this reluctance and/or resistance as possible. One way to do so is through the development of a philosophy that meets the expectation of the sector. An important way to get to know and understand the expectation of the sector is to involve the stakeholders (architects, construction companies, developers, public administration, etc) from the beginning, gathering and analyzing their requirements according to different geographical areas in Europe (Sweden, UK, Germany, The Netherlands, Poland, Spain and Italy).

Once these requirements are known, they can be used as the starting point for the research and development activities that will lead to Open Building Manufacturing. During the course of these activities, their (intermediate) results will be critically checked against the requirements, to assure that the final results meet the requirements expressed at the beginning of the development.

Problem

The Open Building Manufacturing philosophy is new and revolutionary for the construction sector and has been set up by a relatively small group of stakeholders from the sector, which is convinced about the important advantages of the philosophy. However, the objective of the development of the philosophy is a shift of the whole sector from craft and resource-based construction to Open Building Manufacturing. There are however some important barriers for an industry-wide exploitation and take-up of the Open Building Manufacturing, which are partly related to the sector and partly more generic problems.

A first, sector specific, barrier is the fact that the construction sector is made up of a very diverse group of stakeholders, which can have very different objectives and requirements. A well known example is the one of architects and structural engineers / construction companies. The architect is often looking for a unique, nice looking building, while the engineer / constructor is looking for functionality, durability and constructability and would probably prefer to repeat as much as possible to improve efficiency.

Another barrier, that is as well sector specific, is the earlier mentioned traditional sector, which is "reluctant" or even "resistant" to changes. This is partly because of the attitude of those that form part of the sector, but also because of the strong regulation in the sector. Innovative ideas are often not accepted and if they are, regulation often offers no possibilities to include them in current construction.

The last important barrier we want to mention here is not sector specific. For the Open Building Manufacturing to be successful, it is necessary to be able to compete in a more and more globalised world. Although the construction sector still has strong national, regional or even local markets, more and more it has to compete on a global market (especially in the bigger projects) or at least to make use of materials and products that are offered on a global market. However for the Open Building Manufacturing to be successful, it has to be able to take into account local preferences, environmental conditions, building regulation, customs, etc.

Therefore, the following learning objectives were set for this case:

Learning Objectives:

- To define the requirements of the different actors of the construction sector regarding Open Building Manufacturing,
- To understand possible reluctances and resistances of the different actors of the construction sector regarding Open Building Manufacturing,
- To map geographical differences in the above mentioned subjects.

Approach

As a preparation for the interviews, that were done to define the stakeholder requirements, two main documents were developed;

- An initial template,
- An open questionnaire.

Further some additional documents have been developed:

- A stakeholder profile file with an estimation of interviews,
- A letter of introduction to the interviewee,
- A presentation of Open Building Manufacturing explaining the main concepts,
- A manual for the interviewer about hoe to develop the interview.

Initial Template

An initial template was prepared in order to gather information from key team members about the desired outcome from the stakeholders, the main questions they were interested in and the stakeholder profiles.

Open Questionnaire

An open questionnaire was prepared. The questionnaire was divided in six parts:

- Information about the person interviewed,
- General features of Open Building Manufacturing,
- Special questions about building concepts and new technologies in information and communication,
- Specific questions for different stakeholder groups,
- General questions about the construction sector,
- Conclusions.

Information about the Person Interviewed

The information about the person interviewed included name, position in the organisation, name of the organisation, city, country and date of the interview. Further the person interviewed was asked to describe shortly the organisation she/he works for and the role of the person within the organisation.

General Features of Open Building Manufacturing

The person interviewed received a short introduction into Open Building Manufacturing, including the concepts that form the basis of the philosophy. She/he was asked if this introduction and especially the concepts were clear and if modifications to the concept were necessary. After identifying the advantages and drawbacks of the concepts compared with the current construction system, the person was asked if her/his organisation is active in some of the concepts. Finally the readiness of the concepts to be used immediately and the readiness of society to accept the Open Building Manufacturing philosophy were asked.

Special Questions about Building Concepts and New Technologies in Information and Communication

To understand what stakeholders would like to see included in Open Building Manufacturing, they were asked to identify the essential parts of a building that should be included in the philosophy and to identify extras they would like to see included, but are not strictly necessary.

Since an information platform based on Information and Communication Technologies (ICT) will have an important place in the Open Building Manufacturing, stakeholders were asked what functionalities they would expect from this platform and what information from other actors in the supply chain they would require to improve their work. Further they were asked to identify the technological gaps in relation with the available software.

Specific Questions for Different Stakeholder Groups

Some stakeholder groups are of special interest for the development of Open Building Manufacturing. In the interviews people from the following groups were asked some additional questions that were specially developed for their group or various groups:

- Designers (architects),
- Public administration,
- Suppliers / manufacturers,
- Developers,
- Constructors,
- Users.

General Questions Regarding the Sector

To complete the state of the art study done before the start of the development of Open Building Manufacturing, the stakeholders were asked to answer various general questions regarding the construction sector. These questions were divided in the following parts:

- The sector,
- Current building trends,
- The market,
- Procurement process.

Conclusions

In the end of the interview the stakeholders to summarise their expectations, as well technical as economical, regarding Open Building Manufacturing.

Analysis

The analysis of the results of the interviews has been done by applying a qualitative methodology, thereby locating the main barriers and most efficient measures to success in the introduction of this new and revolutionary philosophy, as well as the main market requirements and trends, explaining the most urgent subjects to be dealt with, in the United Kingdom, Poland, Sweden, the Netherlands, Germany and Spain.

Approach to the Concepts of Open Building Manufacturing

Degree of Understanding

In general terms, the assessment of the presentation made to submit the main concepts of the philosophy is a positive one, in the sense of it being understood by nearly 100% of the representative profiles from different countries included in the study. In general terms the philosophy reaches a high level of understanding. However, in respect of conceptual specifications, different agents find it difficult to understand innovative proposals in the stages of the development of the philosophy where they are not active, requiring an explanation with a more accessible language, since there is a mixture of concepts that are not often easily understandable for some of the representative participants of the construction sector, with less technical profiles, in countries such as Spain and Poland.

Both in Sweden and in the Netherlands, some confusions are detected when embracing some concepts, introducing the difficulty at the time of differentiate between industrial and industrialised construction.

Therefore, the main problem of understanding is the non-existence of a clear definition, making that the meaning may vary from one person to another. This stresses a need for a clear definition of the concept and a categorization of levels of implementation and fulfilment of this definition.

Viability of Open Building Manufacturing

Very different opinions were expressed about the viability of Open Building Manufacturing, not only explained by the country of origin, but also by the accumulated experience, the level of automation, the use of new technologies and the participants' attitude. Greater experience in this field was found in countries such us Germany and Sweden.

Positive Positioning

Stakeholders of all countries agree to accept the guidelines of the philosophy, as the direction to be taken by the construction sector, with a good welcome of the concepts proposed within Open Building Manufacturing. There is an important percentage of interviewed persons who, in a greater or lesser extent, state they are perfectly ready to assume, accept and understand the introduction of innovations in this type of sector.

The planned development is understood as the sole possible way forward, starting from the base that everything that is not to drive towards the introduction of the philosophy would result in a serious error. Lots of interest, concerns and demands of innovation have been expressed by stakeholders from the participating countries.

Negative Positioning

However, some representatives of the sector coincide in rejecting the philosophy, ironically due to the ambitious nature of the same, creating, in certain cases, a sense of scepticism. Moreover, from the artistic point of view, it is feared that the constructive process loses all kind of differentiation, understanding the mass building process as an obvious insult or mistreatment to the architecture, apart from limiting their creativity and minimising the project flexibility.

In countries without too much experience in the field, certain reserve or doubt was found in regard to the cost and time saving in practice.

Main Advantages of Open Building Manufacturing

The quality guarantee offered by the new constructive process, that is called “zero-mistakes” in some countries such as Sweden, is seen as a main advantage of the philosophy. As a main profitable factor the possibility of receiving a better quality product is highlighted, since the control of the material handling, the manufacturing and assembly process (fewer errors) and the quality communication are better. These factors will lead directly to the advantage of cost reductions that together with time reductions will be one of the main advantages of the philosophy.

Another great advantage is the reduction in work accidents, that concern mainly to countries such as Spain.

Nearly 100% of the participants observe an increase in the quality of the final project, coming from a better planning. In this sense, Sweden provides the idea of understanding Open Building Manufacturing as a concept very close to the strategic partnering.

From the point of view of the insurance companies immediate advantages at the time of clearly delimiting the responsibilities in every stage of the constructive process are stressed, fundamental from the point of view of the architect and insurance companies.

Main Disadvantages of Open Building Manufacturing

Again, there is an agreement between the stakeholders of most of the countries, in the sense of considering this type of constructive system too rigid, and not as cheap as initially planned, apart from not guaranteeing the aesthetics demanded by the end user.

Main Problems Foreseen In Introducing Open Building Manufacturing

The main risk stakeholders see, is the lack of the power of impact of Open Building Manufacturing. The (European) construction sector is a very conservative one; therefore a radical change is seen as not possible. If the philosophy does not succeed in inspiring the people with the new ideas and concepts and in connecting scientific knowledge with practical know-how, Open Building Manufacturing is not expected to achieve improvements in the construction sector. The difficulty to realise the context of Open Building Manufacturing in a realistic way is pointed out, identifying the following barriers.

Socio-cultural Variables

Amongst stakeholders in countries such as Spain, the United Kingdom and Poland an important presence of the so called “brick culture” is found, which is strengthened because of cultural reasons, the maintenance of this traditional type of construction model or to avoid reminiscence from past (in Poland, Russian post-war building). The brick culture is being attributed to a conservative mind of an important sector of developers, constructors and designers in regard to introducing new materials. The conservative mind is a result of the lack of training of the end users when they have to demand something, as they are at a standstill in traditional constructive systems.

The profile of a new European climate has been signalised, characterised by requiring original and different products.

On the other hand, an important group of professionals linked to the construction industry obstruct in a certain way industrialisation of the sector, due to the lack of habit regarding requirements of the industrial technology, and due to the scarce culture in standardisation and coordination in the minimum levels for using industrialised elements.

Sometimes a problem of communication and marketing has been signalled, and even of good publicity, stressing the orientation towards the customer, as it is stated by various stakeholders from the Netherlands, the demands of users are very poorly taken into account. There is a mismatch between demand and supply.

Economic Variables

The scepticism related to obtaining competitive prices under this philosophy is based on negative experiences of the past, in one or another way, in all the participant countries, except for Sweden, where industrialised housing is a term often used.

Stakeholders question the search for cost-efficiency in the building process, since they signal that the real responsible for the current prices is unquestionable the land management (soil prices) carried out in Europe in a general way.

Occupational and Formative Variables

The lack of qualified labour in the Spanish construction sector is signalled as a serious problem, with a lack of access to experienced professionals guaranteeing the quality of the work. Said occupational gap has come together with an increase in the immigrant population in countries such as Spain, which has filled the gap between demand and offer of labour in the construction sector. Meanwhile, Swedish actors state the damage that can be produced in the professional pride in construction if we risk craft jobs, and stakeholders from the Netherlands report the rejection of the construction employees to work in factories.

Technical and Organisational Variables

The most important problem, signalled by the stakeholders, from which each and every one of the many problems rising in the execution of a work are derived, is the lack of mentally prepared professionals to design the idea from the origin, towards an industrialised building envisaging repetitive elements, assembly and tolerance, assuming the idea that the construction company will adapt the project to the industrialisation,.

Lack of communication, planning, organisation and foresight result in great informative gaps that cause the appearance of constant changes and modifications during the execution of the work.

ICT Variables

The lack of information flow and the bad quality of the information, result in the lack of control of the process in many stages of the building process.

In construction there is a great lack of management systems for cost control, using therefore absolutely primitive methods.

Legal Variables

The main barriers to a successfully introduction and development of Open Building Manufacturing opportunities are related with the existing structures and legal regulations in the construction sector as well as to the missing integration of national and international standardisation organisations. At the same time, e.g. Spanish stakeholders criticise the abundance of regulation.

Steps Proposed for the Successful Introduction of Open Building Manufacturing Paradigm

Socio-Cultural Steps

The most repeated term here by all stakeholders is the term of "Education". A large scale intervention is necessary to revolutionise the "mentality" of all the agents involved in the industry, that it is to say, to the whole European society.

A process of diffusion or dissemination is required with its corresponding investment when highlighting the "strengths" and "opportunities" of Open Building Manufacturing.

The new approach must include an increased customer-orientation and improved processes for integrating design, production, information and management, to be accomplished through change and innovation.

Focusing on the figure of the end user, it is fundamental to join strengths with the purpose of Educate towards a position of Understanding. Success will depend on the marketing policy applied, which must be directed to make relative the drawbacks of the new system, not to neglect them and to highlight the sales of this type of solutions continuously.

Approach to the customer

A clear focus on the customer is a necessity to ensure that the right products, with the right quality to the right cost, are produced for the end-customer. This approach means that thorough surveys and investigations must be done in order to catch the customers' needs and priorities.

It is common to use meetings with the end-users, but looking at the development of the residential buildings one can sometimes wonder to whom we have listened. Customers have often higher ambitions than they are willing to pay for and are thus not willing to pay to meet their requirements and demands. Since the customer himself/herself lacks the capability to define his/her requirements, consultants are given this job to translate the customer's wishes to written requirements.

Economic Steps

From the interviews, a general action plan with three suggested steps can be extracted, which could be summarised as follows:

Most stakeholders coincide in aiming the philosophy towards an initial balanced ratio within a reasonable economic frame. The economy where the sector is established in is a short-term one and is not really useful in the future. This project must be planned in long-term, with credible consequences, with great flexibility for different environments, by means of engineering consortium and construction companies.

Another way would be directed to sales within a high segment, searching the project prestige, planning an improvement in technology, construction, providing all kind of attributes, to avoid any negativity in the reception, dismissing, from this position, its location in a low segment, since all the future possibilities would be closed.

And finally, a project focused on a type of young housing is suggested, close to economic housing, enhancing the features of safety and peace, well working and structural simplicity. It would be a great opportunity for Open Building Manufacturing to create a new market: cheaper building products with a good price-quality relationship. To target e.g. the requirements of families, that could not afford a proprietary by conventional construction processes, by means of prefabrication and industrialised construction processes.

Occupational and Formative Steps

The fear of unemployment among the craftsmen is a risk that could have negative impact on the result. It is important that the skill of the craftsmen are incorporated into the process and used, not in the same manner as on-site today, but in a more intelligent, safe and worker-friendly way.

In countries having the "handicap" of qualified staff, it seems that this qualification is just guaranteed by means of the staff training on the part from the companies.

Systematic Performance Measuring and Re-use of Experiences

In order to get extensive information about the processes and the technical solutions, continuous measuring and follow-ups are needed, regarding as well soft as hard parameters. Experiences and measures are analyzed and the results are input to the development process and to coming developments. Staff from all participating organisations should be part of these activities since experiences from all parts of the processes are important and it is important that all participants feel responsible for improving.

The most important driving forces are the possibilities for mass production with sustained craft quality, the problem of engaging the commitment of the employees and the development of the end-product. The organisations will work with the possibilities inherent in the repetitive work (minimised waste, finding errors, traceability), of improving the image of the sector and in using the commitment of executives to support employees. It has been realised the importance of the customer as the focal point and the minimization of waste.

Technical and organisation steps

Stakeholders of all the countries observe a greater viability of the process through a gradual planning included in different stages. An organisation and a previous planning are required with a coordination of all the figures that take part in the project. All of them motivated by the demands generated by the new contemporary user, every day more engaged with the use of solutions within the sustainability frame and more demanding with the quality of the end product.

With respect to the architects' demands for the success of the project, the necessity to adapt the project to the product that offers the industry is stressed through a greater and better knowledge of the present supply of solutions, starting from the training of the new generations, stressing the fundamental role of the Universities.

If we summarise the needs required for the industrialised construction of a building, we can talk about the specific elaboration of a "Project of Industrialisation", understood as a guide of instructions so that any constructor can make the building.

The preparation of the "Project of Industrialisation" should be done in two stages:

1. Design of pieces,
2. The logistics of industrialisation.

The work protocol considers the preparation of the following documents as essential: The adaptation to the industrialised system.

1. Design of all the pieces,
2. Design of the casts,
3. Joints and constructive details,
4. Daily orders of manufacture,
5. Daily orders of transport,
6. Daily orders of assembly,

The Project of Industrialisation planned from these parameters will allow the following:

1. Execute the work without improvisation,
2. To execute the work with a daily programming,
3. To execute the work without skilled labour: The Project of Industrialisation is the "Book of instructions", so that the work can be executed with the usual labour of the country,
4. To optimise the execution of the work eliminating the unnecessary deliveries,
5. To strictly fulfil the construction regulation of any country,
6. Supply chain management integrated in the construction process.

ICT Steps

The industrialised process requires accurate and reliable information where the concept of dynamism predominates. Modern Information and Communication Technology (ICT) provide tools that effectively handle updates and changes of digital material and provide solutions for information exchange and data storage. An extensive use of modern ICT-tools supports the different processes by enabling more accurate documents and hence good conditions for an effective production where errors are discovered early and problems in the manufacturing and assembly phases are avoided.

Correct information at an early stage is always needed. One should always remember that information on a platform can never totally omit the need of physical meetings and communication.

Several interviewees asked for 3D-models that can be rotated and intelligent graphics, i.e. contains information on each of the parts included, already in the design stage as a working tool, linking design suggestions with the performance of the building – energy use, indoor climate, and so on.

For the creation of the **common portal opened to the user** in Open Building Manufacturing, the establishment of an external staff consortium is essential in order to find and introduce the required material.

Absolutely all of the stages comprising Open Building Manufacturing must be included in the ICT platform.

The importance of the use of a vocabulary differentiated for all and each one from the users' profiles is stood out as well as an easy way of access and the work at real time with almost immediate updates. Further the need for the active participation of the end users of the product is stressed.

The necessity to implant a model made to develop to the work management and the final economic management is suggested, in unique software that allows for countable management and a rigorous control of the work, sending the information in real time, which will allow making predictive cost controls.

The experience of the great companies, suppliers of this type of services, ensures the success of any development arose of R+D+I, within the construction sector, especially when the return of investments in the same year and reductions of 15% in the direct costs are guaranteed.

A greater effort in publicity is required, since at the present time there is not a determined action that covers this informative gap, in relation to the application of new technologies and advanced solutions in the construction world, with simple and clear parameters.

Legal steps; Policies and Performances

As it was previously stressed, an urgent revision of the existing structures and legal regulations in the construction sector is required, being important the integration of national and international standardisation organisations in the project. From an approach based on a strategic partnering, it is necessary to examine and rewrite the current purchasing laws.

Trends and Challenges in the European Market

Trends in the European Market

In the **United Kingdom** a sustainability agenda and a shortage in skilled labour in the traditional construction industry are important trends. Further, the Government is sensed as the main customer, encouraging the improvement in the industry. There is an increase in the use of ICT tools and a growth of offsite manufacturing.

On the other hand, in recent years in **Sweden** some concepts, arisen from the manufacturing industry, have successfully been adapted to the housing industry. The general opinion is that the housing sector is in need of change in numerous areas and industrialisation is mentioned as a step towards solutions to some of these problems, e.g. cost development, productivity and quality. The housing industry has responded to the criticism and at present there are many initiatives claiming that they are working with industrialised housing. Hence industrialised housing is a frequently used term in Swedish housing industry today.

In the meantime, in the **Netherlands**, the use of industrialised elements has been detected, but not integral as the industry seems not to be ready for it. When applied, it is on a small scale.

In addition, the trend of the constructors to improvise and the prefabrication that requires a precise way of work is not adapted to the existing inertia in the sector. Should this flair appeared in the **Spanish** market, this is getting more and more fitted to the new international outlook, having a clear tendency to an industrialised building. Every day it is better understood, because at the end, the results are more effective, efficient and more lasting. Empirically, it is shown that every time Spain is getting more industrialised. Moreover, the **Spanish** industry is contemplated from almost all the profiles as being capable enough to assume a trend of a higher demand without too many problems, on the part of the construction sector.

Trends in the **German** construction industry are very clear and comply with the customer requirements. The reason is simple and economic: the market is shrinking, and the companies want to realise sales. A company that neglects the customer requirements would disappear from the market.

Most of the systems are produced by one company, but there are also interfaces for example to concrete modules etc. of other suppliers. This is a challenge (to achieve the fit), but that’s also the chance to beat the market. To achieve this “fit”, handicraft processes in addition to the manufacturing processes are required. The constructions companies are not “just manufacturers”, but provide deepened know how and handicraft skills.

Nowadays in **Germany** the trend exists to build either in an already existing building environment (reconstruction, refurbishment, extension) or to build in a very individual, luxury manner. The population is decreasing in Europe and the trend goes to individualisation. These two phenomena do not harmonize with the Open Building Manufacturing objectives. The desire for a single house decreases; people prefer the refurbishment of a nice old villa or a stylish flat in the city. Thus, it is questionable, if the “critical mass” for Open Building Manufacturing will exist.

Challenges in the European Market

The main challenges within the construction sector are related with a clear evolution which drives us to a more industrialised sector, in search of the following clear purposes:

- Top quality.
- Reduction in prices.
- Re-education in terms.
- Reduction in occupational accidents.
- Revision in the contracting regulations, appreciating a general distrust towards the criteria and methodology applied when contracting public works.
- Land availability is one of the most important challenges.
- Control of subcontracting chains by the construction companies.
- Real time to study a project and well develop it.

Results and Business Impacts

Key Findings

The key findings of the analysis of stakeholder requirements regarding Open Building Manufacturing are related to the understanding of the philosophy, the advantages and drawback stakeholders see and proposals for improvements received from them.

Understanding of Open Building Manufacturing Philosophy

There is a high level of understanding of the Open Building Manufacturing philosophy although some conceptual specifications are difficult to understand and require an explanation with a more accessible language. On one side, there is an important percentage of interviewed people that is ready to assume, accept and understand the introduction of innovations in the construction sector. On the other, some representatives of the sector reject the philosophy due to the ambitious nature of the same, creating a sense of scepticism.

Advantages and Drawbacks

Main advantages considered with the implementation of the philosophy will be greater quality, real time control of the construction process, cost-efficiency, time-efficiency, safe and controlled structure manufacture, reduction of labour accidents, better planning and organization and the end users participation from the start.

One of the main problems confirmed is the conservative mind of an important sector of developers, constructors and designers to introduce new materials as they are at a standstill in traditional constructive systems. Also, this type of construction systems is too rigid and could not be as cheap as initially planned.

Regarding information and communication technologies (ICT), there is a great lack of management systems for cost control, using primitive methods. However, it is not considered as a problem of the lack of resources, it is sometimes about a passive interest.

Other barriers for the introduction and development of the philosophy are the existing structures and legal regulations in the construction sector as well as the missing integration of national and international standardisation organizations.

Proposals for Improvement

Finally, there are many steps proposed for the success of the introduction of the philosophy. Focusing on the figure of the end-user is fundamental to join strengths with the purpose of education towards a position of understanding. It will depend on the marketing policy applied, which must be directed to make relative drawbacks of the new system, not to neglect them and to highlight the sales of this type of solutions continuously.

Regarding the occupational and formative step, it is important a qualified work force and it is guaranteed by means of the staff training on the part from the companies. Another proposal is about the organization required by this project and a previous planning with a coordination of all the figures that take part. Also, it is stressed the necessity to adapt the project to the product that offers the industry through a better knowledge of the present supply of solutions. The industrialised process requires accurate and reliable information; modern ICT provide tools that handle updates and change of digital material and provide solutions for information exchange and data storage.

Business Impacts

Main key points were obtained from the analysis done by each partner in their countries and from the global analysis. The next key points will be included in the development of the whole philosophy and verified its fulfilment:

- *Flexibility for the end user:* thanks to the diversity of the offer elements and components the end user will be able to select the best options to fulfil their particular needs and make changes after the initial construction of the building. Quality of life of final users will enhance as a consequence of more control, possibilities and internal comfort.
- *Logistics*: manufactures and sites will adopt just in time techniques, optimization of handling devices and tools and automation methods on side achieving costs reductions that are one of the most important issues to be considered.
- *ICT Tools:* development of software tools in order to help the final user for the selection of the adequate options, for instance, a dynamic catalogue. In addition, the use of ICT Tools will facilitate the interrelations between the different stakeholders contributing to the privacy and data protection.
- *Standards, regulations and rules:* industrialization according to EUROCODES in order to assure the reliability of the elements, components, and modules manufactured.

The construction sector will be more competitive thanks to the innovations of the Open Building Manufacturing concept. Major expected advantages are reduction of global costs, increase of quality, time-efficiency and the participation of the end user from the beginning of the project.

Conclusions

Intrinsic Variables to Open Building Manufacturing

The strengths and weaknesses regarding the internal scope of the present philosophy can be summed up as follows:

Strengths

- Greater quality or Quality guarantee.
- Real time control of the construction process.
- Potential cost reduction or cost-efficiency.
- Reduction in terms and time-efficiency.
- Safe and controlled structure manufacture.
- Less labour accidents.
- European prestige.
- The strong consideration of organisational concepts (team building, team management and communication within a building team).It combines the requirements of different stakeholder groups, as the requirements of the investors and the requirements of the users.
- End users will welcome lower cost and higher quality products at lower prices.

Weaknesses

- The theoretical approach and the practical introduction of Open Building Manufacturing to the European market.
- It seems that the prefabrication degree envisaged in Open Building Manufacturing is very difficult to use, nearly unrealisable due to the non-existence of a complete current compatibility of constructive systems.
- Limited access of certain profiles of companies with real capacity to cover the project.
- Difficulty to coordinate all the participant agents in the building process, without a deviation in targets resulting in a harmful monopoly.
- It seems to be a utopia, that there exists a (virtual) stock of single elements, that all fit together and the architect could develop out of them a nice, suitable dwelling.
- The Open Building Manufacturing approach focuses too strongly on technical features and economic issues. The building of an own house/dwelling is something which deals very strongly with emotions and individual requirements. Often the customer does not provide the capability to define his/her requirements exactly and he/she changes his/her needs during the construction processes.

External Variables to Open Building Manufacturing

Opportunities

- The economic prosperity that is being lived in the construction sector in countries such as Spain facilitates an investment outlook.
- The topic of industrialised construction has a long building history in Germany. Open Building Manufacturing can found its research activities on these experiences and knowledge.
- The appearance of a new contemporary user more and more prepared to understand new constructive systems guaranteeing a reduction of prices and an increase of quality.

- The technological revolution characteristic of the XXIst century, with a supply of products is characterized, until the moment, unthinkable or inaccessible.
- In Europe a lot of manufacturers of prefabricated modules exist, with very good products on a high quality level. They provide a specific degree of flexibility in their systems.
- The degree of automation is high, but there is also a part of handicraft.
- Concerning the different type of dwellings, in the sector of single-family houses there exists already a noticeable proportion of prefabricated houses in the member countries, they work already with several concepts of the Open Building Manufacturing approach highly successful.
- Open Building Manufacturing sets the customer in the centre of all construction processes.
- The adaptation of the Open Building Manufacturing philosophy to the construction works onto the area of already existing building stock.
- To develop a new role for the European construction industry: It could be a chance for the European construction industry to become a knowledge based industry, developing concepts and innovations for construction modules/components and outsourcing the production activities abroad.
- It can be judged as very valuable to integrate the "building culture" more strongly into the Open Building Manufacturing philosophy: to offer Europe an open system, that connects high quality, good design (lifestyle) with efficient industrialised processes. Europe could obtain a new role in the international construction sector as an exporter of building culture, innovative concepts and new, suitable and innovative technologies.
- The main chance lies in the adaptation of the concepts onto the area of already existing building stock.

Threats

- The conservative mentality of some agents who are still working with traditional systems.
- The lack of confidence of users when introducing new materials for which they are culturally not used, Open Building Manufacturing does not meet the requirements of the clients of the European construction market:
- Generalized ignorance or the lack of information on the matter.
- The Open Building Manufacturing philosophy neglects the image of prefabrication and the attitude of potential buyers towards prefabrication. This is a problem of the often bad image of prefabrication.
- The Open Building Manufacturing philosophy does not provide a clear link to German/European standardisation organisations. There is a need for international standardisation, to achieve the "fit" between different modules of different suppliers. But this is very difficult, almost unrealistic, considering the variety of the market and the striving of people for individuality.
- The Open Building Manufacturing philosophy neglects totally the legal, governmental authorities. The building processes depend very strongly on the bureaucratic, legal regulations. The Open Building Manufacturing philosophy has to harmonise its approaches, models and tools with the legal regulations and standards.
- The Open Building Manufacturing philosophy neglects the strong power and lobby of some industries and the already existing structures in the European construction sector. It seems to be very difficult to change situations in the Europe construction industries. This results out of the structure of the industry (mainly SMEs) and the political system and chambers.

The main fundamental conclusion that emerges from this chapter is that a set of real-life demonstration projects (real buildings) designed and built using the Open Building Manufacturing paradigm are required for the paradigm/concept/philosophy to be understood, appreciated, and used.

Key Lessons Learned:

- Requirements of the different actors of the construction sector regarding Open Building Manufacturing focus on:
    - Flexibility for the end user
    - Logistics
    - ICT Tools
    - Standards, regulations and rules
- Reluctances and resistances of the different actors of the construction sector regarding Open Building Manufacturing focus on:
    - The ambitious nature of the philosophy
    - The reluctance regarding new materials
    - The supposed rigidity of the philosophy
    - The supposed overestimation of savings through the use of the philosophy
    - The existing structures and legal regulations in the construction sector
    - The missing integration of national and international standardisation organizations
- Geographical differences amongst stakeholders were found in:
    - The market situation: some markets seem ready for the philosophy whilst others are not.
    - The ‘willingness ’of the construction sector: some national sectors seem ready for Open Building Manufacturing, whilst others still have a long way to go.
    - Details: in Spain, for example, the labour problem in general attracts much attention, whilst the Swedish stress on quality was strongly expressed.

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Authors' Biographies

Francisco Capilla Hervás is Industrial Engineer. He has 30 years of working experience in Engineering and Construction companies. Currently he is Director of the R&D Service of FCC Construcción, S.A. and Coordinator of the Standing Committee of the National Construction Technological Platform. Professional experience in: Design and calculation of electric installations, heating, protection against fire, etc. Structural calculations: Metallic structures (pipes and wires supports, industrial premises...), Quality management: Design, development and implementation of the Quality System and Management of R&D projects.

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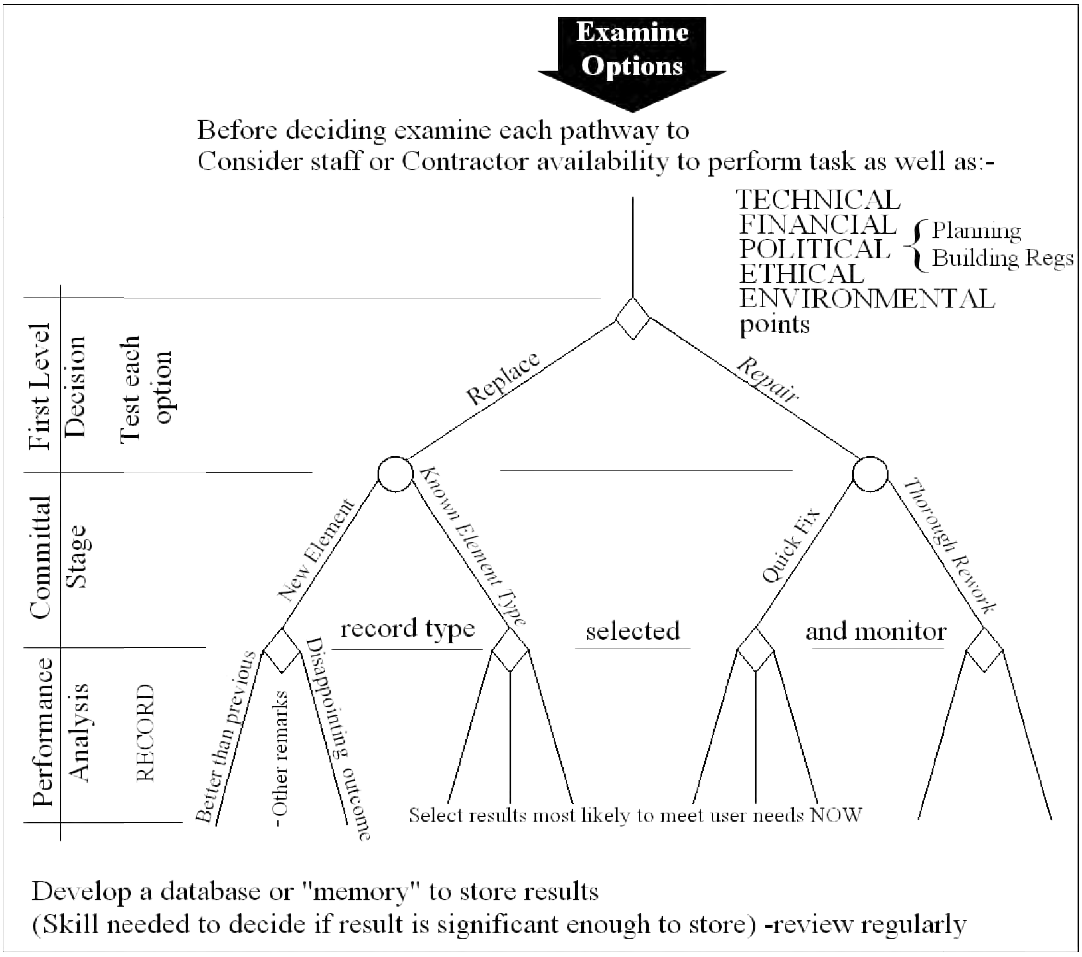
Open Building Maintenance

Brian Woods



Open Building Maintenance

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Abstract

Buildings produced using open building systems are going to need maintaining, and those responsible for them should consider this at the outset. Maintenance requirements of a building through its life and how these impinge on the continuing and changing use of a building and the comfort of its users are considered, and a draft checklist of questions developed. The principal message is that clients, architects and their advisors should ask fundamental questions at the earliest stages of project development and review decisions at intervals. Even a 1% saving in maintenance or running costs, reduction in downtime and disruption will be worth many millions of pounds or Euros or dollars over the life of a building. There will also be quality gains in terms of environmental performance, sustainability and user satisfaction.

Keywords: concepts, maintenance, skills, standards, technologies

Background

Industrial Context

Virtually all buildings, including those produced using open building systems, are going to need maintaining; *virtually* all because, theoretically at least, a maintenance-free building is possible. Such a building could be 'high-tech' with very durable materials and components, long-lasting, and perhaps ultimately self-monitoring and diagnostic, able to heal itself before needing maintenance; or a 'low-tech' building constructed to low specifications with short-life materials and run to failure. The 'high-tech' approach suggests a building able to adapt and be adapted to changing needs and circumstances, conceived, designed and constructed with a range of possible futures in mind. The 'low-tech' building may be better suited to meeting the need of the day, decaying over time until it is replaced with a building appropriate to the then needs (Wood, 2000, 2003a, 2003b). The open building concept provides opportunity for buildings to be produced which are able to be adapted reasonably readily to the needs of changing futures without a need to over-design and to incur additional and disproportionate expense at the outset.

Maintenance is much neglected as an area of serious study. It is commonly perceived as an activity carried out by men in boiler-suits with relatively low levels of qualification. Not a cerebral activity, not 'sexy', the 'Cinderella' of the building industry (Seeley, 1987). Yet extensive sums of money are expended on building maintenance. A report by Barbour Index in 1998 estimated the total value of UK building maintenance-related work at £28 Billion compared with £10 Billion on new-build. A study for the Royal Academy of Engineering (Evans *et al*, 1998) has identified a 1:5:200 ratio between the initial cost of a building, the cost of work done to it over its lifetime, and the value of the work carried out within the building. The precise figures may be questioned (e.g. Hughes *et al*, 2004) but the gist of it is supportable, that the initial cost of a building is small compared with the value of what it is there to support. By extrapolation to the design stage (0.1:1:5:200), it is worth giving serious attention at that time to how the building may be expected to perform over time. A decision to design and construct with open building principles is consonant with an expectation of giving mature and considered attention to a ‘whole-life’ or ‘cradle-to-grave’ analysis of how the building may accommodate to change and how it may best be maintained.

Techniques for the analysis and evaluation of alternative strategies are available and their value clear, for instance in helping determine whether it makes sense to invest more in the initial building, and if so how much. That such techniques may be used infrequently, and certainly not routinely, is testimony to the ‘normal’ short-sighted and short-term priorities of today. Pressures to get on with the project, to commence and complete on site as quickly as possible, and at lowest price conspire against the design team, but there are strong countervailing influences. There are shortages of people with the technical and management skills needed to continue with traditional building and maintenance techniques and many of those currently engaged are poorly qualified. Open building provides opportunity to address building maintenance needs in a fresh and attractive way.

Buildings designed to be manufactured offsite in quality-controlled *environments* using materials and components from a more standardised menu or palette bring the possibility of a more rational, consistent and thought-through maintenance regime. This will require however a new, or at least enhanced, ‘skill-set’ on the part of those designing, constructing and maintaining in this context. Many architects have, in the past, seen the need and opportunity to make their mark, win awards and the acclaim of colleagues, leaving something for posterity, by designing landmark, iconic, architecture; and Architecture Schools have reflected this in their development of the prima donna. Constructors have been able to blame the architect for lack of attention to detail, including how the building is to be built; and the facilities managers and maintenance operatives have been able to blame the architect and the builder for what they are obliged to maintain. The use of an open building approach requires a different attitude, focused on achieving the best overall and long-term result through a more closely-integrated team.

At risk of generalising, architects tend to find more satisfaction in the design of the new and one-off rather than something repetitious and ‘production-line’. Much of the encouragement toward more offsite construction has fallen on deaf ears or been responded to negatively due to the poor image of ‘industrialised building’ of the 1950s and 1960s. That culminated in the progressive collapse of the Ronan Point tower block in the London Borough of Newham in 1968 following a gas explosion. The building was a large panel closed system pushed beyond its limit. Open buildings need to be seen to be providing opportunity for better quality buildings than typically achieved by the one-off hand-built ‘bespoke’ building where little is learned through experience and defects are almost certain to be built in. Egan (1998) estimated the cost of rectifying defects in UK buildings at £1 Billion per annum.

Those responsible for the commissioning of building projects, for their letting, management and maintenance are best-placed to demand that new buildings deliver value long-term as they are paying. Those who are engaged as professionals to advise should do so with humility and with that long-term perspective. This can be rewarding intellectually and financially. The growth of the design-build market, design-build-operate, and the Private Finance Initiative (PFI) reflect the wish of clients for ‘one bum to kick’ when things go wrong. They can also have a realistic expectation that those involved with the project, having a long-term and continuing interest in the effective operation of the building, will be more concerned to get it right first time and every time. This requires a fresh approach to relationships, attitudes and organisation of the design process.

In the so-called ‘traditional’ approach to the design or procurement of a new building the initiator, the client, would select an architect, based on reputation and recommendations from trusted business friends and colleagues, reinforced perhaps by knowledge of recently completed and similar projects. The Royal Institute of British Architects (RIBA) upheld a mandatory feescale based on the value of the construction contract until such time as it was determined to be an anti-competitive restrictive practice. Further professionals such as quantity surveyors, structural and services engineering consultants would be recommended and appointed separately by the client, and a contractor selected by tender on the basis of lowest price. It could be 'pot luck' as to how well the relationships worked. The building contractor had no involvement in the design and there was no-one involved who would have any responsibility for the operation of the building once complete- altogether a recipe for problem creation rather than resolution. The 'team' would quite possibly have never worked together before, and quite likely never would again.

The open building approach needs more open processes and relationships. This needs to start in the places that construction professionals are learning their craft, in the universities. Students need to understand the priorities of their colleagues-to-be and learn how to work together, respecting their contributions. Existing practitioners already scarred by adversarial relationships need to unlearn those ways and learn to work collaboratively in a climate of trust. The involvement of facilities managers who will be looking after and caring for the building and its occupants beyond the so-called 'completion' of the building can be a catalyst for positive change.

Problem

There has been concern for some time that the designers of buildings gave little or no attention to how they would be built. That was not surprising as the typical architect's education would contain nothing on that subject. Difficult enough to show DPCs and flashings correctly positioned on 2D drawings without thinking about how they would be got there in the construction process. Just as buildability needs to be considered, so maintainability needs to be designed into buildings from the outset. That same flashing that needed to be installed will need to be reached to be inspected at intervals, repaired occasionally and perhaps replaced. The development of a building proposal based around an open building system provides opportunity to think through maintenance needs and procedures in a systematic way.

What maintenance is likely to be required of a building over its lifetime? What degree of certainty can be applied? The scope and scale of possible failures and consequential losses and reductions of service and performance need to be considered , together with how responses may be determined. This requires a systematic review of risk and of procedural responses. How to assess, evaluate and prioritise? Who should decide?

For most building components, failure occurs mainly and to greatest injurious effect at joints and junctions; attention should therefore be focused on these areas by both designers and constructors. What kinds of decay and failure can be expected; how often; how serious; how to recognise failure and how to remedy? How to make it less likely that failure will occur; less damaging and disruptive; easier to rectify? Better still, but harder, how to eliminate failure? This kind of assessment requires skill and application, time and money to be devoted early on. The cost of such exercises, though it may seem additional, will be recouped potentially several times over. The cost of dealing with defective design and construction through the life of a building may be many times as much as that to be devoted to reducing or eliminating such defects at the design development stage. It may be difficult to determine precise figures but a business case can certainly be constructed.

Although it may be easier to justify and to execute this kind of exercise for a 'closed' building system where all the details and connections are known and repeated without variation, it is arguably more important to apply to those buildings designed and constructed in an open building system. Attention can and should be given as part of the design of 'the system' (the design framework and component design) and also as part of the individual building design, where those frameworks and components are applied to the particular and perhaps peculiar circumstance. Follow-through will also be required as the building moves from design through construction or assembly to ‘completion’, occupation and operation. There will also be need of involvement in monitoring, adaptation and changes, major and minor, one-off and repetitively, of the ‘built’, and ultimately its disassembly and recycling. Continuity of involvement with the building through its development is likely to be conducive to a concern and care for the building, its wellbeing and that of its users; a corporate memory. A database of experience whether formal or informal will be built up and available to be brought to bear advantageously. There are potential difficulties here though to be addressed. In Figure 1 in relation to a maintenance task (below) I suggest a formalisation of the decision processes and recommend recording details of decisions to inform later choices.

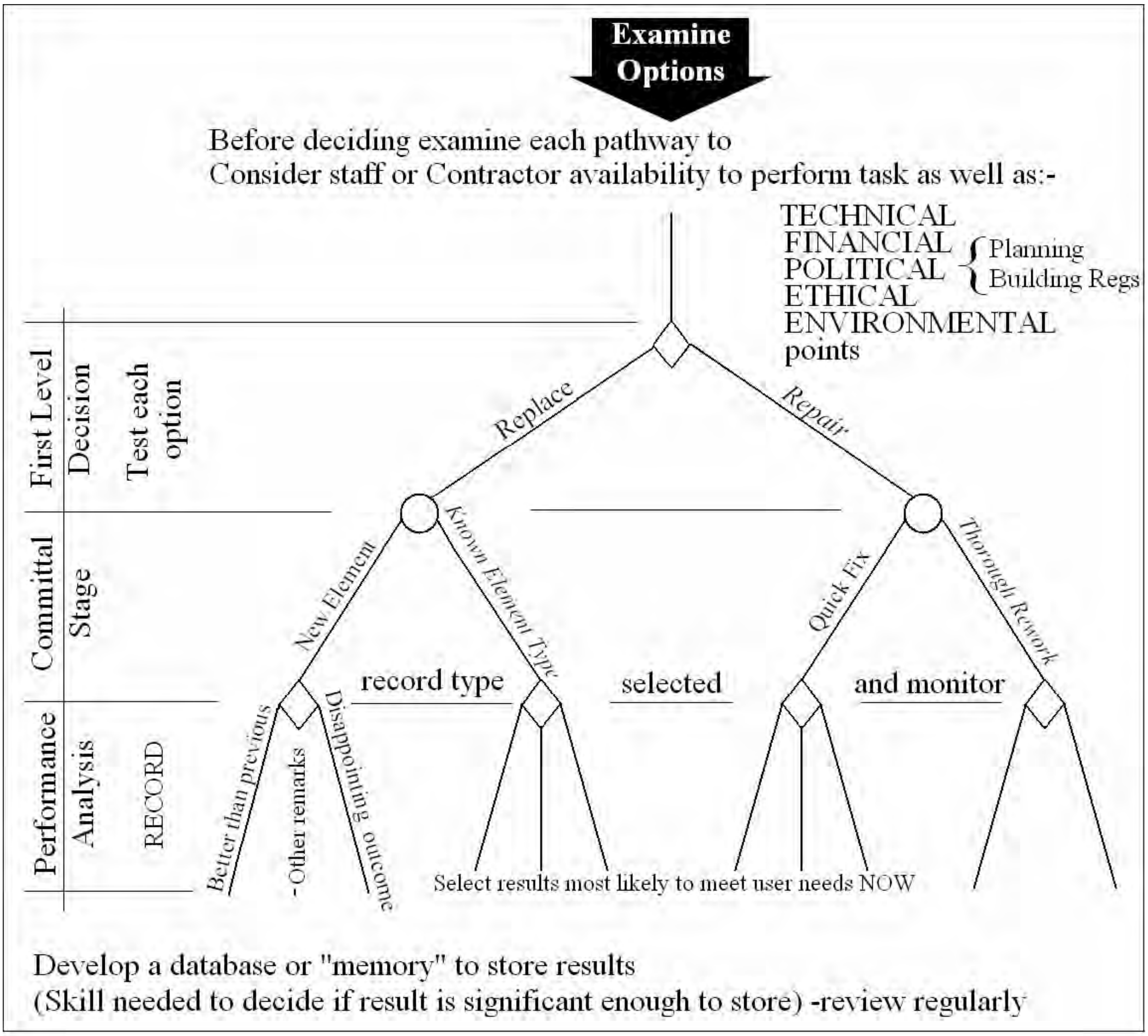

Figure 1: Decision Tree - Map all options and potential consequences

Regarding continuity and communication, in relation to design for instance, if the concept, knowledge and principles related to and applied to the system framework are contained in one organisation (maybe one person) they will need to be understood by those in another organisation responsible for applying them to the design of the particular building. There is plenty of scope for misunderstanding. This will be repeated in turn by those responsible for the construction and maintenance of the building. Rather like with the design details, the problems tend to occur at the interfaces. Therefore that is where attention should be concentrated.

One approach is to reduce the number of interfaces. This could be produced by having fewer and larger organisations, with perhaps greater efficiency and effectiveness but less choice. Similarly in terms of technology, larger panels perhaps and closer to a closed system with its greater design limitations and a different kind of architecture. Another approach would be to aim to concentrate on reducing the effects of any failure when it does occur. This could be facilitated perhaps by reducing the size and complexity of components; alternatively and/or additionally by increasing their robustness to the agents of decay. Yet another approach may be to accept that failure will occur and to concentrate on making repair and/or replacement really easy.

The next section looks at how such choices may be made.

Learning Objectives:

Through reading this chapter you should be:

- aware of the scope, scale and importance of building maintenance
- conscious of the need to consider maintenance at the design stage
- sensitised to the need to keep in mind the building user
- able to evaluate and recommend appropriate maintenance strategies
- equipped to develop open building systems into sustainable buildings, low in use of resources, able to be operated efficiently and effectively through life

Approach

The thrust of this study is to review maintenance needs at a strategic level. This entails the asking, and answering, of fundamental questions relating to the design, construction and operation of the building. When such an examination has been undertaken and appropriate strategies decided, how these work out in terms of design, buildability and maintenance operations can be considered in detail.

For the sake of convenience I will consider these three (design, construction, and maintenance) as separate ‘stages’, though they should be considered together and may be executed in some aspects concurrently. It is really important to have an effective development of the brief to work through into the design. This requires a full exploration of the client’s wants and needs, including how those may be expected to change over time. This can be difficult, especially as most clients commission a building project only once, and there is the pressure to ‘get on with it’. Such clients are not perhaps the most likely to be susceptible to considering the open building concept. The mature client however, likely to be involved with a programme of building projects and/or the management of a property portfolio, is more likely to be open to seeing the potential of open building and the benefit of putting time to such considerations at the inception and design stages.

So what are the considerations that especially need to be made? That’s easier to ask than answer; and it’s easier to think about the kind of question rather than the actual questions! But we must try. A checklist can be a very useful aid. In the absence of a checklist, or as a step towards the development of one, a good start (and more helpful than may be thought) is to work through those little interrogatives: what, when (how often?), where, by whom, how, and especially why? This is not dissimilar from the use of a ‘semi-structured’ interview technique, with broad headings that allow the respondent to make quite full responses without being ‘led’ towards one or another of a set of predetermined answers. Of course, checklists are not without their problems in application. For instance, there is a great tendency to overlook what is not on the list! It is useful to have at least the ‘prompt’ to think and probe more widely by including a section headed ‘other’. It may be possible to work effectively with a prototypical checklist; that is, one based on a building type or constructional form. This is examined in the next section.

Analysis

Some building types and constructional forms may lend themselves more readily than others to the application of a checklist to the development of a proposed building project. As this chapter is focussed upon the maintenance of open buildings we want to ensure that the building’s design takes account as far as possible of the building’s maintenance needs when it is in use after ‘completion’ of its construction. Arguably, building types and clients most likely to be considered susceptible to the open building concept would include repetitive and large-scale developments such as housing (though not ‘one-off’ individual bespoke designs), hotel chains, hospitals, schools, and prisons for instance. Let us endeavour to construct, using those ‘little interrogatives’, an embryonic checklist that may be suitable for use at an early stage of the development of a proposal for a housing development, taking account of its anticipated maintenance needs.

What?

Has the client a clear picture of what kind of housing? How clear? Housing for sale or to rent; ‘social’ housing? Size of the development- a block or terrace; an ‘estate’; the first of a possible programme of similar developments; a ‘pilot’ project? Something ‘traditional’ in appearance and/or layout; innovative or experimental? ‘Family’ units (and, if so, what size[s]), or for singles, or couples? Houses or flats? Target costs, selling prices, rents? Minimum first cost or whole-life? Low (or zero) energy and/or emissions? [This is ***not*** an exhaustive list!]

What will need to be maintained? The simple, straightforward answer is ‘everything’, but within that there will be items more or less likely to need maintenance attention, more or less often and to greater or lesser degree. Hopefully the *structure* of the building will need little maintenance, though if and when it does it will be useful if it is relatively accessible for inspection and attention. But how likely is that, and how often (see below)? Relatively unlikely and rare, if the design and construction are appropriate, which is likely for a building designed and constructed within an open building system. In the relatively unlikely event of a structural problem, it is probable that the building (or relevant part) will be temporarily vacated. It will not be unexpected that some of the building’s finish be destroyed in gaining access to the area of structure in question and subsequently replaced or repaired and made good- indeed this may provide visual evidence that the matter was investigated.

By contrast, rainwater goods may be expected to leak on occasion, especially at times of exceptionally intense rainfall and/or of significant leaf-fall blocking outlets.

When (and/or How Often)?

Leaves fall every autumn; autumn comes once a year and at more or less the same time of year. Thus there is something to be said for an annual programme of inspection or leaf clearing; this will reduce the risk of blockage and water ingress with consequential damage to the building and its contents. But it will not eliminate the risk entirely. A rainwater collection and disposal system may be designed to cope with all but an estimated, say, once-in-fifty-years burst of rainfall. Not only may that rain fall tomorrow, but also the estimate, based on previous records, may be an inaccurate forecast of the future. It is probably unreasonable to expect a client to have a view on how large the rainwater gutters and pipes ought to be, they will almost certainly expect the 'professionals' to assess that and act accordingly. It may be though that the client will have a view about, for instance, the acceptability or not of disposal systems shared between otherwise private and separate dwellings and the associated difficulties of gaining access to another property for maintenance purposes. There are also the related liability and insurance problems of whose fault the problem was and who will pay for the 'clear up'- such problems and their effects can be considered and reduced at the design stage.

Where?

The location of the proposed development may have particular peculiarities that may affect its maintainability. For instance, a property within or near to the Arctic Circle will have long periods of cold and icy weather and of darkness; these could be severe constraints upon the ability to carry out some maintenance activities. Freezing conditions may also make some problems both more likely (like burst pipes) and more destructive. Tropical zones may be expected to be hugely hot (and cold overnight) with perhaps strong solar/UV degradation and extremely high or low humidity; temperate zones less extreme but still with significant diurnal and seasonal changes with related problems such as dampness and freeze/thaw cycles. In addition to climatic issues at the macro level, there are also locational matters at the local/micro level. For instance, a service pipe run may be well-hidden from an appearance point-of-view but very hard to reach for access when required. This is the kind of matter where a client may be expected to have an opinion, a preference for surface-mounting or flush-finished and for an open system to cater appropriately.

By Whom?

Who is going to make decisions about maintenance? If there is going to be a facilities manager responsible for the efficient running of the building it makes sense to involve him or her as soon as possible (preferably at the outset of the project), to at least counsel their views, and better still to adopt their proposals. They have to 'live with' the results of such decisions. They are also therefore perhaps more likely to favour designs and systems with which they already have a familiarity; this should enhance the likelihood of adoption of solutions with lower maintenance needs. If the building is likely to be sold or let out, it makes sense to try to identify the range of expectations of likely occupiers and to cater for them in the design. This is likely to result in a building with a wider range of acceptability, perhaps more 'conservative' in design and with greater simplicity of operation. It is very likely that commercial clients will seek and accept the advice of a professional surveyor or 'letting agent' in this field.

Some clients, particularly perhaps those commissioning a building to be occupied by their own organisation, may also have a view about who should determine the maintenance requirement. Here perhaps the word 'maintenance' may warrant a little exploration.

Many books about building maintenance refer to the definition of maintenance provided by BS 3811 in 1964: 'Work undertaken in order to keep or restore every facility, i.e. every part of a site, building and contents, to an acceptable standard'. This was and is an inadequate definition. BS 4778 updated the definition in 1991 to 'the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function'. This recognition of the performance expectation is a significant improvement, although it is still only an intention. 'Maintenance' has still been carried out even if it is ineffective; and who determines the 'required function'?

My contention is that the client should determine the required function of the building, and its component parts; and this should take as full account as possible of user needs. A building designed with their needs in mind at the outset is more likely to be able to have its required functions performed and maintained effectively. I further suggest that building users should be able to ‘order up’ maintenance in line with their requirements for functionality as and when they perceive performance to be below that required.

How?

- *How to determine what maintenance may be required?*
- *How to put the required maintenance into effect?*
- *How, then, to ‘build in’ maintainability?*

The key to answering the first of these ‘how’ questions is to ask the client. This will help elicit the level of maintenance expected. For instance the client may wish the standard of maintenance to be such that the building retains as far as possible through its life the level of performance of the building when new and first occupied (Grade B). That will require a higher level of maintenance intervention than if it is expected that the acceptable performance of an ageing building will reduce over time (Grade C). A further possibility is that the building should be continually upgraded to meet increasing standards over time (Grade A). That will require more major interventions. A building or element that is performing below the level of acceptability may be considered to be Grade D. An open building, designed and constructed using tried-and-tested modular components assembled in a structured way, may be expected to perform in a more consistent manner than the ‘traditional’ one-off design. The performance of individual components and whole elements can be calculated at the design stage and delivered more reliably. Thus for instance the behaviour of various thicknesses and specifications of protective coatings can be tested in appropriate conditions, evaluated and manufactured consistently. Any amount of accelerated weathering and agents of degradation can be applied in laboratory conditions, such experiments justified by being able to assess appropriate maintenance regimes.

One approach would be to try to maximise component life and thereby reduce, or eliminate, the need for repair and/or replacement. Another approach would be to manufacture components that are both easy to assemble and easy to disassemble. Addressing the second of the ‘how’ questions- how to put the required maintenance into effect- is the key to answering the third question- how then to build in maintainability? Bearing down on the maintenance requirement and increasing ease of replacement of components would seem like a combination likely to improve maintainability.

Why?

The practical person always seems most interested in the ‘how’ questions; the financially-minded, ‘how much?’ These preoccupations run the danger however of eliciting the right answer to the wrong question. The ‘why?’ question is often the most fundamental. Why maintenance? The BS definitions are relevant here; they refer to the intent of the maintenance work or actions: ‘… to keep or restore every facility … to an acceptable standard’, or ‘… to retain an item in, or restore it to, a state in which it can perform a required function’. But they beg the further question, ‘why do we wish to keep, retain or restore the item or facility to a particular standard or level of performance’? Possibilities could include, for instance, to provide working conditions that show respect to those working in the building; or that enable the workforce to achieve high levels of productivity; or to provide a quality of finish that creates an excellent impression to customers and potential customers. Only by asking questions and ascertaining such answers can one determine appropriate maintenance regimes and the design solutions that will deliver them.

Open building systems do also provide the opportunity, if so needed, to be able to change components at a later stage if either the client’s requirements change or are identified once the design has commenced or even after construction has been completed. The interchangeability of components within the open building framework is a positive attribute.

Typical Elements

Buildings designed using open system designs are likely to contain repetitive elements, such as roof, walls, doors and windows, constructed or comprised of repetitive components or modules. An architect, or other building designer, is likely to work from a relatively limited palette of design options- materials, components and assemblies with which they have developed a familiarity and confidence through experience over time. When moving out of that ‘comfort zone’ more assurance is required to justify the higher perceived risk of failure of performance. The basic performance requirements are generally going to be able to be discerned, discussed and decided at the design stage. For instance, in the case of a roof, it is likely to be required to exclude rainfall (and precipitation generally, e.g. snow where relevant) - and that will normally involve collection and disposal, usually in the form of gutters, rainwater pipes and ‘below ground drainage’ to either a sewer or a watercourse for ‘onward transmission’ off-site. However, that requires quite a drainage ‘infrastructure’; perhaps that could be reviewed and reduced by for instance a ‘rainwater harvesting’ scheme, where rainwater may be collected and stored for use in flushing w.c’s or for filtering and/or treatment for drinking. The component parts of such a system are still likely to comprise gutters and pipes, and various connections, gullies, storage tanks and provisions for overflow. Calculations can be done for sizing the various components based on historic and projected data; give or take global warming and increasing intensities of rainfall, that exercise can be done with relative ease and confidence. The most appropriate maintenance regime however is less certain. How long are the components likely to last? Can a decay rate of the constituent materials be determined with any confidence? What if the installed system is found in practice to be in some way inadequate? What if an additional bend was introduced at the construction stage to overcome some other problem; or a jointing compound failed unexpectedly in service? Of course it is not going to be possible to consider all the ‘what if’s’, so some ‘contingency’ is going to be required in any system, but a good number of possible failure points can be anticipated.

A ‘worked example’ of the development of a ‘typical’ checklist follows.

A ‘Typical’ Checklist: Rainwater Disposal from a Roof

This is an example of how a checklist for an element of structure may be developed, commencing at the initial design stage. An attempt has been made to identify the kind of questions to be asked (and why) and to consider some of the implications. Needless to say perhaps, it is not exhaustive; it is intended as a starting point to promote discussion and facilitate decision-making.

- Why dispose of rainwater? Rainwater is limited and a ‘free’ resource. Could/should it be stored? If so, how? Could/should roof and other materials be absorptive and able to ‘dry out’ later; with what (and acceptable?) effects in terms of material degradation, movement, etc?
- If rainwater is to be disposed of, where to; at what sort of rate? Can the infrastructure cope?
- If rainwater is to be collected and channelled from where it falls to somewhere else, what is the range of acceptable methods, routes, etc? For instance, it is invariably preferable from a consideration of the effects of when the ‘system’ is inadequate, to have gutters and pipework as far as possible on the exterior of the building rather than hidden and relatively inaccessible internally. Such arrangements may offend aesthetic sensibilities but are likely to be preferred operationally.

- What will be the ‘knock on’ effects of deciding to have external gutters and downpipes- e.g how will they be fixed? Will those fixings impair the waterproofing protection of the walls to or through which they are fixed?
- How readily can damaged or failed rainwater goods be detected, reached and repaired or replaced? Who will do that?
- Should regular inspections be carried out; if so at what intervals and by whom? If not, could remote sensing be worthwhile; in which case how to build that in; and who will monitor it?
- Other?

Results and Business Impacts

Key Findings

Maintenance is both disruptive and expensive; it is therefore worthwhile to spend time at the conceptual and design stage of a project to try to minimise future risks and expenditures. Many such maintenance activities will be in relation to issues and occurrences that could have been predicted and either allowed for or designed out.

A maintenance-free building has been postulated and, in theory at least, is possible. It could be provided in a fairly basic shell of a building. Alternatively it could be provided by use of probably expensive durable components whose life is expected to align with (or exceed) that of the building, which will be demolished (or perhaps relocated and rebuilt as, in essence, a new building) when it has out-lived its usefulness. Such possibilities should be considered at an early stage of the development of the brief.

However, even if a building is expected to be maintenance-free, it may fail to perform as hoped, or users’ ideas as to needs may change once the building is occupied, and/or perhaps after some time in use. Building uses and user needs change over time and this should be allowed for. This is not to say that a lot of ‘redundancy’ should necessarily be designed in; that may be unnecessarily expensive, both financially and/or in terms of use of more material resources than otherwise adequate. A flexible building may be expected to be more expensive initially; it may repay with lower cost alterations and adaptations later on; it may not. It is difficult to forecast the future; it may be cheaper overall to provide a building designed to meet the needs of today.

It is appropriate to consider at the briefing stage what kind and degree of changes may be expected in the building over a period; what magnitude and frequency of change? How much can and should the design try to cater for such changes? The ‘traditional’ approach has been to over-design to allow for how the building may be used and abused. For instance an office floor needed to allow for the possibility of a bank of filing cabinets full of paper placed mid-span (the worst place for loading and deflection). Perhaps the ‘paper-less office’ would allow a reduction in the factor of safety to be applied, thereby reducing design loads and consequential size and weight of structural members.

The key factor is the quest to provide user satisfaction. Satisfaction is partly achieved by seeking it in the first place. At risk of sounding trite, a person who has been consulted is already being shown respect and that they are valued. Of course that good feeling is somewhat lost if the views offered at that consultation are then ignored. Even when good ideas are not implemented, many people will accept the outcome if the reasons are explained to them. A happy workforce is a productive one (Clements-Croome, 2000). And people like to be in control of their working environments. A number of studies (Haves, 1992; Bunn, 1993; Leaman and Bordass, 2000) have shown that people like to be able to sit near an openable window, even if they don't open it. People are adaptable and will adapt to a wide range of environmental conditions.

But when things go wrong, while people may 'put up with it' for a while, they would like it to be corrected once they have reported it. A good responsive maintenance system is critical. Once a building and the way it is cared for start to deteriorate, a strong message is conveyed about how the building users are cared for. If people are an organisation's greatest asset, they should be treated as such. This is a key determinant of success or failure of what the building is there to do.

Business Impacts

Having recognised that user satisfaction is the key to the success of a building, it should perhaps be expected that the design and production stages of the building project would benefit in a similar way. The thrust of this chapter is to suggest that maintainability should be an integral part of the design process. This may mean some major refocusing of the design team, its membership, their processes and their priorities.

Until comparatively recently a lot of the education of construction-related professionals was focused around the accumulation and assimilation and onward transmission of knowledge. This may work well when passing down traditions: 'we have always done it like this'. Building design and construction are more complicated today. We are trying to achieve buildings that are much more effective in their performance, for instance in their energy efficiency. In Britain in the 1960s there was no thermal insulation requirement; in the 1970s a requirement for a maximum U-value of 1.0 W/m2degC was introduced in the building regulations in response to the energy crisis; today a U-value of 0.4 and lower is fairly routine. We expect to achieve air-tight, damp-proof and condensation-free buildings. This has given much focus to the need to meet technical standards, and the educational syllabus has reflected that.

However, much that goes wrong, contributing to the difficulty of meeting those standards, is due to poor communication and inter-personal skills amongst the team of people needed to inform and execute projects with this level and kind of sophistication. Atkinson (1998) showed that more defects were attributable to management failures than to technical misunderstandings. For most 'traditional' constructions there is no shortage of information, guidance and experience- but pressures of unrealistic budgets, timescales and 'promises' given but not intended to be kept, mean corners are cut and shoddy work accepted. This kind of culture will not support open building.

A successful open building project puts the client and the intended and actual building users at the centre of consideration from the outset and throughout. This means those involved with the processes need to understand and respect them and their requests, and to respect each other. The traditional rivalries and arguments over who is to blame for this or that error must be consigned to history as Latham (1995) and Egan (1998) and so many before them and since have said.

It is clearly going to be helpful if the design and construction team are able to work together as an integrated team over a number of projects, gaining confidence in their fellow team members and learning through repetition and experience of solving problems together. There is then opportunity for feeding back information from assembly and erection problems on site into subsequent designs. Senge (1990) wrote extensively on the value of teamwork and shared learning. Clients will expect to see a return on their up-front investment of time in developing the open building rather than taking the 'normal' product in their usual way.

By making an allowance for all the possibilities for each element a feed back stream of information can be created to pour back into the "fountain" of maintenance knowledge (Figure

2) as the use of the building progresses and used to inform both future projects and refurbishment decisions for the current building.

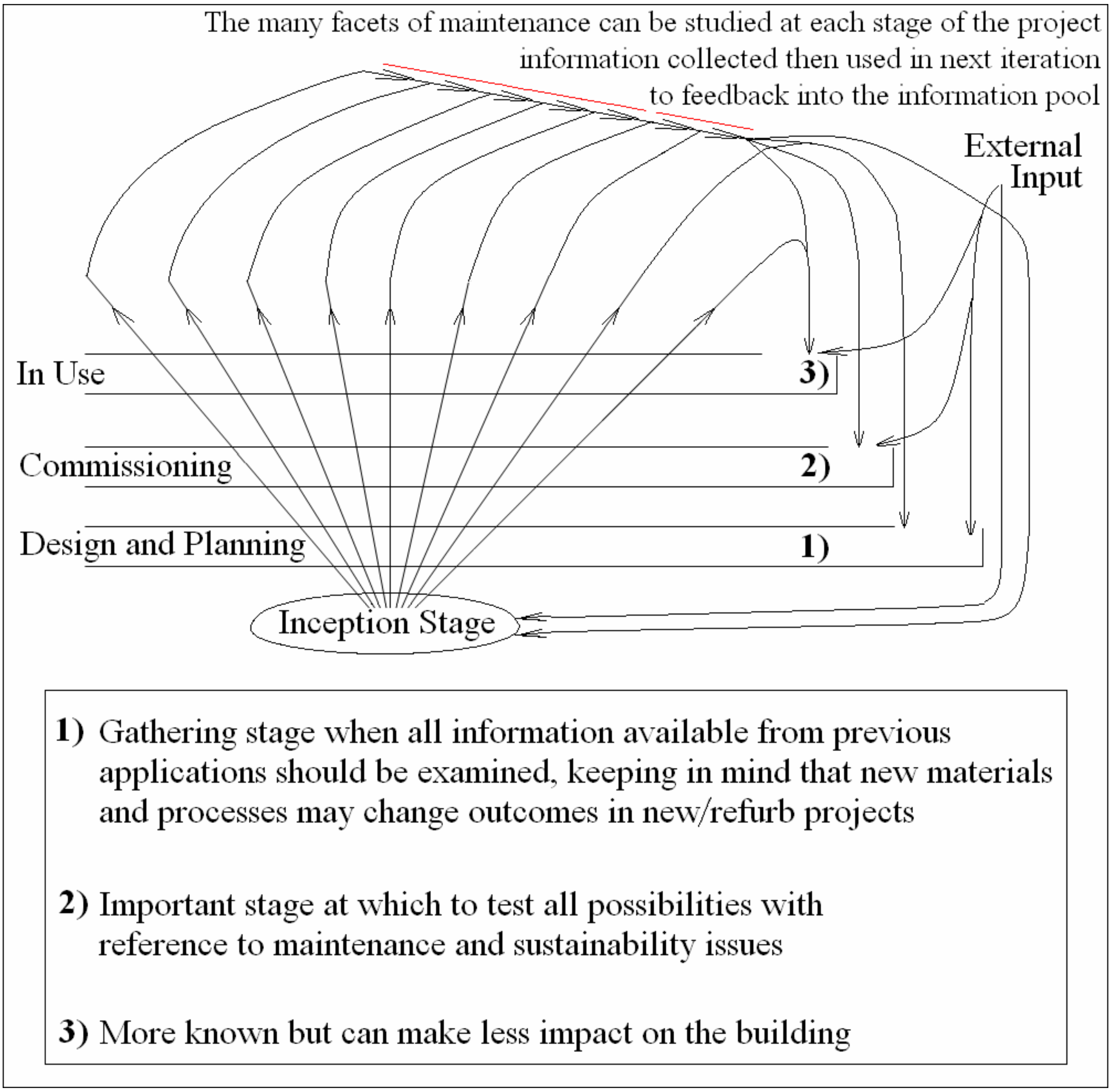

Figure 2: Fountain of Maintenance Knowledge

Using a diagram to document the process may help to visualise all the processes to consider. We start with little knowledge of how what and where maintenance will be required, however we can use existing information to inform our search for useful design input, at the lowest level of the “fountain” (see Figure 2). The Inception Stage (as also each subsequent stage) is informed by past experience from all stages as well as external input from suppliers and academic research. The kind and amount of investment needed in manufacturing capability and capacity- machinery, factories, staff recruitment, training and skills development also demands a reasonable expectation of a financial return. These will be substantial up-front costs, more willingly incurred if there is a reasonable certainty of good returns in the longer-term. Quality standards will also need to be high, requiring manufacturing to close tolerances if expensive rejection of non-conforming product is to be avoided; good quality assurance and control procedures will be needed.

This level of confidence and continuity is most likely to be achieved through long-term committed partnerships. ‘Partnering’ has been fashionable for some time (Bennett and Jayes, 1995); and the so-called Scandinavian School has been singing the praises of ‘relationship marketing’ for some time too (Grunroos, 1994, Gummerson, 1994). The ‘Private Finance Initiative’ (PFI) and Public-Private partnerships (PPP) offer the opportunity of good long-term relationships. Where building contractors are responsible for the operation and maintenance (and costs thereof) of a building for 20 or 25 years they are bound to be more concerned to minimise the total of those costs and the construction cost. Where that contractor is able to work together with the client on a number of similar building projects over a number of years there is good opportunity to feedback experience into the next design.

This process of semi-continuous review and refinement is represented in Figure 2.

Conclusions

This chapter has focused very much on the importance of maintenance and that it should be considered at the outset of a project and the building’s maintainability should be reviewed at intervals in the design development. Although, and because, it is not possible to identify all the detailed questions to be answered the proposition is that generic issues should be addressed through a kind of open questioning:

- What maintenance is likely to be required?
- Where?
- How often?
- How should it be carried out?
- By whom?
- And why?

The building proposal and its proponents can and should be interrogated at concept, outline and detail design stages before ideas and their ‘carry-through’ into the design intent are frozen; it is difficult, expensive and generally undesirable to try to ‘unpick’ designs once they have been ‘finalised’.

This is likely to mean a radical revision of the way designs are developed. For many involved in design and construction this will require a review of their previous priorities and procedures, refocusing on the human dimension rather than on the ‘technical’.

The open building concept both requires and facilitates this integrated team approach with the opportunity to introduce and consider maintenance issues throughout as part of the fundamental design concept, seeing maintenance of the finished building as a professional and strategic issue.

Maintenance is an expensive activity. The costs of maintenance of a building over its life will be several times its construction cost; and the value of the operations that take place within the completed building several times more. Design costs are infinitesimally small by comparison; it is well worth taking time at that important stage to give the fullest of considerations to the maintenance implications of the design. Getting this right will repay many times over.

It would be a useful extension of this study to:

- Prepare and present some Case Studies of successful open building projects where maintenance was a serious consideration within the design, for instance in relation to the ManuBuild project.

- Through such case studies to provide substantiation for claimed cost reductions, quality enhancements including improved health and safety, better building performance and reduced maintenance.
- Work towards a more complete and definitive series of elemental design, construction and operation checklists
- Share good practice to help those designing with open building systems, particularly to help 'first time' adopters.

Key Lessons Learned:

- Building maintenance is expensive and disruptive and needs to be considered at the design stage
- The optimum building solution will take full account of the anticipated use of the building and changes over time
- Open building can be a route to achievement of successful sustainable buildings that meet the needs of building users

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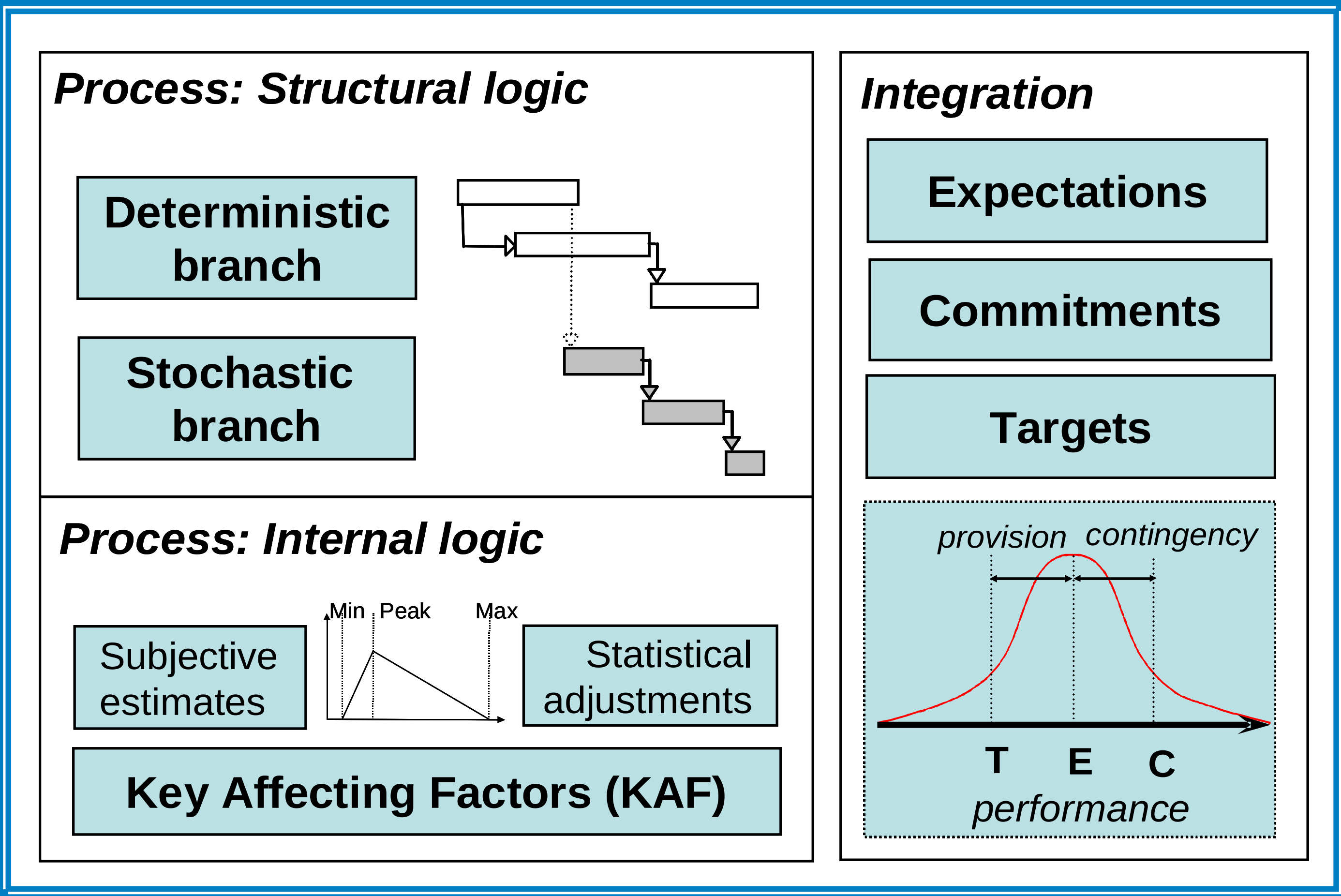
Author's Biography

Brian Wood (BA [Hons] Dip Arch MCMI RIBA MRICS MBIFM FCIOB) has been Field Chair for Building and Construction Management programmes at Oxford Brookes University since 1992. Before that he worked as an architect and surveyor in and for local and central UK government and in the private sector. He has been involved with the preparation and implementation of planned maintenance and improvement programmes for extensive stocks of buildings. His experience confirms the value of time spent at the conceptual and design stages, bringing and applying intelligence to the project and task.

10

Stochastic Process Modelling in the Development of Standardised Services

Kalle Kähkönen & Abdul Samad (Sami) Kazi



Stochastic Process Modelling in the Development of Standardised Services

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Abstract

The main objective of this chapter is to present stochastic process modelling as an approach in the development of standardised services for open building manufacturing. It is considered that standardised services have usually a repetitive nature and thus it is valuable to understand the statistical reliability of the process. The widely used traditional business process modelling approaches produce passive models that shall not change or react in any case. An active model on the contrary is a model that acts by it-self or reacts when a user interacts with it. This is seen as a way to understand the behavioural aspects of the processes that seem to be omitted in traditional business process models. Key elements of stochastic process modelling are presented that form a basis for practical implementations of stochastic modelling in open building manufacturing environments.

Keywords: process models, process modularisation, performance metrics

Background

Industrial Context

Development of service oriented professionals, their capabilities and relating products is an improvement area of key significance for the modern building construction sector (Barrett, 2005; ManuBuild, 2005). It looks obvious that the most desirable service products are the ones having characteristics such as approachability (scope easy to understand, easy contacting), transparency (content, accessing progress data) and reliability (minimal variances in time, cost and quality). Profound understanding of customer needs is always behind of the overall set-up of any service product. Standardisation is considered as a key avenue for the development of service products that can be configured and assembled according to end-user requirements. The resultant service can be characterised as a system, the development of which can have different needs (or their combinations) as follows:

1. *Packaging* of processes and results according to the identified main needs,
2. *Segmentation* of service products towards different customer groups using key parameters,
3. *Constant performance creation* where processes are standardised for having highest possible reliability,
4. *Integration* of processes of several companies in the form of service products, and

5. *Homogenisation* of operations and enabling solutions (for example information systems) regarding service suppliers. On the other hand the homogenisation can mean also a standardised information source for accessing building data by any selected service provider.

This paper addresses the development of standardised services for the life-cycle of (manufactured) building products. The word life-cycle is particularly challenging when we are dealing with buildings that can have a long or a very long time of usage. This is divided, in a rather simple manner, in two parts that are i) building construction and ii) building maintenance. The main rationality of this is their clearly different nature. This can be outlined using the organisational characteristics of services for building maintenance. Building construction is primarily a *construction champion and/or project sponsor centric* operation. These parties usually initiate the building construction that is next equipped with the appearance of potential building end users and owners if they are different from the previous ones. On the other hand the nature of building maintenance operations and relating services is different. Building maintenance operations are usually dependent upon the maintenance policy of building owners and thus these operations are initiated by this party. Therefore we can consider that building maintenance usually includes *owner centric* operations.

The discussion above has covered two different views (system, organisational) for understanding the characteristics of the development of standardised services. Business process modelling (BPM) is often used as an approach when standardised service products need to be developed. BPM enjoys wide usage in relation to general business process re-engineering and development of company wide ICT systems which as examples demonstrate the overall importance of business process modelling. As a consequence of this position there are several hundred BPM tools available. Behind them one can find many process modelling techniques. The purpose of most BPM modelling techniques is qualitative modelling that is particularly suitable for understanding and communicating operational details to those involved.

The less understood BPM modelling approach is the quantitative modelling of processes in question and as to what are the main achievable benefits from the quantitative modelling. Whereas qualitative modelling is successfully meeting many of the service system modelling needs listed earlier, quantitative modelling is particularly meeting the need for creating processes with constant performance. With a probabilistic dimension (stochastic models) the quantitative modelling can provide a source for understanding the statistical performance of established services on the long run. This model can be used for setting up the reachable but realistic targets for the performance of standardised services. Additionally quantitative performance indicators can be extracted from the model to be used as tools for monitoring the performance and providing feedback to the process itself.

The main objective of this paper is to present stochastic process modelling as an approach in the development of standardised services within the context of open building manufacturing.

Problem

Traditional process modelling can be characterised as a task oriented towards hierarchical activity mapping. Hierarchical mapping usually applies a top-down strategy; first the highest level abstractions of processes are named that are then broken down into smaller units. This demonstrates the need for understanding first the total overall picture followed by a more detailed analysis of its parts.

A process is a series of activities (tasks, steps, events, operations) that takes an input, adds value to it, and produces an output (product, service, or information) for a customer (Anjard, 1998). This definition reflects the focus of the traditional thinking model on business processes. It has resulted in descriptive modelling techniques where operational functions of interest are each first named with a *verb* plus *context description*, e.g. prepare bid, assign resources, etc.. Often this leads to interesting discussions where the formal and informal processes are described with findings concerning organisational inconsistencies. Results from many years of applying these techniques in practice propose that the most valuable part of a corporate reengineering occurs when employees map their existing processes (Hammer & Champy, 2003).

Different modelling tools incorporate approaches that significantly vary from each other:

1. *Process*-centred modelling: The scripting example above (*verb* plus *context description*) explains briefly this intuitive approach that is the most often used when business process modelling is commenced. The IDEF0 modelling technique is a good example of process-centred modelling (Figure 1). This formal modelling technique still enjoys popularity and has been a source for many variations and modelling efforts in construction sector.

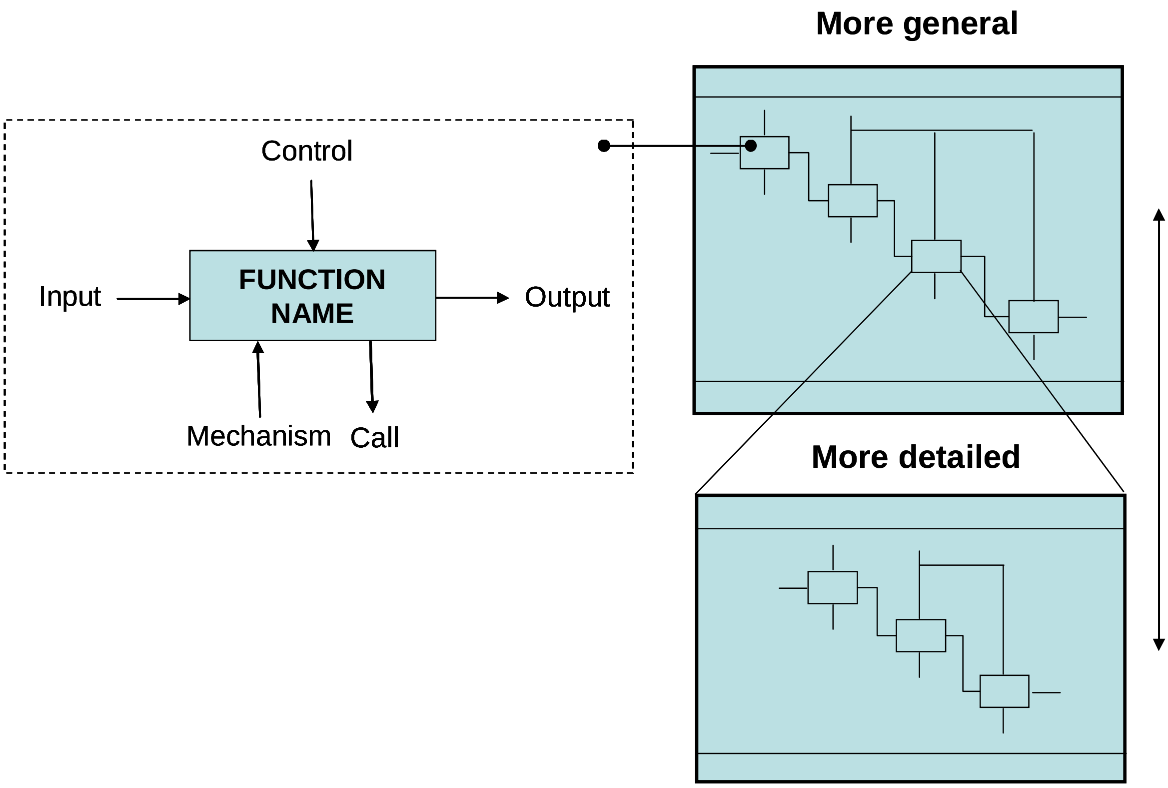

Figure 1. Main components of the IDEF0 modelling method (IDEF0, 1993)

2. *Data*-centred modelling: In this approach the main attention is put on the inputs and outputs of activities and their relating logic. The well-known data flow diagramming technique is perhaps representing in a most genuine manner the data-centred modelling approach for process modelling. Since the notation has not been standardised data flow diagramming can be categorised as an informal modelling technique.

3. *Behaviour*-centred modelling: This approach aims to capture the behavioural aspects of a system. This can mean for example, the details of synchronisation, communication, resource sharing between concurrent processes and resultant performance. In other words these modelling tools can describe the transitions in the state of objects and the factors that are affecting it. Many different types of modelling methods and a wide-set of modelling tools can be included in the behaviour-centred modelling field. IDEF3 is one of the best known classical modelling methods clearly focusing on the behavioural

modelling of processes (Mayer et al, 1995). In general terms, the rich family of various simulation tools can be also seen as representatives of solutions for behaviour-centred modelling (Savén, 2002).

The best known and most widely used traditional business process modelling methods can be characterised as graphic representation oriented solutions that have proved to be useful particularly when discussions and communications need to be facilitated for revealing the characteristics of the business processes in question. The resultant models from such exercises can be usually classified as passive models. Passive models are typically static ones that will not change or react in any case (Savén, 2002). Figure 2, provides an example of a static model.

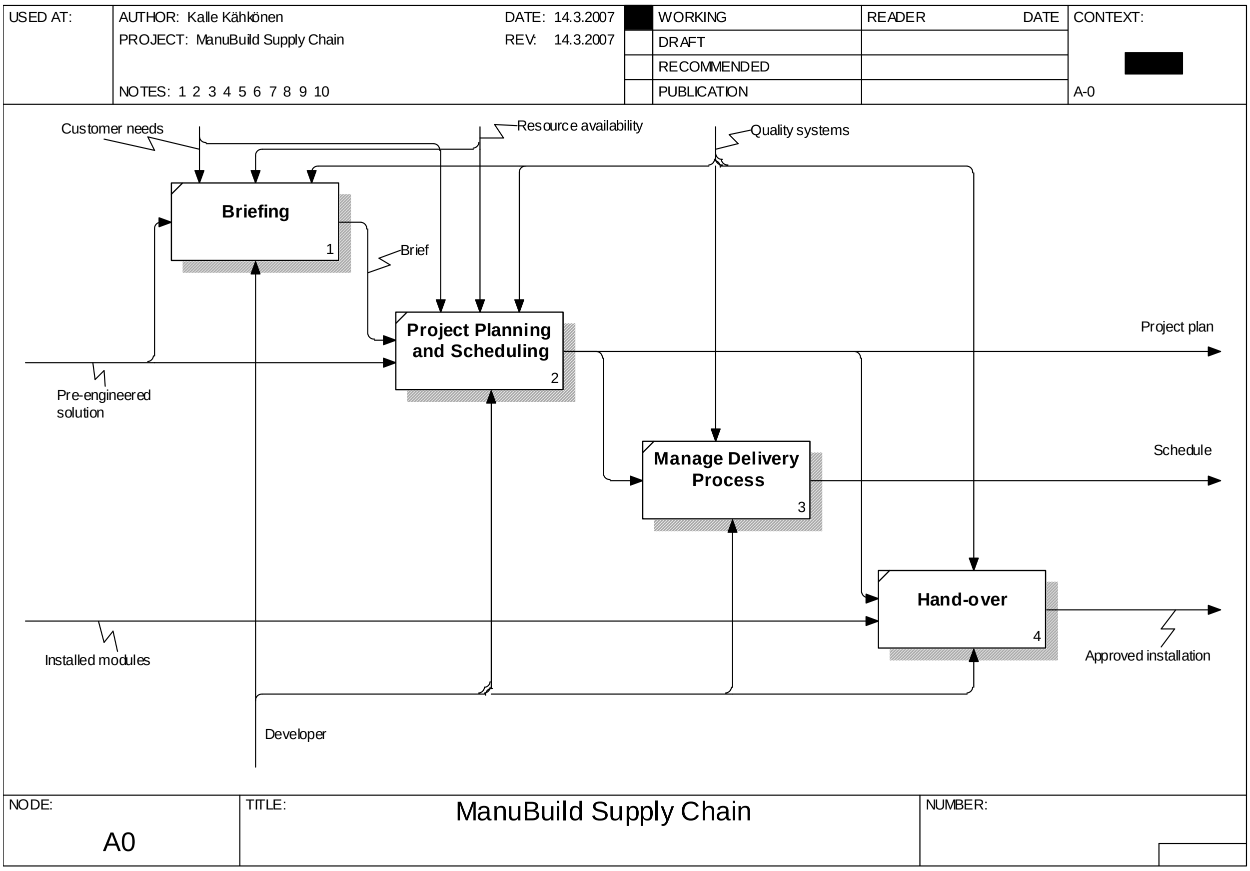

Figure 2. Top level view of static model of a supply chain using IDEF0 method.

An active model on the contrary is a model that acts by itself or reacts when a user interacts with it. In simple terms an active model is like a spreadsheet for exploiting costs and risks with the "what if" factor (Schrage, 2000). IDEF3 and other simulation models can be characterised as active models since they are often capturing the dynamics of surrounding conditions and their relevant factors. In IDEF3 the main modelling elements are called Units Of Behaviour (UOB) that can form a natural way also to model how and where products or processes gain added value during business procedures. In this type of modelling one is often confronted with soft issues such as quality, values, and desires, which all can be conscious or even unconscious needs. This can be called the modelling of experiences that seemingly shall have an increasing role also in terms of business process modelling. This shall advocate the movement towards active models and increasing use of relating modelling methods. Otherwise companies' brave attempts to have "customer oriented business processes" can lack a sound base. In other words, one should avoid the use of process-centred or data-centred modelling methods when targeting models of customer oriented business processes. Rather behaviour-centred modelling approaches need to be applied in these cases.

Learning Objectives:

- Role of stochastic process modelling for the development of standardised services
- Inclusion of stochastic process modelling alongside traditional deterministic process modelling
- Presentation of stochastic modelling in company environments

Approach

Most traditional process modelling methods are deterministic meaning that input data represent fixed and historic singular values. In addition to this it is usually assumed that all different tasks or processes included in the model shall take place unconditionally. This means that e.g. all four tasks included in the process model in figure 2 shall take place in all conditions.

Stochastic models intend to capture the uncertain nature of the actual conditions. Input data for these models can be randomised based on probabilistic distributions. Furthermore the realisation of certain parts of the total process is conditional or uncertain. This situation is illustrated in figure 3 which includes a set of fallback activities that are only carried out under certain conditions. Examples of this kind of conditional activities are rework, waiting and claiming.

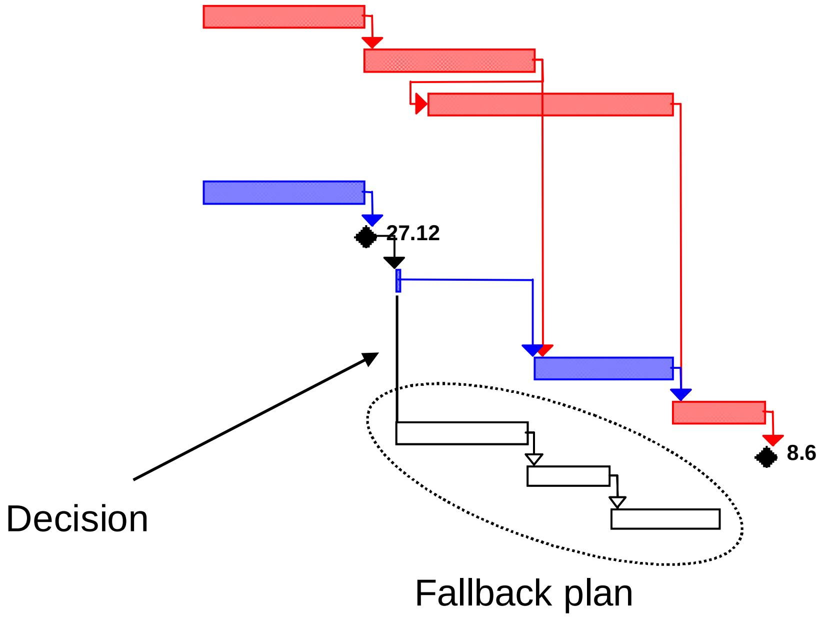

Figure 3. Conditional tasks inside stochastic process models

The main modelling approaches for the inclusion of conditional parts in the process models are:

- *Conditional branching* = the next successor activity is selected in terms of making a decision on the basis of progress - or lack of it - elsewhere in the model. This provides the opportuntiy to have conditional clauses in the model, likewise in live contracts, this enables realisation of certain actions.
- *Probabilistic branching* = the next successor activity is selected in terms of the estimated probability. Usually this is applicable in situations where some historic data is available concerning the statistical performance that can be then used as a basis for probabilistic variables.

The described stochastic model provides a starting point for process simulations that can show the performance of the process under different conditions. The resulting data statistically present the overall spectrum of process performance in different situations; best case, worst case, most probable performance etc. This data can furthermore be used as reference material for defining target values for different performance indicators.

Figure 4 shows a process performance control system based on thinking arising from stochastic modelling. The core of the system is i) coherent objectives set annually by company management and ii) daily site reporting. The performance objectives consist of absolute values for performance attributes, their typical deviations and the expected rates of improvement. Analysis and definition of the industry’s best practice forms the perspective and final goal for the performance objectives (benchmarking). Daily site reporting aims to provide consistent and continuous understanding of a project performance and its improvement. (Daily site reporting obviously requires appropriate education and attitude toward recording daily site data properly.)

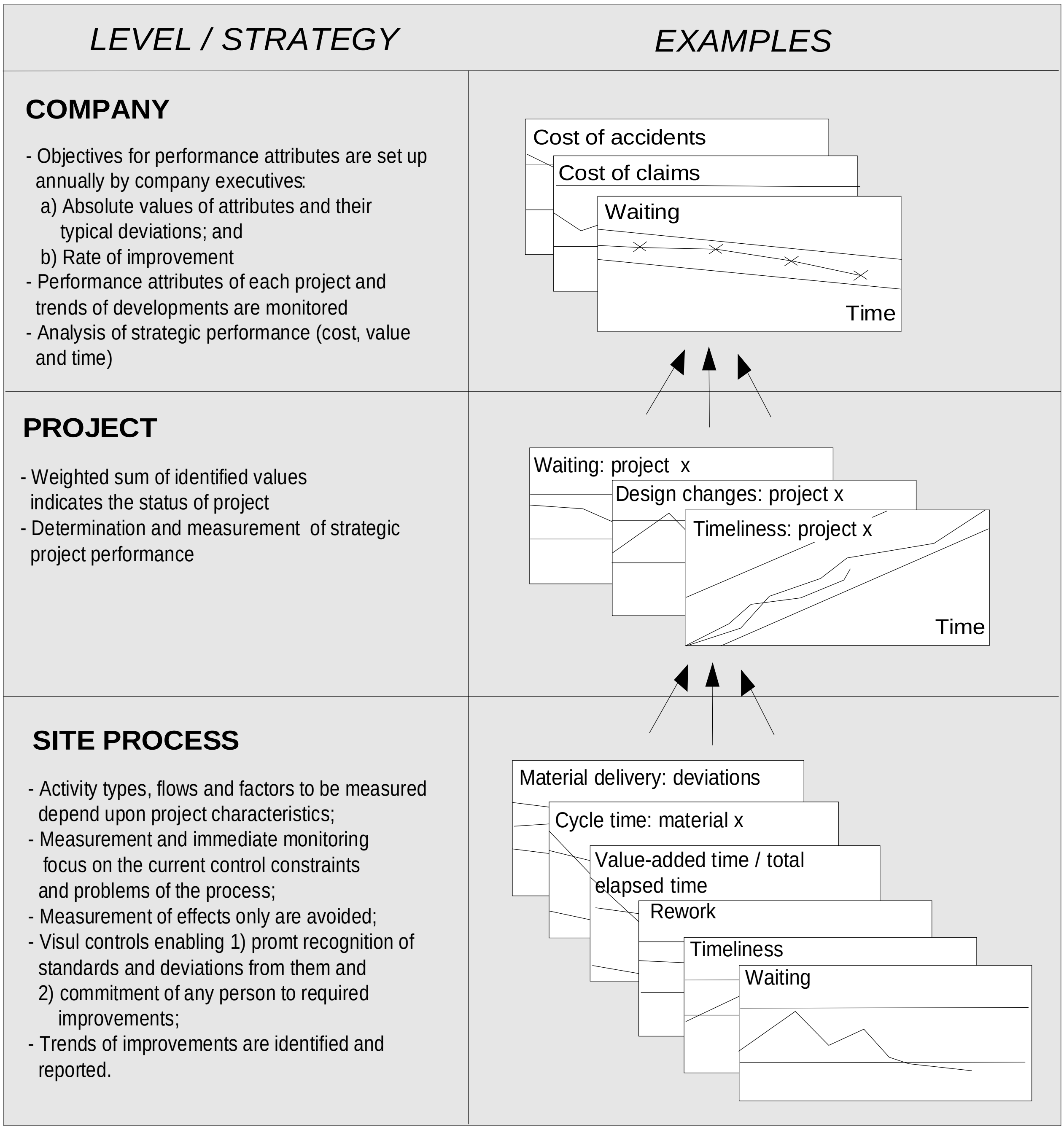

Figure 4. Measurement of project performance based on the new model

One should notice the examples of performance attributes provided in figure 4. The amount of waiting, amount of design changes, ratio value-added time / total elapsed and timeliness (how the times of the project and its parts match that which was planned) are examples of common measures to evaluate the output of a project. These measures can easily reveal the potential problems relating to the performance rather than showing only the technical performance which seems to be case with many conventional methods.

Analysis

Elements of Stochastic Process Models

Stochastic process models are usually considered as comprehensive models where deterministic elements are present along with new stochastic elements. This is the rationale behind the development of the classical GERT (Graphical Evaluation and Review Technique) and causal loop diagramming of System Dynamics (Phillips & Garcia-Diatz, 1981; and Sterman, 2000, respectively). Developers of these famous methods considered the fact that traditional deterministic modelling techniques have limitations that do not meet the typical requirements for modelling the dynamics of complex business operations. The resultant modelling techniques include probabilistic functions that determine the realisation of activities linked to them. These techniques have provided original sources for numerous modifications of the original technique, case studies and a large number of simulation tools (For recent examples refer to Kenzo and Nobuyuki, 2002; www.palisade.com; www.systemdynamics.org). Having all this history behind and all the emerging new results we should be able to identify the most viable elements of stochastic business modelling and name their potential usage.

Usually researchers have put their attention on the limits of earlier development that has resulted in increasingly powerful but also more complex modelling methods and tools. Many rather comprehensive modelling methods together with modelling examples exist. These have been used as reference material for studying the requirements and content of stochastic process modelling that would preferably be widely applicable in company environments. Figure 5 presents the key elements of the stochastic process modelling that have resulted from this study.

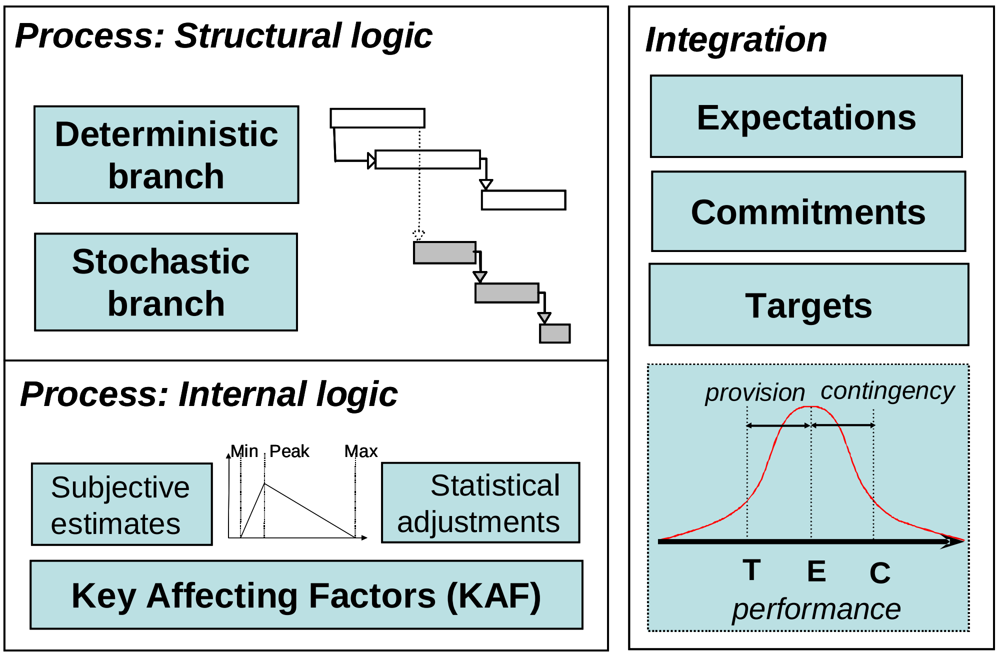

Figure 5.Key elements of stochastic process models for business operations

The key elements and their related requirements are:

1. *Structural logic* is composed of i) process objects including deterministic part and stochastic part, and ii) process objects (e.g. activities, tasks) on timeline. It is important to understand stochastic modelling as an extension of deterministic models. Whenever uncertainly plays an important role regarding the realisation of a key task then one should turn attention towards the stochastic branching of this part of the process. The importance of the presentation of a process on a timeline should not be ignored. Schedules, and particularly bar charts/Gantt charts, are perhaps the most effective way to communicate and effectively understand the structure of processes or complete projects.

   Requirement: *Exotic solution that is far away from other frequently used and well-known modelling methods/techniques should be avoided.*

2. *Internal logic* is composed of i) Key Affecting Factors (KAF), and ii) Estimating methodology. KAFs are factors that explain the behaviour of stochastic objects. Estimating methodology is based on subjective estimates, i.e. experts' judgements. The target is to have consistent estimates in the terms of the amount of information available and the level of detail of the estimates. The credibility of estimates highly depends upon the balance of the level of information available/missing and the level of detail of the estimates.

   Requirement: *The level of knowing or understanding the content and details of processes can vary greatly from one situation to another. For having plausible results the estimates need to match with this phenomenon*.

3. *Integration* is addressing the overall applicability by linking the main results of stochastic process models to corresponding business and managerial logic. This is achieved by three concepts:

   i) Expectations are best estimates on what should happen on average,

   ii) Commitments are to be decided and show the level of performance present in contracts, and

   iii) Targets are internal objectives for stretching people towards higher performance and additional benefits.

   They are used for presenting the key figures from the quantitative analyses.

   Requirement: *Separate solutions from management decision making and daily management need to be avoided.*

Let us now explore these key elements of stochastic process modelling through three case studies.

Case Study 1: Structuring the Logic of a Model

A stochastic process modelling case study has been completed where a building element system delivery process was modelled. The motivation of modelling was to build a reference model in a situation where the company is starting to use 3D modelling technology as a key tool in their product design operations. The modelling study was completed using Microsoft Project and @Risk for Project Professional software packages. The first software is a well-known tool for project management and for preparing models of projects for this purpose. The second software is an add-on tool for the first software for providing a stochastic dimension for a standard project management package. It can be used for demonstrating the appearance of the key stochastic modelling elements presented earlier.

From a research perspective the main interest in the case study were the lessons learned from presenting stochastic objects alongside deterministic ones. Figure 6 presents the resultant model in the form of standard bar chart where the stochastic branches are separated from the deterministic ones using rectangles. It was found that the need for having stochastic branches appear usually together with certain key activities, for example after reception of goods there is a chance for unexpected claims and waiting.

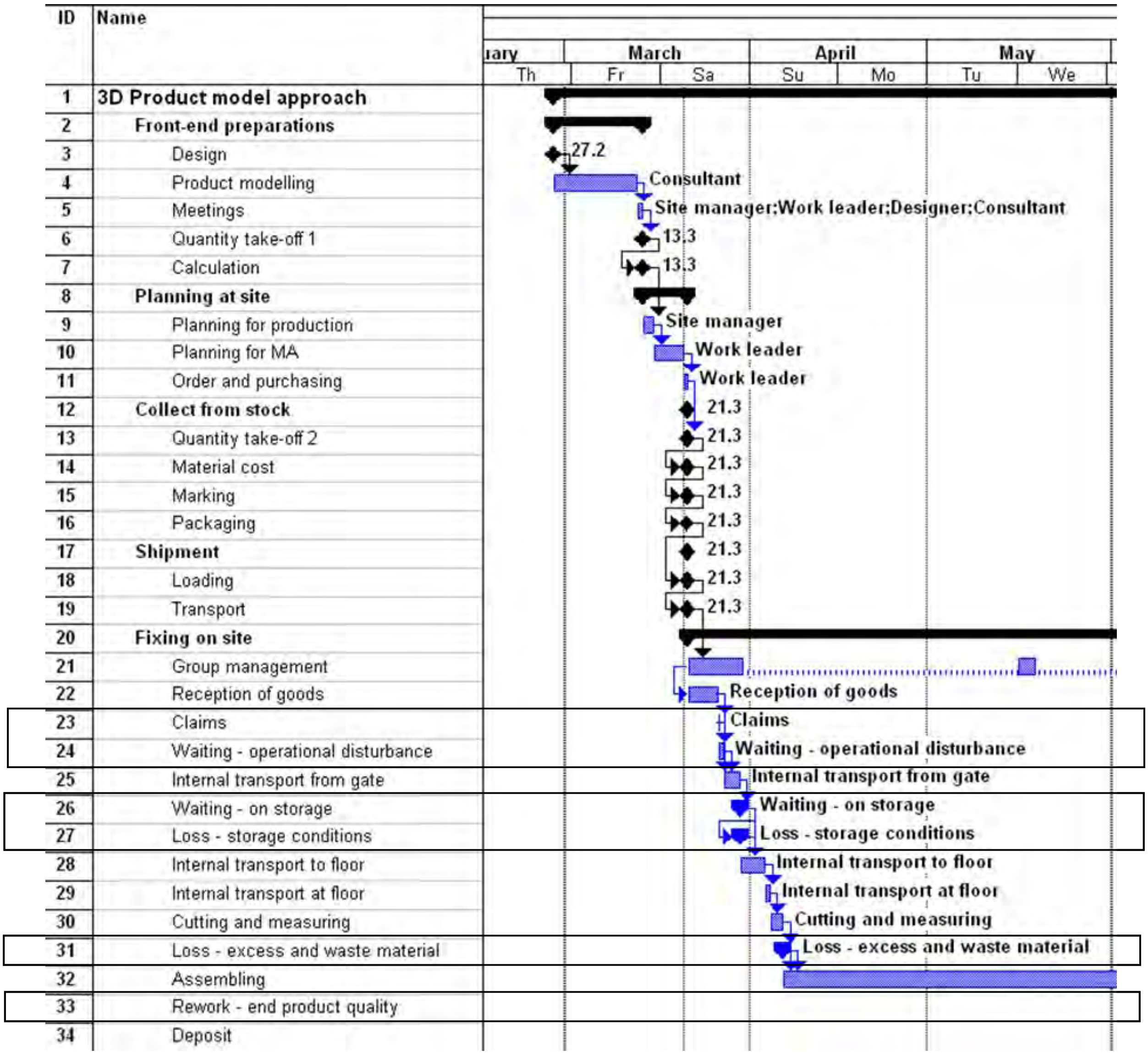

Figure 6. Case study where the stochastic processes modelling approach was applied. (Stochastic branches are shown with rectangles in the model)

The resultant model can be considered as an active model capable to explain the behavioural aspects and dynamics of the processes in question. The critical factors explaining the overall performance of the project or the local performance of certain activities variances can be identified through a series of simulations as shown in figure 7.

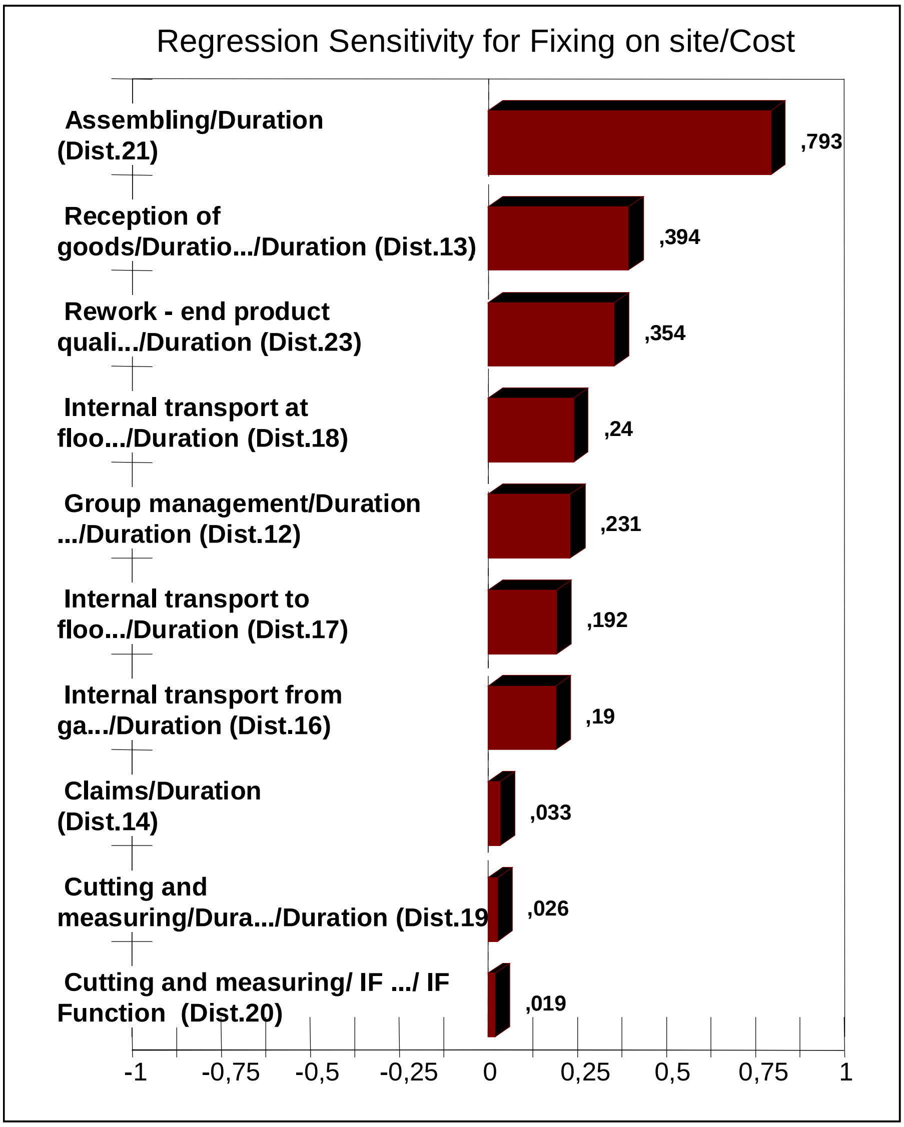

Figure 7. Results from simulations showing the relative contributions of different factors for the cost variance of site installation.

Case Study 2: Identification and Modelling of Factors Impeding Process Performance

Identification of KAFs i.e. Key Affecting Factors is an important task to have a proper background for preparing subjective estimates. Exploration of potential KAFs can easily result in a wide variety of factors from which one need would need to extract the most important ones. The following case study demonstrates the study over key affecting factors.

Influence diagramming technique is a communicative method for graphically describing relations between various risk factors and consequences. Constructing decision trees or other tree structures is an analogous methodology for depicting relations between risk factors and consequences.

This case study demonstrates the procedures and outcomes of risk identification and analysis in a major industrial equipment supplier firm. This study was completed in 2003 where the main objective was to understand the world of risks and opportunities in the main operations of this company (Figure 8).

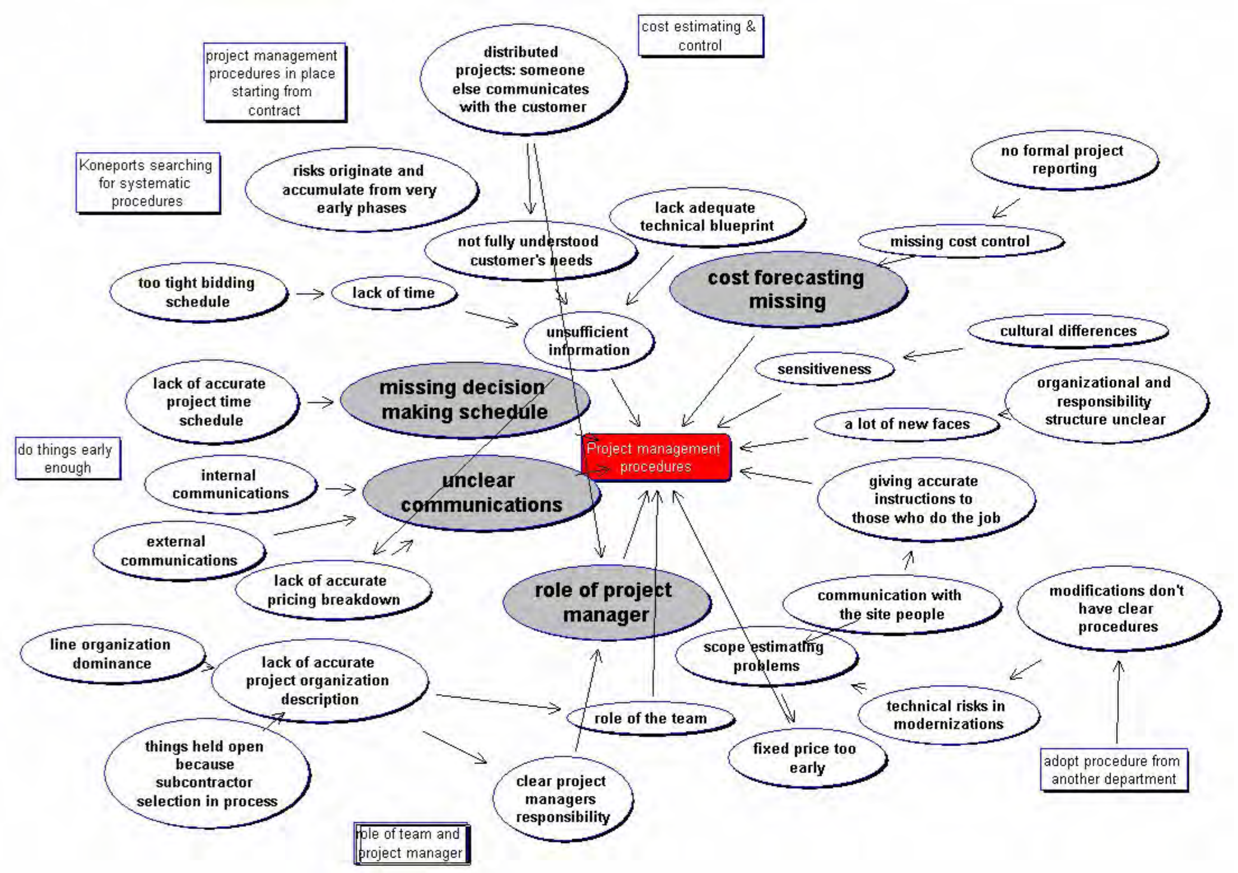

Figure 8. The identified cause-effect network around the risk category "Project management procedures". (Four key affecting factors are the highlighted ovals.)

The study comprised:

1. Pre-workshop survey for gathering information on risks, opportunities and risk management activities. For completing the survey a questionnaire was distributed to the participants of a risk management workshop. The questionnaire was addressing *unfavourable* events with certain possibilities of occurring, then, based on the responder's experience about the firm's projects or the business related to projects, which of these could cause problems to project processes. Having this as a starting point the responders identified the five (5) most important risks. A corresponding questionnaire was used for gathering information on opportunities (potential positive events).

2. Survey data analysis. The survey data was categorised which resulted in 10 risk and opportunity categories. Risk and opportunity categories appeared to be similar despite of some minor differences. In this exercise the participants were mainly thinking opportunities in the terms of risks they had already identified. This is an example of how human thinking can easily be anchored to previous findings or ideas. For opening a new thinking avenue a new stimulating question or issue dimension need to be presented. The identified, risk and opportunity categories were:

   1. Project management procedures
   2. Contractual risks
   3. Accidents
   4. Project planning procedures
   5. Counterparty risks
   6. Project bidding procedures (+ project marketing)
   7. Business and client risks
   8. Human and organizational issues
   9. "Unproven technology, Technical performance“
   10. Local conditions (+ global market environment)

3. Workshop. A workshop followed the described survey where the causes behind each identified category were studied. This resulted in cause-effect networks from which it was possible to identify the main root causes of problems. Reasons for classifying a certain node as a root cause were
   - Centre of many incoming and outgoing links
   - Close presence (1 or 2 steps) to the actual risk with an obvious importance

   A simple but an important technique is to ask the question "*Why?*" to get beyond any risk towards root causes.

Case Study 3: Subjective Estimates

Subjective estimates refer here to the fact that the impacts of KAFs must be estimated by knowledgeable individuals. Deriving subjective estimates means that estimates are prepared by encoding individuals' experiences and beliefs. The use of the judgement of knowledgeable experts does not mean that those estimates would necessarily be unreliable, but the subjective estimate approach of expressing risk in this context rather refers to the fact that the best possible source of information - i.e. knowledgeable people - is used. Although the best possible information source is used while using subjective estimates for encoding experts' beliefs, both the goodness of estimates and biases in estimates become important issues to consider (Kähkönen & al, 2006).

The goodness of estimates and biases can naturally be seen as objects for improvement but another different aspect is to focus on understanding and communicating the overall quality of the estimates. In practice, background variables, their formulas and dependencies over objects in the model can easily become invisible and thereby the overall credibility of the model can decrease dramatically. Graphical cause-effect networks (as shown earlier in figure 8) have proved to be a working solution for recording and communicating the total picture of different aspects constituting the internal logic of a model.

When preparing a stochastic process model one usually faces the need to make a choice of a probabilistic distribution. In the case studies carried out, triangular distribution has proven to be a distribution approximation that usually met in a sufficient manner different modelling needs with the absence of real data.

Results and Business Impacts

Key Findings

This chapter has presented stochastic business process modelling as an expansion to more traditional deterministic process modelling. Deterministic modelling can be appropriately used for portraying the usual body of the process in question. However, after that the model can be equipped with stochastic branches that are realised only conditionally when signals from the performance are demanding that. This can be seen as a key ingredient for performance monitoring and improvement with open building manufacturing settings. By these features the final model can reflect the uncertainty in live situations and resultant variances.

Stochastic process modelling can be effectively used for a deeper understanding of the behavioural aspects inside processes, such as waiting, rework and losses that are increasingly considered as key indicators to be managed. Stochastic process models provide a basis to model and understand the content of these aspects in an explicit manner.

Key elements of stochastic process models for business operations have been presented in this chapter. The main target is to define the content of stochastic process modelling in a way that is applicable in different company environments and in particular in inter-company project settings. The requirements of the solution that were used as a starting point demonstrate the practical needs company people have when they are trying to expand process modelling towards a probabilistic world. Perhaps the most important requirements are the integration and communicativeness of the model. The resultant key elements present in a compact way the main objects to be taken into account when stochastic modelling is applied in companies.

Business Impacts

Standardised services usually are of a repetitive nature. This is particularly the case when dealing with structured manufacturing like process as opposed to those of craft-based production. Through stochastic process modelling, companies can have explicit access to factors, such as waiting, rework and losses, which include the biggest potential for process improvements.

Conclusions

Stochastic modelling has been presented in this chapter as a means to model standardised services within settings such as open building manufacturing. The key elements of stochastic process models presented in this chapter provide a framework that can be used as a starting point when companies commence modelling exercises that include stochastic parts.

It has been demonstrated through three case studies how the behavioural aspects of business processes can be modelled and understood in an improved manned with the aid of stochastic process modelling. Value adding can also be considered as a deep behavioural characteristic of business processes. This is a potential topic for further research.

Key Lessons Learned:

- Standardised services that have a typically repetitive nature are good targets for stochastic business process modelling.
- Stochastic modelling should not be seen as an exotic and isolated modelling approach that has only relevance in academia. It has all potential to be used alongside traditional business process models and it can provide very useful additional understanding for improving competitiveness
- Stochastic process modelling, can be successfully applied in understanding service processes within open building manufacturing settings

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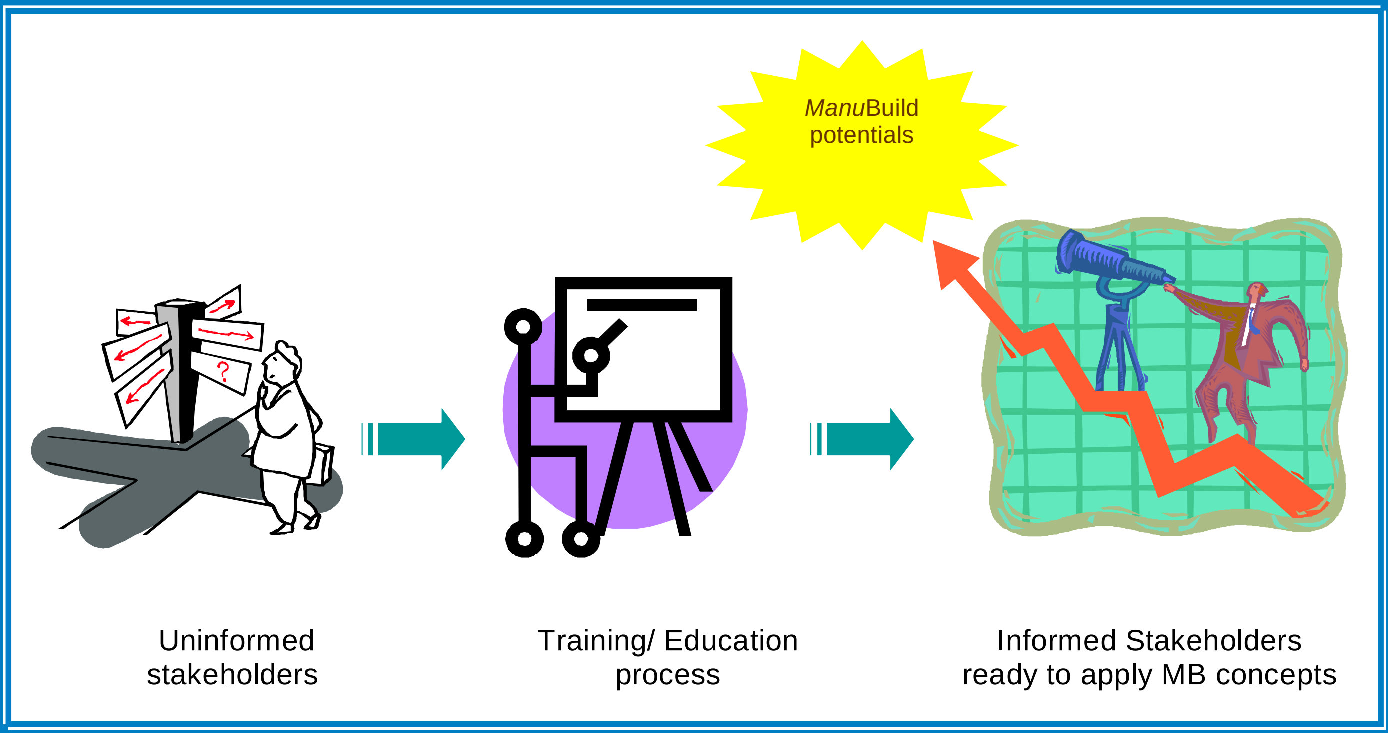
11

Training and Education for Open Building Manufacturing - Closing the Skills Gap Paradigm

Mustafa Alshawi, Jack Goulding & Wafaa Nadim



Training and Education for Open Building Manufacturing

Closing the Skills Gap Paradigm

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Abstract

The construction industry is constantly confronted with challenges, and opportunities in new markets. These are often passed over, predominantly because of the lack of relevant skills. Similarly, 'Open Building Manufacturing' (ManuBuild), a radical paradigm shift from the current "craft and resource based construction" towards "knowledge and value driven industry" opens up new high quality job opportunities (which will require new skills). However, these opportunities will not be able to be fully leveraged if these skills are not addressed.

The operationalisation of ManuBuild will require an extensive transfer of knowledge, skills and technology, in order to reorient a change in business process, organisational structures, roles and responsibilities, culture, and IT. Hence, 'Training and Education' is the cogent backbone for the realisation of the ManuBuild concept. However, 'traditional' training and education models currently in use are often criticised for the lack of coordination between the industrial needs and the actual training/ education delivered. This dichotomy is often characterised as the 'skills gap'. In this context, for ManuBuild training and education not to get 'trapped' in this 'skills gap' paradigm, industry needs and expectations have to be addressed through new pedagogical approaches (to ensure learning outcomes are matched to learning styles). This will be achieved through innovative 'package' delivery of 'practice-based' industrial training; blended with university education, a teaching factory, and through the use of a construction site simulator. This structured will involve the distillation of a comprehensive literature review, the identification of stakeholders' requirements, pedagogical teaching and learning methodologies, learning styles, and instructional design methodologies.

The ManuBuild Training Concept is based on a proactive practice-based training and education approach to adapt employee qualifications to job requirements - thereby enhancing industry's capability to compete. This will be pursued under the umbrella of 'Workforce Development' and 'Educational Development', and subsequently endorsed by relevant training, education, and professional bodies.

Keywords: construction, education, simulation, training, teaching factory

Background

Industrial Context

The construction sector is one of the largest industrial employers in the European Union (EU) [circa 2.3 million enterprises] with a total of 11.8 million employed. Jobs held by 26 million workers in the EU are highly dependent (directly or indirectly) on construction. However, 96% of construction enterprises in Europe are small to medium enterprises (SME's), with fewer than 20 operatives. In this context, the construction sector is of significant importance to the EU with a gross domestic product (GDP) contribution of 9.8% and a European employment rate of 7.1% (Business Watch, 2005). Notwithstanding this importance, the construction industry is constantly facing changes and challenges which need to be addressed in order to remain competitive (Latham, 1994; Egan, 1998). It is thus argued that firms often pass up opportunities in new markets because of the lack of relevant skills. This shortage of skilled people is partly attributed to demographics, and partly to the reduced attractiveness of industrial activities, when compared to other activities such as finance and other deviated services (ECTP, 2005). In this regard, the construction industry tends to lag behind other industries in taking advantage of new technologies and innovative practices. Furthermore, by sacrificing innovation it is argued that improvements in safety, cost-effectiveness, quality of life, competitiveness and productivity etc. are most likely to be compromised.

From a research perspective, many EU research projects have been acknowledged for producing and achieving high quality results. However, from a dissemination and impact perspective, the adoption of 'proven' and emerging technologies is argued to be questionable. The gap between the different EU research and technological developments (RTD) project results and industry practices has been identified as one of the reasons for the industry's reluctance to embrace and embed new technological solutions into practice (Rezgui and Zarli, 2006), along with issues surrounding the familiarity trap phenomenon (Ahuja and Lampert, 2001), path dependency (Coombs and Hull, 1997), and technology dominance (Utterback, 1994).

Problem

The *Manu*Build concept will require an extensive transfer of knowledge, skills and technology to clients, suppliers SME's etc. This will necessitate: a change in the whole business process to improve performance; the creation of new organisational structures, roles and responsibilities, measurements and incentives; a change in how information and communication technology (ICT) are used and leveraged; a change in the way training is conducted and delivered; and a change in which skills and shared values are procured and managed. This mandate will therefore require considerable investment from a number of key stakeholders, not least senior management support and commitment.

The aforementioned changes will place demands in several areas, not least the implementation of effective training concepts to broaden the impact of *Manu*Build to the whole industry (by addressing and fulfilling the needs of the different stakeholders). Hence, *Manu*Build training and education will need to equip students and professionals with timely and relevant skills to successfully apply the *Manu*Build concept. Consequently, training and education will help to ameliorate the skills gap paradigm by leveraging stakeholders' needs and expectations, thus creating a 'win-win' working relationship. In this context, students/professionals would acquire the necessary skills for a successful and rewarding career; and employers would have the opportunity to select from a wide range of skilled workers ready to work. In this regard, training and education will be seen as an investment which prepares organisations not only to adapt to the changing environment, but also to remain competitive.

From an education and training perspective, ‘experience-based' or 'experiential-based' training/learning can have the dual benefit of appealing to the adult learner's experience base, as well as increasing the likelihood of securing performance change through training. Hence, structured on the job training (OJT) has emerged as a core method to capitalise more systematically on the ‘value’ of experiential learning as a tool to develop new employees more effectively through the use of experienced co-workers (Laird, 2003). However, OJT may not always be the practical answer for a number of reasons, most notably being too expensive, and often limited by the unavailability of training context (Clarke and Wall, 1998).

*Manu*Build training and education will therefore be required to satisfy industry needs and expectations; which by default, will need to be delivered in an innovative way to suit the different learning styles, whilst embracing cultural and disciplinary diversity.

Learning Objectives:

- The need for training
- Experiential training and education approach/initiatives
- The different learning styles
- *Manu*Build training and education concept
- Crucial questions to action *Manu*Build Training and Education

Approach

This chapter covers the development of a 'Training Concept' for delivering practice-based training and education in 'Open Building Manufacturing' to the EU construction industry. This training and education will embrace cultural diversity and discipline disparity.

A structured methodology will be used to tailor the training and education initiatives to the *Manu*Build concept. This will involve the distillation of a comprehensive literature review, together with the investigation of stakeholders' requirements, pedagogical teaching and learning methodologies, and instructional design methodologies. Furthermore, learning styles and interfacing nuances associated with culture and discipline disparity will be incorporated.

This concept will be presented to all relevant industrial practitioners and domain experts for validation vis-à-vis content, level, relevance etc.

Analysis

The Need for Training

Training can be considered an integral part of organisational learning and change. In this context, training often embraces adult learning and development, experiential learning, and cognitive abilities (Lingham *et al*., 2006); and it can also be considered as a management tool and instrument for addressing skill deficiencies. The primary rationale for training is to adapt employee qualifications to job requirements (Krogt and Warmerdam, 1997), but it can also act as a conduit for linking organisational strategies and goals (Andrews, 1987; Porter, 1985; Sleezer, 1993). These procedures should however be integrated with the long-term needs of the company (Kumaraswamy, 1997) in order to leverage success.

Within the construction industry, training has often been linked to improved levels of productivity, but more fundamentally, it can also be used to address critical weaknesses, improve the transfer of skills and knowledge, and help develop a common culture within the organisation. Training can also help facilitate and provide a change in organisational behaviour, which can often enhance an organisation's capability to survive (Kessels and Harrison, 1998). In this context, Kelliher and Henderson (2006) made a distinction between the dynamics of learning within a large organisation with sufficient resources and industry 'power' to facilitate emergent learning; and small firms with scarce resources that operate under severe time, financial and expertise constraints. Hence, for small firms, learning new capabilities is argued to be problematic because of these constraints. However, contextual factors are claimed to force smaller firms to more rapidly adopt new learning in order to rapidly meet dynamic environmental demands (as they tend to be more agile in responding to the market). In this context, the process of providing training should be seen as a continuous process (Gilgeous, 1997), the investment of which prepares organisations to adapt to the changing business environment (O'Connell, 1996). Organisations should therefore aim to balance a range of skills and competence to meet business goals (Mintzberg and Quinn, 1991).

From a semantics perspective, the term "competence" is used to define a particular level of skill, knowledge or observable characteristic (Prahalad and Hamel, 1990), whereas skills are an amalgamation of human expertise and facilities, blended together by the organisation, processes, systems and culture (Klein *et al*, 1998). Skill and competence levels are therefore crucial for delivering organisational success (Drejer, 1996). Furthermore, the development of competence within organisations can often provide access to a variety of new markets, and also help to contribute significantly to the overall customer experience. Thus, competence can be categorised into four distinct categories: technical, business, personal and intellectual competence. The type and level of business and technical competence can however vary across organisational levels. For example, executives often tend to have high levels of business competence, but conversely, have low level of technical competence; whilst at the operational level, operatives are required to possess high levels of technical competence, but conversely, tend to have low levels of business competence (see Figure 1).

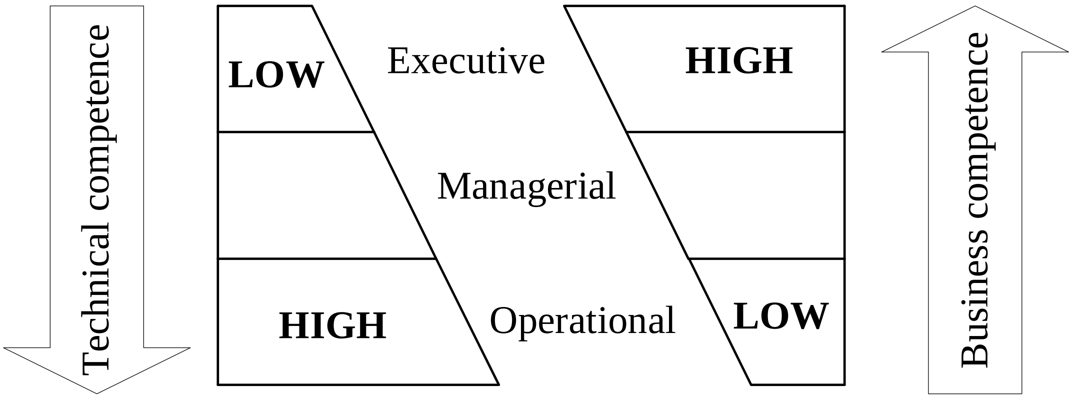

Figure 1: Relationship of Technical and Business Competence to Personnel
(Adapted from Goulding and Alshawi, 2002)

Training and Education

From a training and education perspective, it is important to understand the differences and similarities between Training and Education (Buckley and Caple, 2004), before exploring the means by which these can be tailored to support the *Manu*Build concept.

The 'Glossary of Terms' (Department of Employment, 1978), argue that there is no clear 'dividing line' between education and training – reiterating the importance of integrating both concepts. However, Buckley and Caple (2004) highlight some distinctions between training and education in respect of: process, orientation method, content, and the degree of precision involved. In terms of precision, training usually involves the acquisition of behaviours, facts, ideas, etc; and it is argued that training is more job-oriented than person-oriented. Education, on the other hand, is claimed to be person-oriented, and its objectives are less amenable to precise definition. The distinction between training and education was also expressed in terms of process and effect (see Figure 2); where training was seen as predominantly mechanistic and uniform, whereas education tends was more organic and variable (Buckley and Caple, 20004). From a timescale perspective, clear distinctions can be made between education and training vis-à-vis immediacy of effect. For example, the process of training tends to provide observable short-term outcomes; whereas, educational outcomes tend to manifest over the long-term (Buckley and Caple, 2004).

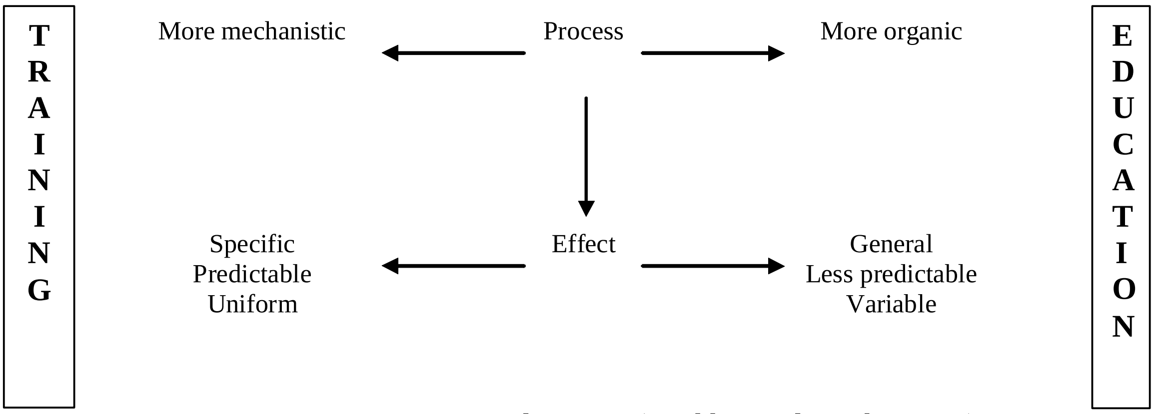

Figure 2: Training vs. Education (Buckley and Caple, 2004)

A number of factors have been highlighted which tend to drive enterprises to train/educate employees (Smith and Hayton, 1999), these include:

- Improvement of employee performance
- Improvement of the adaptability and flexibility of the workforce
- Investment in new technologies
- The adoption of new work practices
- Changes in business strategy
- Increased competition
- To leverage innovation opportunities

The primary key of engaging firms in training and education activities lies in the identification of the most pressing needs, and the development of an appropriate training/education programme to address those needs (Sargeant, 1996). Furthermore, to enable the training programme to be successful, it is argued that firms need to: link their training to their key strategies; redefine career paths; map out a plan for continuous learning; and use interactive learning as a means of employee engagement. In this context, educational establishments need therefore to tailor the specific content of their provision to meet the needs of employers through a set of tangible (immediate) advantages - the remit of which requires close collaboration between the academic community, industry and professional institutions (Tener, 1996; NWDA, 2004) to indoctrinate change by:

- understanding and communicating better with each other
- working closer together to deliver courses that are more relevant to industry's needs
- creating higher education (HE) programmes that excite and motivate participants
- allow participants to experience multidisciplinary teamwork

In this regard, 'education' is required to give students exposure to more than the academic aspects of the construction process. A proactive approach should therefore, be initiated to make education curricula more adaptable to the 'ever-changing' needs of the built environment (Chan *et al.* 2002), thereby embracing the capabilities needed by graduates (Tener, 1996). Furthermore, by taking traditional educational methods and including real-world factors e.g. interaction with industry personnel, access to state of the art of equipment, environmental responsibilities and economic considerations etc., these issues can help students gain valuable experience and insight into future career responsibilities (Foroudastan and Hardymon, 2003).

'Cooperative education' (Asher, 1994) incorporates productive work into the curriculum as a regular and integral element of a higher education to create experience-based education. In this same context, McHardy and Alan (2000) proposed 'micro-worlds' or 'simu-worlds' advocated by Keys *et al.*, (1996), to give students an experiential ‘taste’ of how practitioners learn; where students are encouraged to ‘feel’ risk taking (Pedler, 1983), learning through experimentation without the ‘do-or-die’ consequences often encountered in the real life environment. In addition, 'micro-worlds' (Keys *et al*, 1996) are argued to compress time and space to 'microcosms of real world settings', where complex situations can be simulated (Senge, 1992), and which can also bring about changes in thinking to adapt to the market place imperatives using the 'strategic discomfort' concept (Vandermerwe, 1995).

ManuBuild Training and Education Concept

The appreciation and acceptance by professionals of 'training and education' to enhance construction practices (in general) has always been faced with difficulties for a number of reasons. These include (but are not limited to): the culture of the organisation, relevance of training/education to the business, return on investment (ROI), technology used, etc.

*Manu*Build 'training and education', has the added complexity of introducing:

- the new *Manu*Build knowledge
- the benefits and potential of training and education to provide the relevant skills to industry vis-à-vis the adoption of 'Open Building Manufacturing'
- the use of innovative training and education delivery methods

The 'proactive training approach' advocated by Buckley and Caple (2004) is considered a starting point for *Manu*Build training and education. This approach is suitable when introducing new technologies and processes that necessitate the creation of entirely different jobs, as well as the acquisition of an extensive range of new skills. This is often referred to as 'innovation' in the construction practice, rather than 'implementation' or 'improvement' (Hackett, 1997). Hence, for the *Manu*Build training and education approach to be 'appealing' to employers and employees, it will need to be pursued along two major interrelated routes. These can be articulated as: 'Workforce Development' and 'Educational Development' (Harrison, 2005). These two routes will help enable new industry thinking, create a new type of construction professional, and consequently, help take the *Manu*Build concept forward. However, these two routes will need to be endorsed and supported by the relevant institutions and professional bodies for subsequent industry uptake.

During the initial stages of developing the ManuBuild training and education concept, the stakeholders' requirements investigation concluded that different stakeholders were somewhat sceptical about the *Manu*Build concept and subsequent potential to meet their expectations. Hence, ManuBuild training and education will need to 'train' and 'educate' those stakeholders to help them better appreciate and understand the potential of training and education to deliver the relevant skills needed to adopt the *Manu*Build concept (see Figure 3).

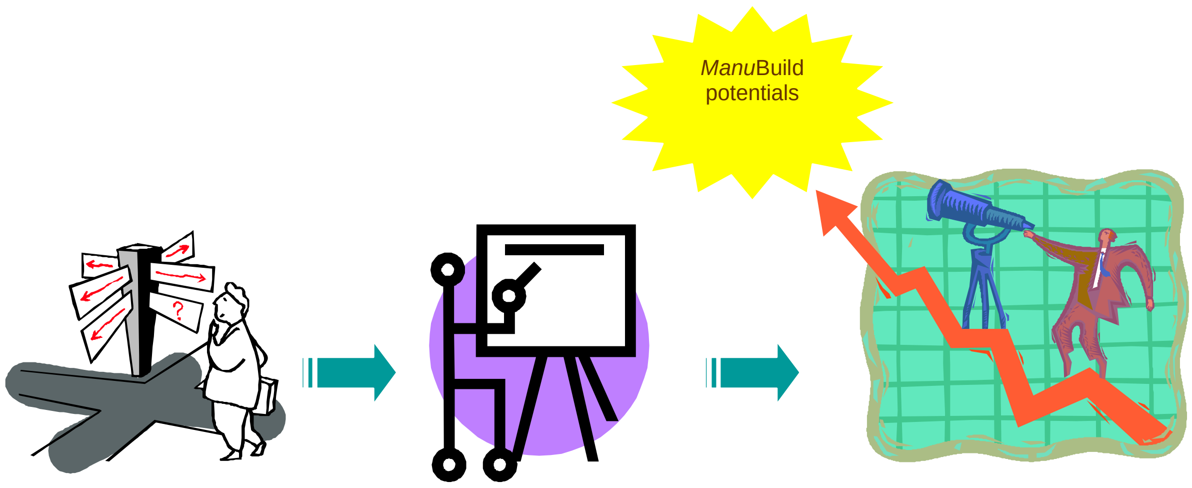

Figure 3: The Training and Education Problem

From a programme perspective, educational programmes that include experiential learning are claimed to be preferred by construction industry employers (Fester and Haupt, 2004), as experiential learning is argued to have been 'long' recognised as being one of the most effective means of acquiring professional education and training (Davies, 2000; Hicks, 1996). However, in the context of learning, Kolb (1984) is widely acknowledged for defining learning as the process where knowledge is created through the transformation of experience (Figure 4); whereas, Laird (2003) explains that learning is more about the interaction between content and experience rather than the acquisition or transmission of content. From this juxtaposition, other authors e.g. Honey and Mumford (1986) and Felder and Silverman (1988) expanded upon Kolb's model to embrace learning styles and student preferences respectively.

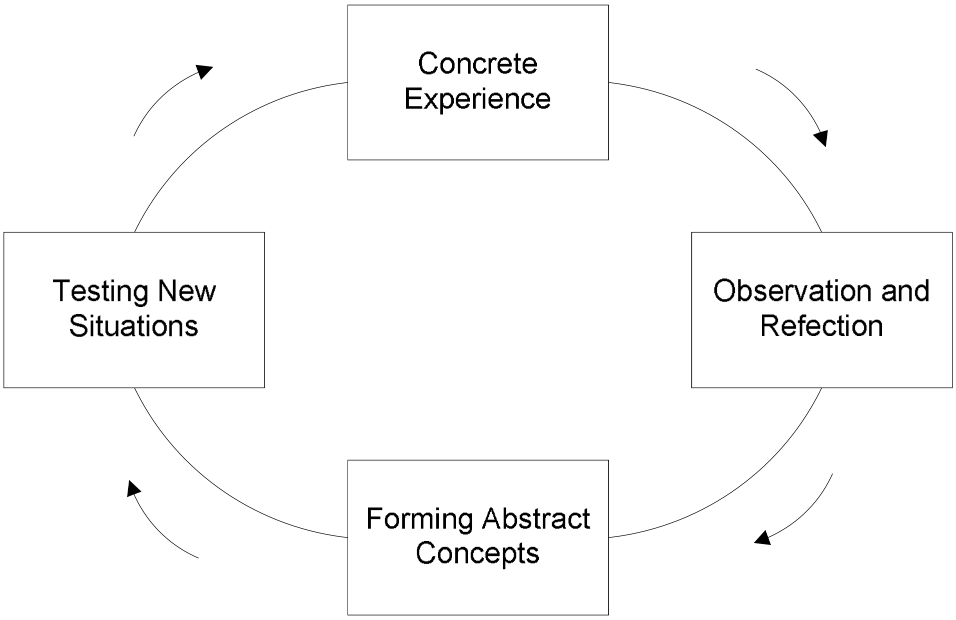

Figure 4: Experiential Learning (Kolb, 1984)

*Manu*Build Training and Education will specifically target professionals and postgraduate students, and in this context, there is a direct need to embrace 'adult learning' (Knowles, 1980) as a precursor. Kruse and Keil (2000) summarised Knowles' theories on adult learning through 'Andragogy', the core concepts of which are as follows:

- Adults need to know why they are learning something and should be told how it affects them directly
- Adults have a repository of lifetime experiences that should be 'tapped'
- Adults use a hands-on problem-solving approach to learning
- Adults want to apply knowledge and skills immediately; retention decreases if the learning is applied only at some future point in time.

In the same context, Laird (2003) emphasised the importance of transferring learning into job performance; and Baldwin and Ford (1988) argued that for any 'transfer' to occur, learned behaviour must be generalised to the job context, and maintained over a period of time on the job. This was reinforced by Lim and Johnson (2002), whose work identified prime factors which supported the transfer of learning i.e. to include the opportunity to use the new learning on the job (and the post-training work environment of the trainee). However, learning can not accommodate a "one-size-fits-all" policy (Clay and Mindrum, 2003); therefore, different learning styles will need to be accommodated for training and education (contextually). From this premise, the following three different categories of learners were described by Kruse and Keil (2000):

Auditory learners	comprehend and remember material most effectively when they hear it;
Visual learners	comprehend and remember material most effectively when they see it;
Kinaesthetic learners	comprehend and remember material most when they physically interact with it.

The Integrated Learning Approach

Researchers into experiential learning often quote the Chinese proverb "*I hear and I forget, I see and I remember, I do and I understand*" to emphasise that learning is more effective through 'doing' rather than through 'hearing' or 'watching' (Snee, 1993; Rosenthal, 1995; Koo, 1999). According to Roussou (2004), this axiom was endorsed by Amthor (1992), noting that people retain 20% of what they hear, 40% about what they hear and see, and 75% of what they interact with (hear, see and do). Drawing on Amthor (1992), and the different learning styles (Kruse and Keil, 2000), an integrated learning approach will be adopted for the *Manu*Build training and education provision in order to link 'theory' with 'visualisation' and 'practice'.

In conclusion, for the *Manu*Build training and education provision to satisfy the different learning styles and subsequently add a new dimension to practice-based experiential training and education, an integrated approach for learning will be used to leverage and synthesise different delivery methods and approaches vis-à-vis the: training courses, university education, teaching factory, and construction site simulator. The key element in this concept is the combination of a robust education curriculum (pedagogy) supported by coordinated opportunities for application and hands-on experience - thereby eliminating the traditional boundaries between academia and industrial practice (Lamancusa *et al.*, 1995).

Results and Business Impacts

Key Findings

*Manu*Build training and education is highly dependent upon the proactive practice-based/experiential training concept that underpins the delivery mechanisms: training courses, university education, teaching factory and the construction site simulator. The training concept is informed by the stakeholders' requirements as well as the main research and technological developments (RTD) of *Manu*Build: the building concept, the value driven business processes, ambient manufacturing, and ICT support. Furthermore, for training and education to be successful, there is a need for a 'promotion' tool which demonstrates the training areas/needs that will be addressed through the various *Manu*Build delivery techniques. This tool is the 'training demonstrator'. The training demonstrator will be used to showcase *Manu*Build training and education to stakeholders (public, industry, and academia), thereby promoting the new training and education concept (see Figure 5).

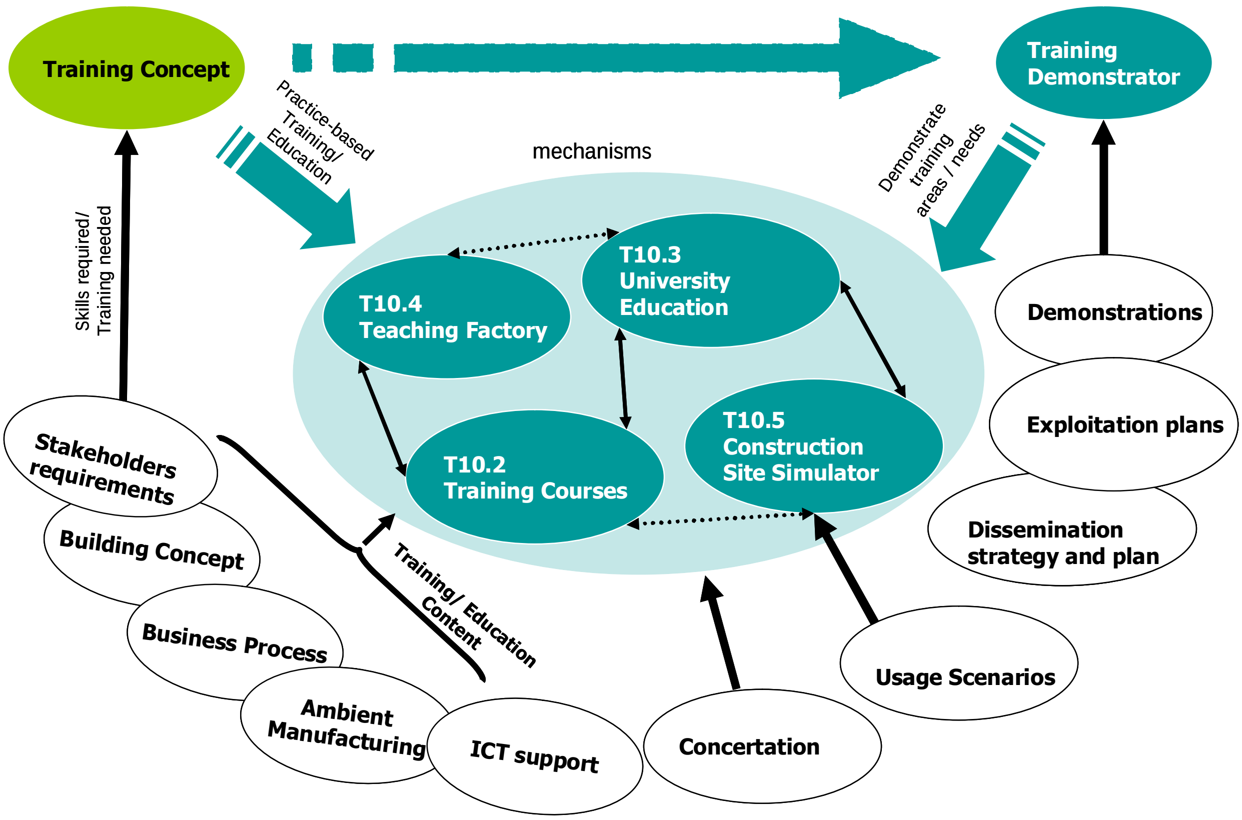

Figure 5: Main RTD and Training Work-package Interrelationship

ManuBuild Training and Education Content Development

In order to identify the content material for the *Manu*Build training and education concept; it is necessary to:

- link/map the stakeholders requirements with/against the *Manu*Build main RTD, to demonstrate the relevance of the *ManuBuild* concept
- link/map the *Manu*Build performance improvements with the main RTD, to demonstrate the *Manu*Build potential and relevance to construction practice

The multi-cultural and multi-disciplinary aspects of the training concept and the importance of projecting and linking these with *Manu*Build performance improvements and impact (to satisfy the relevance of *Manu*Build concept) can be seen in Figure 6. This holistic relationship will help facilitate better construction practices in order to fulfil industry needs, as well as ambivalent stakeholders regarding their requirements and expectations.

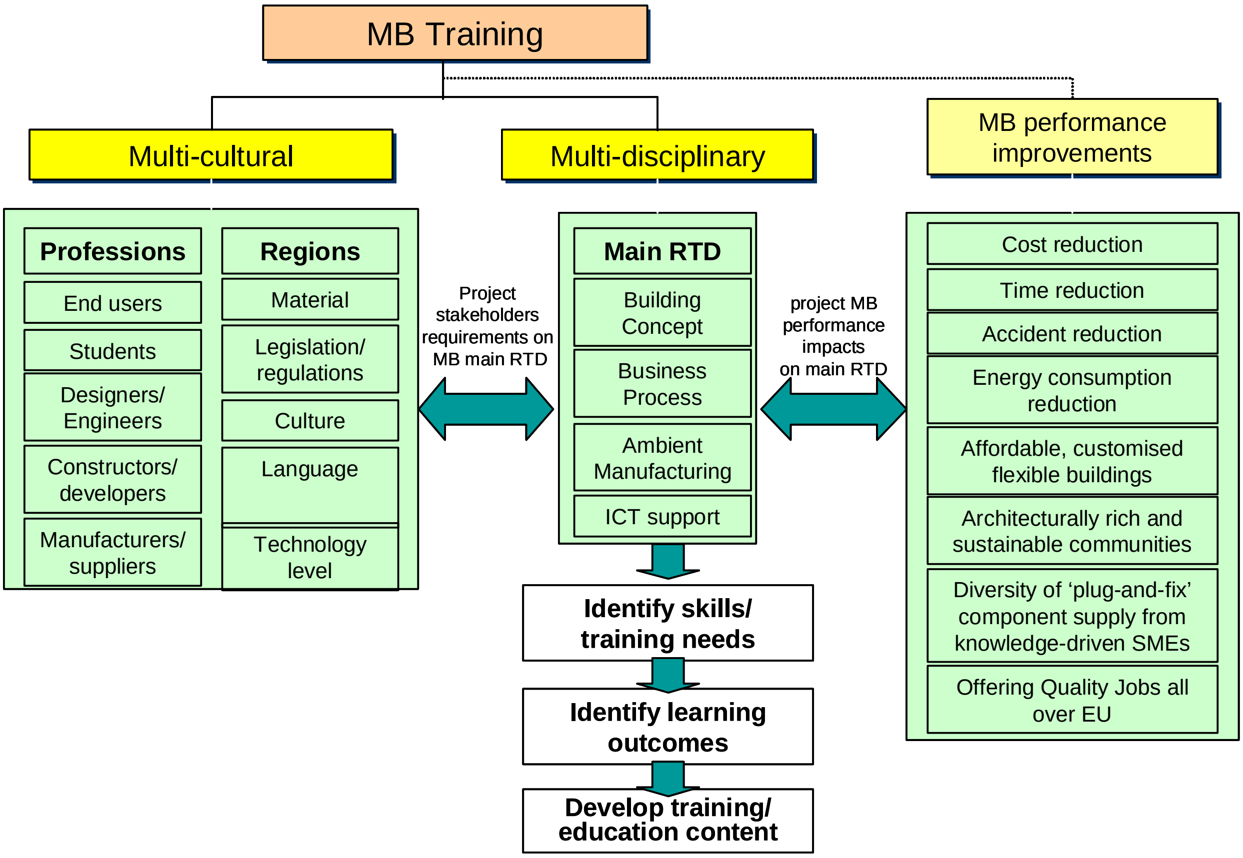

Figure 6: ManuBuild Training and Education Content Development Approach

ManuBuild Training and Education Delivery Concept

The delivery of *Manu*Build Training and Education encompasses innovative linking of theoretical knowledge and practical experience through integration (rather than duplication of delivery methods), as illustrated in Figure 7.

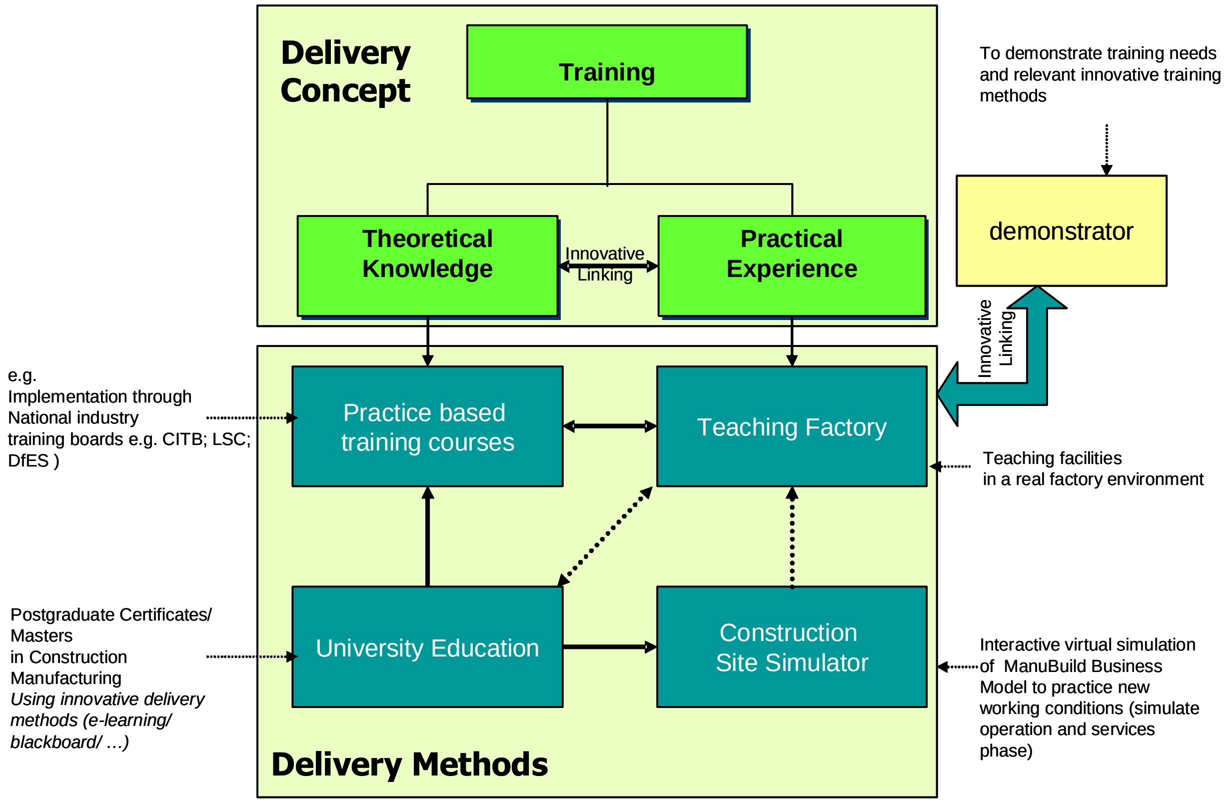

Figure 7: Training and Education Delivery Concept

Figure 7 identifies the interrelationship of the training concept to the core delivery methods. The innovative link between theoretical knowledge and practical experience is promulgated thorough the: practice-based training courses, university education, the teaching factory, and the construction site simulator. However, from a RTD perspective, the main RTD (*what*) informs the Theory, and Practice (h*ow*), which will be delivered to the stakeholders (*who*). The demonstrator will also be informed by the main RTD in order to demonstrate the 'Training Needs' and 'Skills' required (and the possible means for delivering training and education). This holistic training model can be seen in Figure 8.

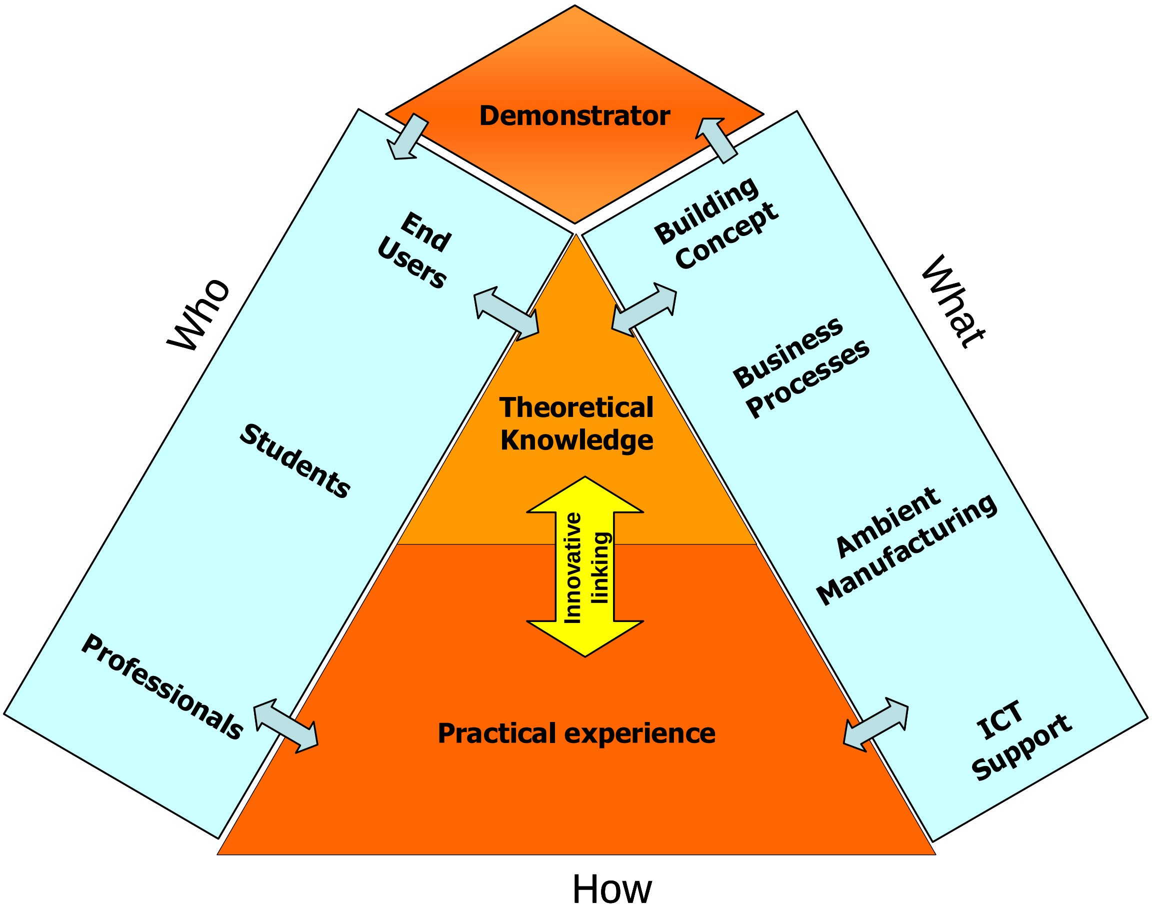

Figure 8: The Holistic Training Model

The Integrated/ Interrelated Training and Education

The practice-based training and education uses the 'University Education' and 'Training Courses' in the central core (theoretical knowledge) – see Figure 8; whereas, the 'practical' aspect of the training and education will be achieved through the integration of the 'teaching factory' and the 'construction site simulator', along with the training courses and the university education – see Figure 9.

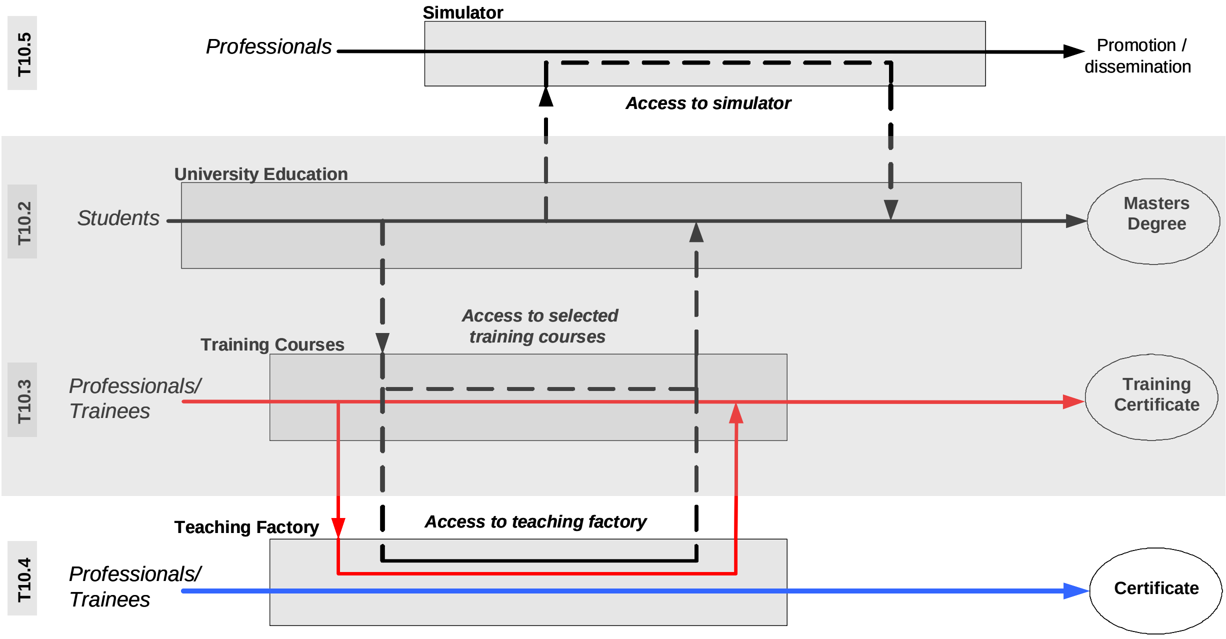

Figure 9: ManuBuild Training and Education Interrelated Approach

The 'Training Demonstrator' will be introduced to industry (executives, managers, operatives) and academia. This will enable them to better appreciate the new *Manu*Build concept and how it would operate in practice. Hence, derive real value and need for *Manu*Build Training and Education. Figure 9 identifies the importance of University Education, Training Courses, and the Construction Site Simulator, as synopsis of which follows.

University Education

A comprehensive model curriculum (O'Connor, 2004) will be developed, consisting of 'technical competence', 'business competence', 'interpersonal competence', and 'intellectual competence'. This curriculum will ensure that the learning opportunities encompass the multiple roles of the different professionals. Students will enrol on either a postgraduate certificate or master's programme in 'Open Building Manufacturing' within a University setting using prescribed pre-set of modules. All assessed work will be matched to specific learning outcomes aligned to these four areas of competence. Students will have access to:

- The construction site simulator to experience and research into the construction site of the future.
- Selected training courses and its application in the Teaching Factory.

The University Education component will enable students to gain an MSc award or postgraduate certificate in 'Open Building Manufacturing'. This provision will mainly be used to satisfy the short to medium-term needs of industry vis-à-vis acquiring the skills and competence needed to embrace the *Manu*Build concepts and leverage them through company processes and strategies. However, short-term provision will be facilitated through prescribed training and development programmes geared to a specific area or need. This may be undertaken through bespoke seminars, workshops, conferences, continuing professional development (CPD) courses etc.

The Industrial Training Courses

Love *et al.* (2001) noted that training courses should be used to increase skills and competence in order to teach the 'how' aspect of the job. In this regard, professionals/trainees will be admitted to the 'Training Courses' to acquire the relevant 'technical skills'. This provision will predominantly target operatives (from a vocational perspective) in a real factory environment (using the Teaching Factory). From an advanced manufacturing perspective, Koepfer (1995) noted several benefits of ‘local’ teaching factories, the provision of which naturally embraces industrial demographics, and helps target need (thereby addressing demographic deficiencies).

The Construction Site Simulator

On-the-job training (OJT) is argued to be particularly effective in dealing with complex tasks where a great deal of independence is granted to the task performer. However, this provision is often criticised for being too expensive, and can also often lack relevance regarding the training context itself. These deficiencies will be addressed through virtual reality (VR) solutions, as several success stories using simulation have been recorded (Ponder *et al.*, 2003; Blümel *et al.*, 2004; Rainsford and Murphy, 2005). For example, using a VR environment, users will be faced with interactive scenes that contain multiple virtual objects that undergo interaction and respond with certain behaviours (interaction with the VR space) through interactive scenarios. This has considerable benefits, for example, a VR environment can be employed for analysing issues which occur on the construction site such as: engineering design concerns, process concerns, logistics concerns, and operatives training, health and safety etc.

A virtual training environment also has the potential of:

- reducing training time
- facilitating a higher transfer of expert knowledge
- increasing operator safety (by highlighting risks)
- minimising the risk of machine failure through operator errors
- training personnel under extreme situations
- supporting extended decision making (what-if-analysis)

The Construction Site Simulator will predominantly be used to satisfy both the short and long-term training needs of the market. The short-term needs will be in the form of workshops given to executives and managers, and the long-term needs will be leveraged through (and with) the University Education provision.

The Teaching Factory

Manufacturing engineering curricula is often criticised for being overloaded with a high percentage of theoretical science content; thereby by default, little emphasis is placed on deeper learning of the total manufacturing environment (Dessouky *et al.*, 1998). In this context, the *Manu*Build Teaching Factory therefore, will provide teaching facilities in a real factory environment for practicing and developing skills in advanced manufacturing. This facility will also be used to enhance the collaborative learning experience (working as part of a team), and tease out core production-related issues that require collective decision-making. In addition, the Teaching Factory will form an integral part of *Manu*Build practice-based training and education curricula, and advanced manufacturing facilities (to help eliminate the traditional boundaries between academia and industrial practice). The Teaching Factory will also provide a real factory environment to professionals/trainees, where they can experience a hands-on approach to the new *Manu*Build technology. Using this mantra, students will actively experience the product realisation process, thereby creating 'shop-ready' employees who can immediately do the work.

The Training Demonstrator

Buckley and Caple (2004) noted the importance of training, particularly at senior management level. This acknowledgement is particularly important, as the 'informing process' helps mangers better understand the impact that training can bring to businesses. In this context, the Training Demonstrator will be used to identify the training needs from the all the other different demonstrators (Sales Office Demonstrator, Manufacturing/Logistics and Assembly Demonstrator; and the Building Demonstrator). The Training Demonstrator will therefore demonstrate how holistic needs can be satisfied through the practice-based Training and Education. It will also identify the technologies used to deliver Training and Education (see Figure 10), the technologies used, and potential benefits of: University Education; Training Courses; the Construction Site Simulator; and the Teaching Factory (see Figure 11).

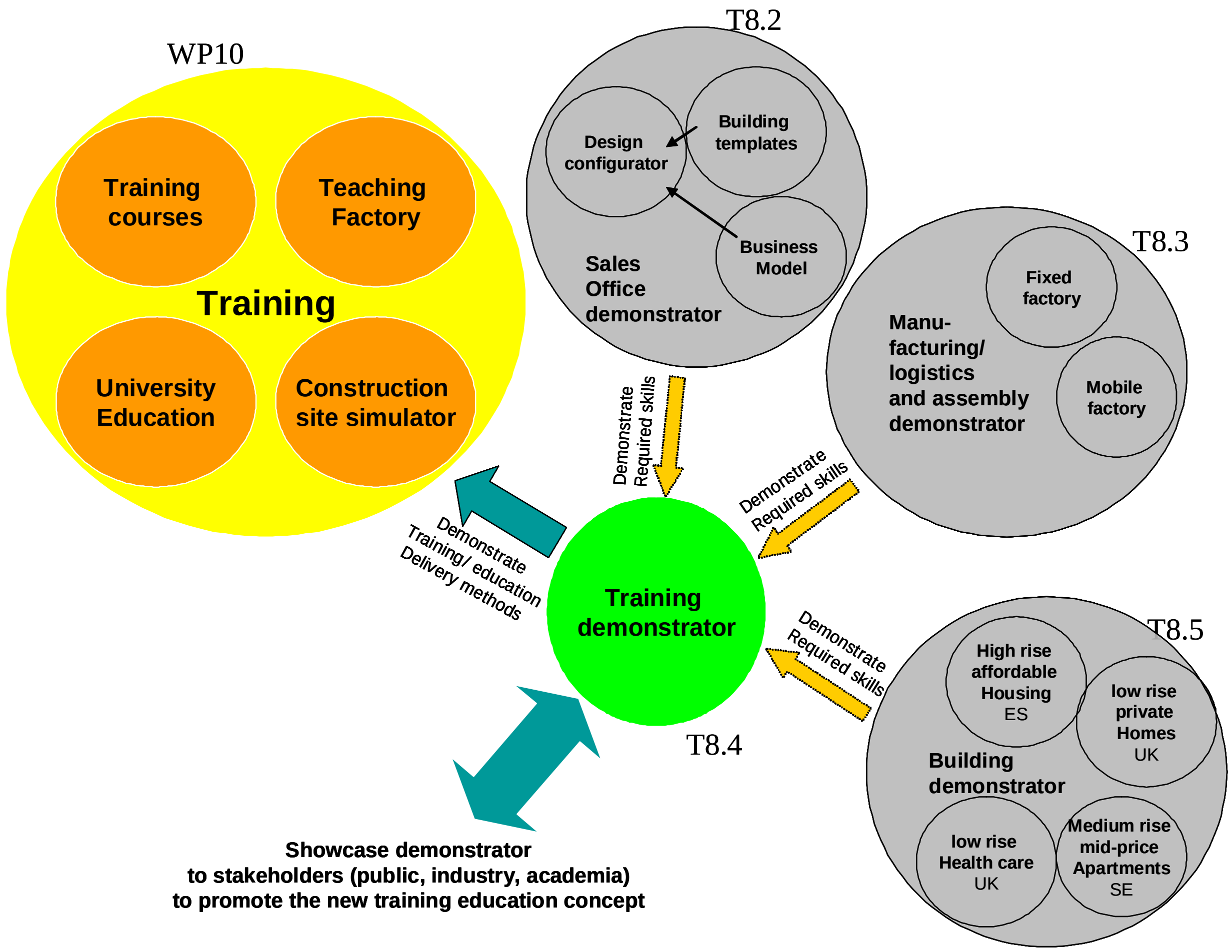

Figure 10: Training Demonstrator Interrelationships

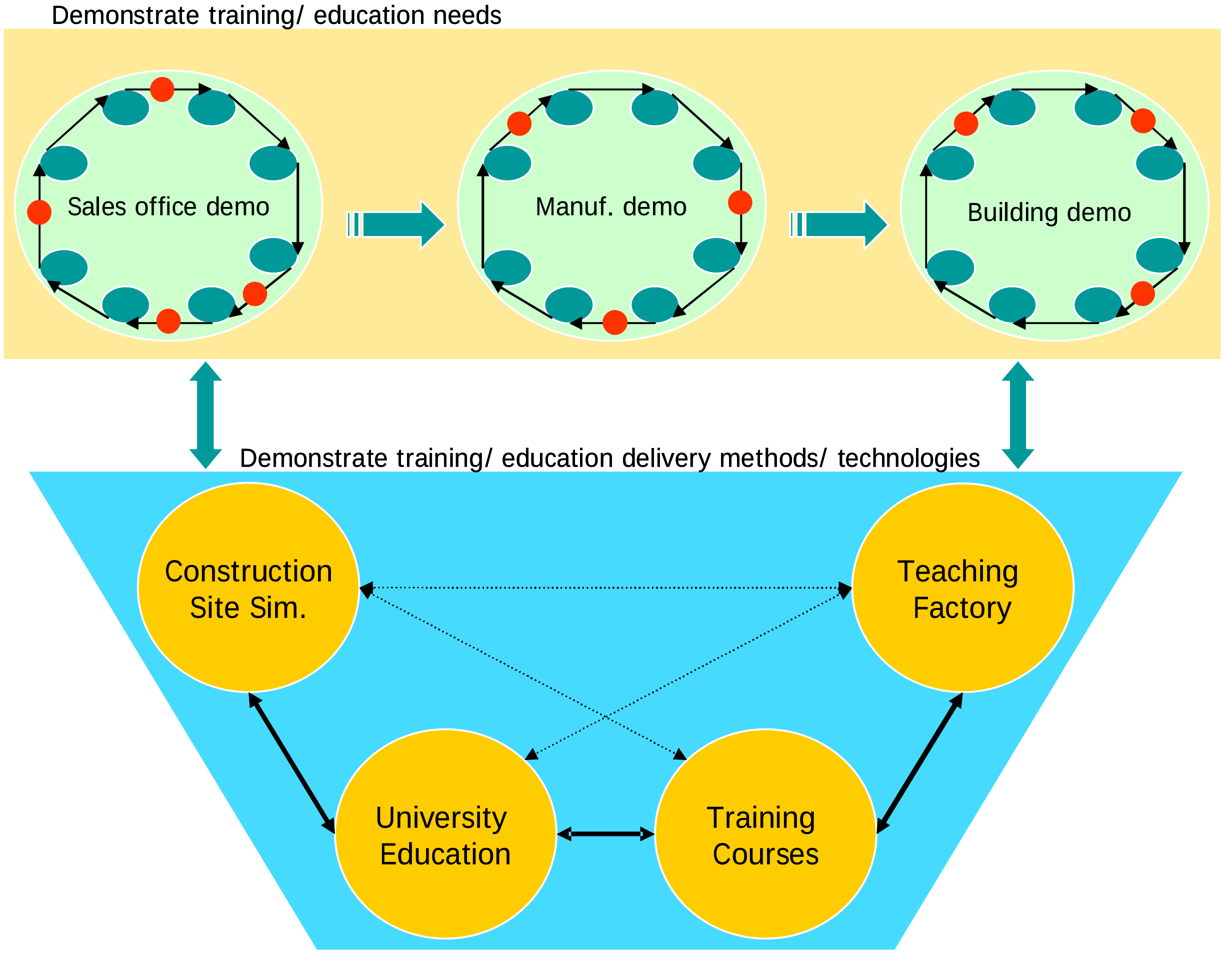

Figure 11: The Training Demonstrator Conceptual Model

The Next Step

After defining the *Manu*Build Training and Education Concept (which underpins the delivery of training and education), the following steps concern the development and delivery of the Training and Education. During this stage, all training and education activities will need to satisfy and identify the following issues:

The precise definition of objectives and training scenarios (ref. demonstrators)

- The analysis of needs and core content
- All learning outcomes (generic and specific)
- Matriculation requirements
- Validation/accreditation conditions and requirements
- Course content
- Language (variances and semantics)
- Pedagogy (interface, media, interaction, design etc)
- Infrastructure/ resources
- Time/place arrangements
- Assessment criteria (rubrics, dependencies etc)
- Evaluation (type, metrics etc)
- Management

- Cost (initial, operating etc)
- Documentation

Notwithstanding the above issues, an incumbent question needs to be raised at this juncture vis-à-vis the applicability and relevance of Training and Education to all stakeholders regarding expected and perceived benefits. These issues have been formally acknowledged and are distilled into six core issues- see Table 1.

Table 1: Six Core Questions

Issue	Aspect
What should people be able to do after training/education?	[impact]
Where and when will they apply the knowledge?	[level; temporal factors]
Will industry accept *Manu*Build?	[validity; accreditation etc]
How will success be measured?	[internally, externally]
Who will sponsor students?	[bursaries, companies, funding agencies etc]
Is there a viable market?	[supply and demand]

Conclusion

The vision of developing EU capacity to successfully support and implement the *Manu*Build concept for Open Building Manufacturing largely depends on providing training and education to the wider European community. Training and Education will therefore be the backbone through which the *Manu*Build concept and vision will be realised.

The gap between the different EU RTD project results and industry practices has been identified as one of the main reasons for the industry's reluctance to embrace new technologies and concepts (Rezgui and Zarli, 2006). Training and Education will therefore play an important role in communicating and demonstrating technological solutions and benefits to all stakeholders (technology adoption). However, 'conventional' methods of delivering programme curricula have often been criticised for providing generic skills (often too generic), with the anticipation that the prospective employer would be responsible for delivering on-the-job training (specific training). This dichotomy is often classified as the 'skills gap'.

For *Manu*Build Training and Education to have a better opportunity of embracing the different construction industry stakeholders' needs, the delivery of training and education will need to encapsulate the fulfilment of the different stakeholders' requirements/expectations. In this context, these will have to be specifically linked (i.e. theoretical knowledge and practical experience) through the integration of innovative delivery methods: the Teaching Factory - to provide teaching facilities in a real factory environment; and the Construction Site Simulator - a virtual simulation of the construction site of the future.

To achieve the *Manu*Build Training and Education, it will be necessary to go beyond the concept of a 'learning organisation' (McHugh *et al*, 1998; Huber, 1991, Senge, 1992), to the concept of a 'learning sector'. Hence, it will be necessary to approach training and education under the umbrella of 'Workforce Development' and 'Educational Development', in order to establish new industry thinking (with new professions and skills). In this regard, one critical success factor will be to secure endorsement and subsequent validation from the relevant institutions and professional bodies. Notwithstanding this issue, through Workforce Development and

Educational Development, *Manu*Build Training and Education will be able to create a 'win-win' working relationship, where students and professionals would be able to acquire the necessary skills and competence to leverage maximum impact. This will be maximised through the use of 'experience-based' or 'experiential' learning in order to secure optimum cognitive impact.

However, learning can not accommodate a "one-size-fits-all" policy (Clay and Mindrum, 2003). Therefore, different learning styles will need to be accommodated for training and education to satisfy the different learning styles etc. In this context, an integrated learning approach will be adopted through the *Manu*Build Training and Education Concept to not only facilitate theses issues, but also disseminate these issues to the wider multi-cultural aspects of the EU construction industry (e.g. different materials, regulations, working practices etc). The Training Concept will therefore depend to a large extent on the Training Demonstrator to communicate and promote *Manu*Build Training and Education, as this will be used to demonstrate: the potential training needs and areas for applying the *Manu*Build concept in practice (Sales Office Demonstrator, Manufacturing Demonstrator, and Building Demonstrators); and to demonstrate the innovative delivery of the Training Courses, University Education, Construction Site Simulator and the Teaching Factory.

Through the 'University Education', a comprehensive curriculum will be developed, consisting of 'technical’ competence, 'business’ competence, 'interpersonal’ competence and 'intellectual’ competence. This curriculum will ensure that the learning opportunities encompass the multiple roles of the different professionals. Students will enrol on either a postgraduate certificate or master’s programme in 'Open Building Manufacturing' within a University setting using prescribed pre-set modules; and the Training Courses will be used to reflect the regional and industrial demographical nuances (as appropriate).

The Construction Site Simulator will be used to provide a virtual reality simulation of the construction site of the future. This will have the added benefit of providing a risk free environment, where learners will be able to evaluate how their decisions will have an impact on their business e.g. health and safety, production, engineering design concerns, process, logistics, operative training etc.

The Teaching Factory will form an integral and important part of the practice-based training and education curricula with advanced manufacturing facilities. This will use a real factory environment to enable learners to experience ‘hands-on’ practice regarding new *Manu*Build technologies and processes. Furthermore, the Teaching Factory will be used to enable learners better appreciate and experience the product realisation process (which will also have an added benefit of making them 'work-ready' and capable of immediately undertaking the work they have just experienced).

Key Lessons Learned:

- *Manu*Build Training and Education - relationship with the main RTD
- Training and Education - satisfying the multi-cultural and multi-disciplinary aspects of the EU construction sector; relationship to the *Manu*Build performance targets
- Linking theoretical knowledge with practical experience through innovative delivery methods
- The role of University Education, Training Courses, Teaching Factory, Construction Site Simulator, and the Training Demonstrator
- The key questions for the successful delivery of *Manu*Build Training and Education

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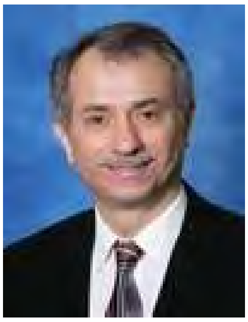
Authors' Biographies



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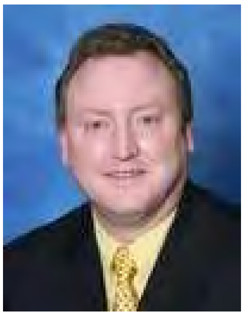

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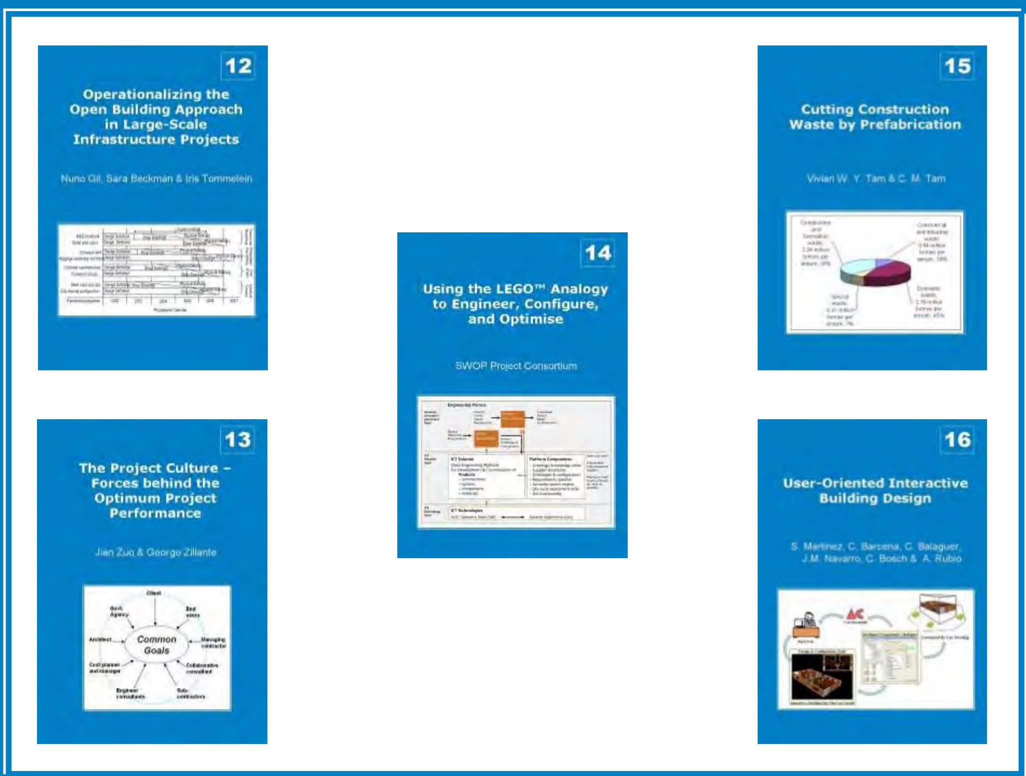
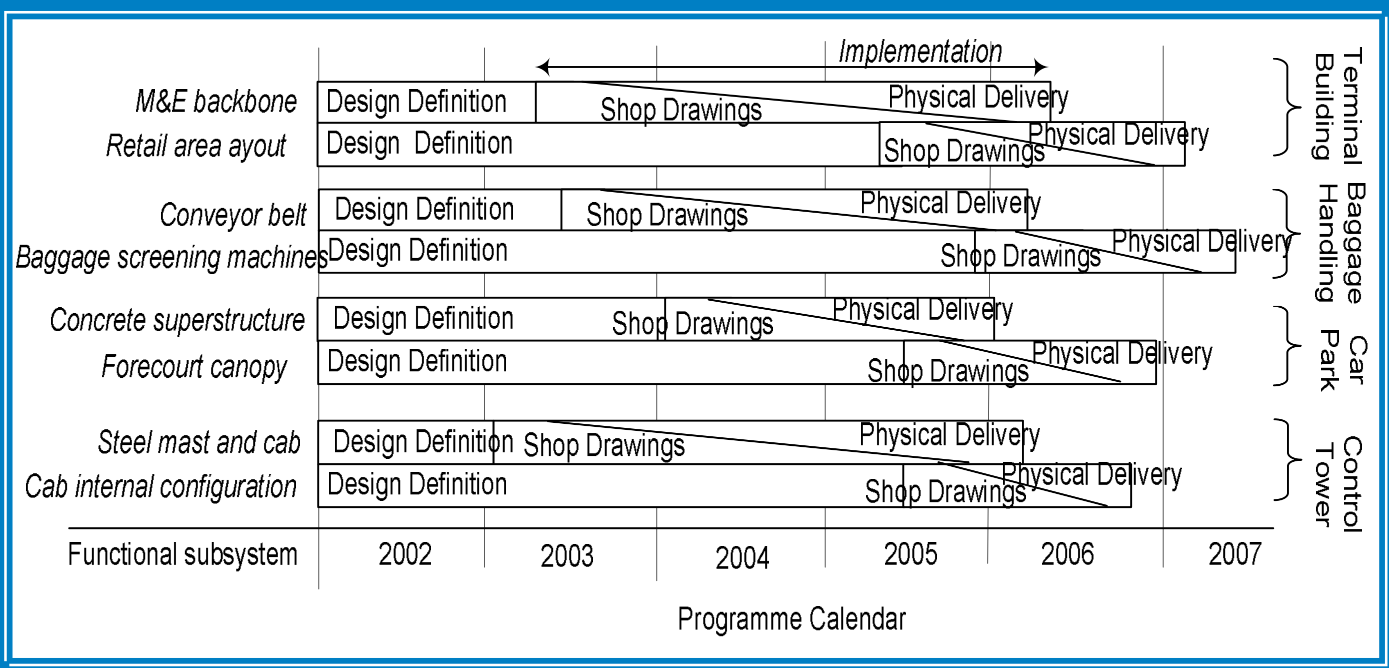
Solutions & Applications



12

Operationalizing the Open Building Approach in Large-Scale Infrastructure Projects

Nuno Gil, Sara Beckman & Iris Tommelein



Operationalizing the Open Building Approach in Large-Scale Infrastructure Projects

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Abstract

This study examines the appropriateness of alternative coordination strategies to manage the application of design postponement, or the overlapped approach, in the development process of large engineering (physical infrastructure) projects, and what the trade-offs are. The overlapped approach suits to design and physically execute the upstream base building with preliminary information about the downstream business-critical fit out. Base-building subsystems provide serviced space for occupancy, whereas fit-out subsystems make the space functional. We investigate how to problem-solve upstream design under uncertainty and ambiguity through a multiple-case study of concurrent development processes. We systematically find that the designs of base-building subsystems can show low sensitivity to incremental changes in fit-out as they are seldom optimized to eliminate slack. Yet, they can show high sensitivity to radical changes in fit out when base-building and fit-out subsystems have integral architectures. In the face of the slow resolution of downstream uncertainty and difficulties in physically decoupling the subsystems, upstream developers avoid starvation by making working assumptions and limiting set-based exploration to an early 'optioneering' design stage. Two patterns for problem-solving upstream stand out: iterate design when releases of preliminary information are ambiguous, or precise but unstable; and design in buffers when preliminary information lacks precision but is not ambiguous. Buffers can be designed out if downstream uncertainties resolve favourably before physical execution. A lesson for open building manufacturing is that efforts to prefabricate base-building modules off-site do not automatically lead to flexible infrastructures with modular architectures.

Keywords: base-building and fit-out subsystems, overlapped approach, product architecture, design modularity, postpone fit out, uncertainty, ambiguity

Introduction

This study examines the appropriateness of alternative coordination strategies to manage the application of design postponement, or the overlapped approach, to the development process of large engineering (infrastructure) projects. The overlapped approach seeks to compress the lead time needed to design, physically execute, and ramp-up a new infrastructure before it begins to generate revenue, yet retain the capability to adapt the design to late changes in business, technology, and operational requirements. We examine the overlap of upstream design and physical execution of the base building with the downstream design of the business-critical fit out. The base building consists of the set of functional subsystems that collectively provide service space for occupancy, such as the foundation, steel/concrete superstructure, envelope (façade and roof), and supply subsystems (e.g., power, fresh air, exhaust, drainage, gas, telecom, water). The fit out consists of the set of infill functional subsystems used to create and articulate interior space in the base building and make it functional, including wall partitions, flooring, ceiling, and specialized equipment (e.g., check-in counters, baggage screening machines) (adapted from Habraken 1998[1]).

In our research setting, the administrators of a 6-year programme to deliver a new, high-end airport terminal campus (many with background in the automotive industry) instituted a design postponement policy to speed airport expansion, yet retain flexibility to adapt the terminal design to late changes stemming from the continuous evolution in air products and services. We systematically find a replication of early overlapping between interdependent functional subsystems: base-building and fit-out design tasks start at the same time, but one finishes earlier and the other continues (Joglekar et al. 2001) (Figure 1).

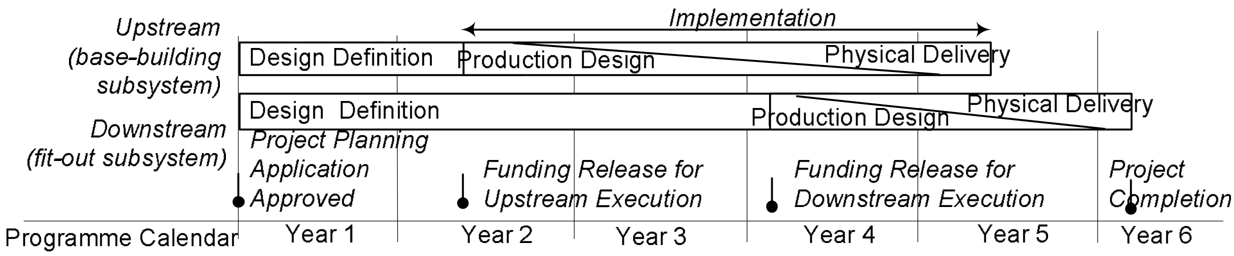

Figure 1- Application of the Overlapped Approach to the Infrastructure Development Process

In the development of the multi-storey car park for the new terminal, for example, the freeze of the design definition for the forecourt canopy on the top level of the car park was postponed about 18 months in relation to the end of the design definition for the concrete superstructure. This lag sought to give time for architects to creatively generate a concept that met the design brief, which spelled out that the forecourt should be a 'wow factor,' i.e., a functional element whose aesthetics 'would cause users to draw breath.' Likewise, the design of the baggage screening subsystem (involving around 20 machines, the more expensive costing 1.5€ million each) was frozen about two years after the end of the design definition for the conveyor belts. Developers felt they could not reliably predict how rapidly technology and U.S. legislation would move from the X-ray machines that were endorsed by the Department of Transportation toward 2-D and 3-D CT-scanning machines.

In both cases, base-building design progressed based upon preliminary information released by fit-out designers. Preliminary information is uncertain if the problem-solver understands enough of the structure of a situation to be able to define a range of values which will contain the final solution, but lacks the knowledge to be precise (Schrader et al. 1993). Preliminary information is ambiguous if the problem-solver has limited knowledge both of the variables themselves and of the problem-solving mechanisms required to increase understanding of the situation (ibid.) In the canopy example, preliminary information was ambiguous as the outcome of creative design processes can be genuinely unpredictable (Ghery 2004). In the baggage screening example, preliminary information was uncertain but not ambiguous: developers released a preliminary set of procurement alternatives for the baggage screening machines.

[1] Habraken's (1998) definition is far-reaching: base building and fit out are defined as 'environmental levels', i.e., interrelated configurations of physical elements and decision clusters that occur within a larger dependency hierarchy.

We empirically found that the efficient application of the overlapped approach depends both on (1) the degree of modularity of the interaction between the architectures of base building and fit out; and (2) the stability of the fit-out design definition We borrow the concept of product architecture to define infrastructure architecture. Product architecture is the ‘scheme by which the function of a product is allocated to physical components’ (Ulrich 1995). Product architectures that are strictly modular exhibit a one-to-one mapping from functional elements to physical subsystems/components and decoupled, standard physical interfaces. In contrast, products with integral architectures include complex (many-to-one, one-to-many, or many-to-many) mapping and tightly coupled interfaces between subsystems (Ulrich 1995). Most products are hybrid, i.e., they include a number of functional elements that map to physical subsystems that interact in a modular way with the other subsystems, and other functional elements that map to subsystems which are integral to other subsystems (Ulrich 1995, Ulrich and Eppinger 1995). Infrastructure architectures with decoupled interfaces between base-building and fit-out subsystems suit the overlapped approach. Modularity enables parametric evolution of the fit-out subsystems to take place without redoing the base-building subsystems as long as changes conform to the design rules agreed upfront.

We also found that base-building developers resort to two main ways to move work forward with risky preliminary information. They invest in decoupling the physical interfaces between the architectures of the base-building and unresolved fit-out subsystems. Base-building subsystems are rarely engineered to eliminate slack because the gains in performance and cost fail to outweigh the development effort. This slack makes base building subsystems inherently flexible to accommodate ‘incremental’ changes (Shenhar and Dvir 1996) in fit-out components with a marginal penalty to performance. However, reworking a base-building subsystem to accommodate a ‘radical’ change (Shenhar and Dvir 1996) in the architecture of a fit-out subsystem rarely comes cheap. The modularization of the interaction between the two systems is one way to increase the adaptability of base building to changes in fit out. Not always, however, developers succeed to modularize this interaction. In these circumstances, developers may resort to building buffers in the design definition of base-building to make it adaptable to economically accommodate changes in the unresolved fit-out subsystems.

Further, we empirically found it unlikely that base-building developers apply a set-based design strategy despite unresolved uncertainties with fit-out, i.e., develop an open set of base-building possibilities that would gradually narrow to converge towards a single solution as uncertainties in fit-out get resolved (Sobek et al. 1999). Rather, we observed base-building developers investing time and effort to conceptualize and compare a set of options at the very early stages of design definition, which they term ‘optioneering.’ Yet, they progress design definition with a single option to move forward into physical execution, knowing that uncertainties in fit-out are likely to stay unresolved until the very late stages of physical execution of the base-building.

The rest of this chapter is organized as follows. We first we describe our theoretical background, industrial context, and research approach. We then examine our empirical data and discuss some coordination strategies to resolve upstream base-building under preliminary information about fit-out. Finally, we summarize the key findings and discuss the business impacts.

Background

The problem of efficiently overlapping interdependent tasks has long been studied from an ‘information processing’ view (Eastman 1980, Clark and Fujimoto 1991). This perspective primarily uses analytical models to investigate the role of preliminary information exchanges when an information-sender task upstream overlaps with an information-receiver task downstream (e.g., Krishnan et al. 1997, Loch and Terwiesch 1998, Terwiesch and Loch 1999). Preliminary information is characterized along two dimensions (Krishnan et al. 1997): (1)

Upstream evolution refers to the speed of refining information from a set-based preliminary form to a single-point value — slow resolution of uncertainty slows the evolution of information; (2) Downstream sensitivity refers to the relationship between the gradual narrowing of upstream information with the duration of the downstream iterations — a downstream task is highly sensitive when long rework cycles are needed to adapt to upstream changes. The overlapped approach suits well when upstream evolution is fast and downstream sensitivity is low in which case the gains in the quality of the upstream design solution more easily outweigh the cost of reworking the downstream design (Loch and Terwiesch 1998).

In the world of managing large engineering projects, early literature advises against the perils of ‘concurrency’ under uncertainty as reworking upstream decisions can be too costly and irremediably delay delivery after cascades of interdependent moves are made to move the project forward (Morris and Hough 1987). Instead, scholars recommend investments in front-end strategizing, including scenario planning, risk management, and contingency planning (Morris and Hough 1987, Morris 1994). Front-end strategizing cannot, however, eliminate uncertainty in design requirements when an infrastructure takes up to a decade to deliver (Genus 1997, Shenhar and Dvir 1996, Miller and Lessard 2000). Recent process research recommends that infrastructure developers do not lock in specific design configurations unless postponement is not feasible and further studies are unlikely to reveal valuable new information (e.g., Miller and Lessard 2000, Gil et al. 2006). This work says little, however, on how to resolve base-building under uncertainty and ambiguity, especially when base-building and fit-out are integral.

Another stream of work recommends that developers conceptualize the definitions of infrastructures for the built environment as ‘open’ or ‘living’ entities, decoupling the physical interfaces between the base-building and fit-out ‘levels’ (Habraken 1998, Kendall and Teicher 2000). The principle aims in part to transfer the construction process from building to manufacturing. This, in turn, can promote ‘regenerative’ infrastructures that can efficiently respond to transformations in the environment. Accordingly, the base building should be a stable set of subsystems that is adaptable to a variety of ‘individual territorial claims’, enabling occupants to move in and out with different fit-out subsystems over time (Habraken 1998). This work is conceptually close to research on the role of product architectures and modularity in manufacturing (Ulrich 1995, Baldwin and Clark 2000), but still lacks compelling exemplars.

Industrial Context

Four projects encompassed by an airport expansion programme provided the industrial context for this study. Project management adopted a formal stage-gate system (Cooper 1990) in which developers could only move work from one stage to the next after completing a set of deliverables that demonstrated ‘fitness to proceed.’ The design definition stage consisted of developing and integrating a set of functional subsystems using specialized software packages and a graphical 3-D CAD platform. Once developers were able to demonstrate a degree of design completion and supplier involvement enough to support a cost and programme certainty at 95%, administrators released the funding needed to begin the implementation of those subsystems. Implementation included manufacturing, assembly, and site construction based upon detailed shop drawings that suppliers released in parallel.

In the face of a 5-year lead time to design, execute, and ramp up the infrastructures vis-à-vis the fast-changing nature of some business requirements, the private airport operator instituted a postponement policy to ‘ensure that time and resources are not wasted developing schemes that are almost certain to change.’ This policy allowed developers to postpone the completion of the design definition for selected fit-out subsystems to a ‘Last Responsible Moment’ (LRM) defined as the ‘date for the start of an activity at which there will be an impact on the project costs or baseline programme if a decision is not made that would allow that activity to start.’ Before we present next the analysis of the database on the application of this policy, we summarize the learning objectives of this paper:

Learning Objectives:

- Differentiate base-building from fit-out in the infrastructure design definition
- Apply the concept of modularity to characterize the interaction between the architecture of base building and fit-out subsystems
- Understand the implications of applying the overlapped approach to infrastructure development from a design problem-solving perspective
- Identify the alternative coordination strategies to resolve the design of base-building subsystems under uncertainty and ambiguity about fit-out
- Understand the tradeoffs between the iterative and buffering design strategies for resolving base-building design with preliminary information

Approach

We chose to investigate concurrent development through a multiple case-study design, in which multiple units of analysis are treated as a series of experiments that (dis)confirm emerging conceptual insights (Yin 1984, Eisenhardt 1989). Our units of analysis are four distinct concurrent development processes across four different project settings (see Figure 2). In a grounded theory fashion (Glaser and Strauss 1967), we drew from constructs in the product development literature to iteratively collect fine-grained data, perform theoretical coding, and play emerging theory against data (Miles and Huberman 1984, Strauss and Corbin 1990). We resorted to graphical mapping and tabular displays to systematically make cross-case comparisons and test the plausibility of the proposed relationships within our set of concepts (Glaser and Strauss 1967). Data collection – in the context of a broader research programme (Gil et al. 2007) - involved 72 in-depth, semi-structured interviews lasting one to two hours, as well as thorough analysis of over 100 documents, including clips from trade and business press, programme procedures, project reports, and progress videos. Our strict data collection protocol involved transcribing all the interviews, organizing the transcripts into a database, and organizing write-ups for each case. We present a summary of the selected problems resulting from the application the overlapped approach in Table 1.

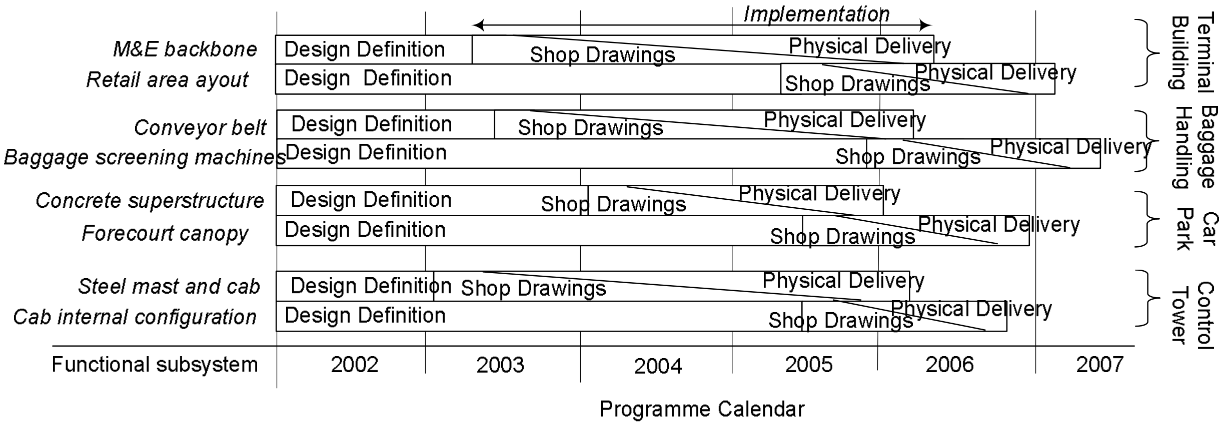

Figure 2 – High-level Programme for the Early Overlapping of Functional Subsystems

We handled the issues of construct and internal validity by, first, triangulating interview data across three groups of respondents – designers, project clients, and end-users, and by sampling cases from four different project contexts. And second, by triangulating interview data against archival documentation and on-site observations. Two one-week stays on-site as well as numerous 1-2 day visits helped to build a sense for the massive scale of the work (e.g., a single-span terminal building able to fit 50 football pitches across five levels); the investments to pre-fabricate large-scale modules offsite to assemble on-site, the demands of coordinating work among over 1,000 designers geographically dispersed and a workforce of 4,000 on-site at peak; and the difficulties in speeding physical execution stemming from site congestion, industrial relations issues, insurance underwriting, scarcity of skilled labour, and stringent regulation and bylaws in health, safety, environmental impacts, and security

Table 1 – Summary of Data on the Overlap of Interdependent Infrastructure Subsystems

Case: Upstream / Downstream Subsystems	**Base-building implementation lead time**	**Uncertainties for fit-out design**	**Interdependency between base-building and fit-out subsystems**
Upstream: Backbone mechanical & electrical elements Downstream: Retail area layout	~ 3 years to procure specialized items, pre-fabricate modules off-site, transport, and assemble on-site	High *"In the world of retail, we can never be too rigid about the layout because consumer spending is quite volatile." (Retail Director)*	High *"Even if you are just changing the location of a toilette block, you have to resolve a problem... we had big problems with moves of catering units because ducts need to be fully accessible " (Design Manager)*
Upstream: Baggage conveyor belt Downstream: Baggage screening machines	~ 2 ½ years to manufacture, assemble, test & commission	Moderate *"You want to leave it to the LRM to get the machines with the quickest throughput times and best price" (Security Representative)*	Low *"Baggage handling systems have been traditionally modular …. Provide us the volume and we will install our kit of parts." (Production Leader)*
Upstream: Car park concrete superstructure Downstream: Forecourt canopy	~ 1 3/4 years to build the concrete superstructure	High *"We have always felt that they wanted something more dramatic than the original canopy design." (Structural Designer)*	Moderate *"The thickness of the forecourt top slab constrains the maximum momentum load on the base of the posts supporting the canopy" (Project Leader)*
Upstream: Control tower mast and cab steel structure Downstream: Cab internal layout	~ 3 years to build the control tower mast and cab	High *"You are absolutely convinced that things will change when your human factor experts look to the layout later" (Head of Engineering)*	Low *"We are in version 22 of the controller's desk layout (02/06). This gives you an idea of the flexibility of the [base-building] system; we went to a flexible design from day one" (Head of Engineering)*

Analysis

We start the analysis of our database by examining the patterns of the releases of preliminary information about the fit-out subsystems. We investigate: (1) the speed of evolution of uncertainty, and (2) the downstream ambiguity (see Table 2). We use the term progressive to refer to a pattern in which the high-level architecture of the fit-out subsystem was fixed early on, but the designs of the sub-subsystems and of the components were gradually firmed up over subsequent releases. This process was explained by the Director for Design and Development:

> "The idea about flexibility of approach or 'progressive fixity' is that I'm not going to make all my decisions at the same time, but will do them in a way that gives me some certainty that the decisions are consistent with what I promised to deliver. Hence, I'm going to rank

and chunk the decisions a little bit like Russian dolls. They can stagger because they work within a shell of control."

When the fit-out developers adopted this progressive approach, such as in the design of the layout for the retail area, the speed of uncertainty and ambiguity resolution was relatively fast for the high-level architecture (e.g., where do we put retail blocks vs. circulation areas) but slowed down significantly at the definition of the sub-subsystems (e.g., how many retailers go inside each retail block and how much space does each unit take), and even more at the component level (e.g., exactly which mechanical and electrical services are required by each retail unit). Hence, the preliminary information releases were precise and stable at the high-level architecture, yet lacked both precision and stability at the more detailed level.

Table 2 – Analysis of Preliminary Information Releases Sent by Fit-out Developers

Case	Preliminary Information about Fit-out			
	Speed of Uncertainty Resolution	**Precision**	**Stability**	**Exemplar**
Upstream: Backbone mechanical & electrical elements Downstream: Retail area layout	~ 2002, fix high-level blocks (colour-code circulation vs. retail areas) ~2004, fix user allocation (e.g., shops, duty-free, catering, toilettes) ~2005, fix exact subdivision (i.e., which retail brand goes in which space, and what are the exact service requirements)	Pro-gressive	Pro-gres-sive	*"We fixed the big retail blocks about 3 years ago [2002], and gave working assumptions about the inside shop functions. We fixed the location of catering units 1 ½ ago, and 1 year ago we fixed the third-party demise lines. Last month [March 05], we gave detailed information about the use of units, but I cannot guarantee that it will not have to change again." (Retail Director) (*)*
Upstream: Baggage conveyor belt Downstream: Baggage screening machines	The same two options — CT-scan OR X-ray machines — remained open over ~ 3years	Moderate (binary set)	High	*"Early on our colleagues in security gave us the impression that technology was going to move from X-ray towards CT-scanning… we have just now [April 2005] started the acquisition process, and machines will not be delivered until 2007" (Baggage Production Leader)*
Upstream: Car park concrete superstructure Downstream: Forecourt canopy	~ early 2003, first design solution ~ summer 2004, 1st review ~ spring 2005, 2nd review	High (single-point)	Low	*"The original scheme had canopies that were aligned and studded between …there was a feel that it was not good enough. The design had already gone through some change in a previous review, and we were not completely surprised that it changed again"* (Structural Designer)
Upstream: Control tower mast and cab steel structure Downstream: Cab internal layout	~ 22 versions between 2002 and Summer 2005	High (single-point)	Low	*"We are in version 22 of the layout. We started off with a circular layout with control desks outside and supervision in the centre, we then had middle high desks but no podium, then a rotating podium, then a fixed podium (…) In July 05, we firmed the final concept"* (Head of Engineering)

(*) Third party demise lines indicate the exact location of the perimeter walls separating retail from public areas

In other cases, the ambiguity in the design of the fit-out subsystems was low from the outset of development: fit-out developers defined sets of options that remained stable throughout, yet the resolution of the uncertainty about the most suitable option within the set was slow. For example, decision-making on whether to install X-ray or CT-scanning baggage screening machines (a binary set) took over three years. First, fit-out developers wanted to wait for foreseeable changes in the North-American legislation; second, the fast speed of technological evolution made it attractive to procure the machines as late as possible; and third, the baggage security division was interested in aligning the configuration of the new system with the replacement of existing systems which were due in 2007. In a second situation, releases of preliminary information put forward single or precise solutions that were likely to change later. The configuration inside the control tower cab, for example, went through 22 versions over 3 years to accommodate evolution in radar technology, learning from visiting new towers around the world, and feedback from the process of training controllers to use new equipment in a mock-up room. In this case, the base-building developers understood that the fit-out design was prone to change, but could not anticipate exactly how it would change between versions. We next examine the costs to adapt the base-building subsystems to the fit-out changes.

Base-building Adaptation Costs

We observed a literal replication of the pattern of base-building sensitivity when fit-out preliminary information was unstable (columns two and three in Table 3): When the interaction between the architectures of the base-building and fit-out subsystems was integral, often exhibiting interwoven or ‘nested geometries’ (Ulrich 1995) for efficient use of built space, base-building subsystems were highly sensitive to changes in fit-out that affected the interfaces agreed upon upfront. Conversely, the base-building adaptation costs caused by changes in fit-out subsystems were low if the interaction between the two architectures was modular. In both cases, the base-building adaptation costs went up once the work moved from design into implementation, corroborating what Terwiesch et al. (2002) call an ‘almost universal pattern.’

Table 3 – Analysis of Upstream Adaptation Costs [adapted from Terwiesch et al. (2002)]

Case	**Cost to Adapt Base-building**			
	If Fit-out Information is Not Stable		**If Fit-out Information is Not Precise**	
	How flexible is base- building design to fit out deviations?	**Does base-building flexibility change after design definition?**	**Starvation: Can base-building continue based on preliminary information?**	**Duplication: Can base- building prepare for multiple outcomes?**
Upstream: Backbone mechanical & electrical elements Downstream: Retail area layout	Contingent on whether it is a an incremental or radical change *"We can flex to accommodate small changes, but we need to agree on major constraints"* (M&E director)	Yes, rework costs go up dramatically *"We must freeze design 6-months before we start to prefabricate; after, change is costly"* (Project Director)	Yes. The problem is not novel *"We are dependent on what others do, but we can proceed with general layout"* (Concept Guardian)	Difficult, programme lag is too long *"The need to procure specialized items with long lead times forces design commitments*" (Design Director)
Upstream: Baggage conveyor belt Downstream: Baggage screening machines	Very, the interaction between conveyor belts and screening equipment is modular *"The baggage hardware is a kit of parts that we can adjust"* (Production Leader)	Not much, rework is local *"Reworking the conveyor belts if we get it wrong costs perhaps £20,000, not a big risk"* (Production Leader)	Yes. Working assumptions can be made *"We can make educated guesses based on existing machines"* (Production Leader)	Difficult, programme lag is too long "We *have to assume one type of machine to manufacture a temporary conveyor and start testing*" (Designer)
Upstream: Car park concrete superstructure Downstream: Forecourt canopy	Yes, but changes cannot impact slab depth since some physical interfaces are not decoupled. *"The local design rework is not very complicated"* (Project Leader)	Concrete subsystem remains flexible until shop drawings are done *"There's a bit of capacity in loads and cross-sections" (Head of Structural Design)*	Yes. The problem is not novel *"We had to make a lot of assumptions"* (Structural Director)	Within limits, options for alternative canopy designs stay open until very late *"In detailing the steel reinforcement you have ability to fine tune"* (Structural Designer)
Upstream: Control tower mast and cab steel structure Downstream: Cab internal layout	Very, but modular interfaces must be respected *"Fit out uncertainty was OK as long as it did not request more space inside the cab"* (Structural Designer)	No, but modular interfaces must be respected *"The technology that goes inside changed, but did not impose structural changes"* (Structural Designer)	Yes, modularity decouples the subsystems *"You can make assumptions, but you have to work close to your client"* (Structural Designer)	Yes, but for a limited time *"We looked to various cross-section possibilities for the mast: a triangle, a circle, a square, but quickly reduced options"* (Design Manager)

We also systematically found that the sensitivity of the base-building subsystems was low to incremental change in fit-out components, even when the interaction between the two subsystems was integral, because the base-building subsystems were rarely optimized to eliminate slack. For example, after structural developers ran the computer simulations to assess the loads on each steel/concrete element, they would conservatively choose the cross-sections for the beams, columns, and floor plates; subsequent efforts to standardize the cross-sections for manufacturability would again be carried out on the conservative side. The rationale for this approach was explained by a programme administrator:

> "In a car program, the infrastructure is massively optimized because an extra few kilos of weight adds a few pounds of money and that matters massively, impacts manufacturing cost, fuel economy, safety, etc. Here, it is not worth the relationship between the amount of time and effort to optimize the engineered solution and the value that you can get."

The capability of the structural solution of the car park to accommodate a very late change in the geometry of the forecourt canopy exemplifies this pattern. The change was required when the beginning of the concrete pouring for the top slab (the forecourt slab) was only 2-months away, which meant that the shop drawings detailing the reinforced steel that went into the slab needed to be released within 4-weeks to keep with the programme. The structural designers ruled out a radically different geometry for the canopy (a dramatic wave-shaped cross-section supported on single posts) because it increased the loads imposed by the post connections beyond the maximum design capacity of the slab — changing the slab thickness would ripple through the entire architecture of the concrete subsystem. However, developers jointly agreed to support the dramatic wave-shaped cross-section on diagonally-strutted posts. This reduced the self-imposed loads enough to resolve the design problem by increasing the amount of local reinforced steel under the post connections close to the upper limit allowed by the design code.

We also repeatedly observed a pattern of upstream sensitivity when information downstream lacked precision (columns four and five in Table 3): upstream developers systematically made working assumptions to avoid starvation in the face of the maturity of the engineering problems. As one respondent put in the case of the terminal building "except for the fire engineering concepts that are cutting edge, nothing else here is high-tech." The capability to make working assumptions was illustrated by a designer's description of conceptualizing the electrical subsystem in the terminal building:

> "The shell-and-core design we have now [November 2004] *is fundamentally what we tabled in 2002 when we did not know what was actually going in each floor*. So we forecasted consumption levels for each area and designed a system that retained total layout flexibility. Since then, we've collected new consumption figures whenever there is a change: the overall load has never been a problem, but sometimes we need to take local loads to a different transformer if we have dramatic changes." (emphasis added)

We next examine the resolution of base-building design under uncertainty and ambiguity.

Base-building Problem-Solving Under Uncertainty and Ambiguity

Theory on preliminary information exchange in concurrent development processes suggests that decision-makers resort to iterative and set-based exploration, as well as to substitutes for information exchange (buffering and modularity) to solve downstream design problems under upstream uncertainty and ambiguity. Our findings on the reverse problem (summarized in Table 4) extend the validity of some theory, but also suggest dissimilarities that we discuss next.

Table 4: Analysis of Coordinating Strategies to Solving Base-building Design Problems

Case	Coordination Strategy based on Information Exchange		Coordination Strategy/Information Substitute	Substitute for Information Exchange
	Iterative Base-building Design	**Set-based Base-building Design**	**Buffering Base-building**	**Modularization of Interaction Base-building/fit-out**
Upstream: Backbone mechanical & electrical elements Downstream: Retail area layout	Yes *"We constantly updated load forecasts, and occasionally departed from original design"* (Concept Guardian)	No evidence	Yes, but some buffers were later designed out *"Our initial design allowed us to locate anything anywhere, but we removed allowances later on"* (Design Manager)	The interaction between electrical/retail architectures was modularized, but not the one with the mechanical subsystem *"The bus bar, a plug-in electrical system, has some ability to transfer loads, but the mechanical guys don't have that luck"* (Electrical Designer)
Upstream: Baggage conveyor belt Downstream: Baggage screening machines	Yes *"Should we get assumptions wrong, we will rework the conveyor belts"* (Production Manager)	No evidence (although downstream released set-based information)	No evidence	The baggage handling hardware was available ex-ante development with modular interactions *"We are a kit of parts that we install in a volume"* (Production Manager)
Upstream: Car park concrete superstructure Downstream: Forecourt canopy	Yes, to some extent *"At one stage, the designs had a 600KNm moment that the slab could not take."* (Structural Designer)	No evidence	No evidence of buffers built on purpose, but there was residual slack	Integral interaction between the two subsystems' architectures
Upstream: Control tower mast and cab steel structure Downstream: Cab internal layout	No Substituted by buffers and modularity	Only as 'Optioneering'	Yes *"Bear in mind you do not want cable trays to be too full, you allow 50% anyway just on keeping it tidy"* (Head of Engineering)	The interaction between the two architectures was modularized *"Our brief was to develop a steel design for the cab so the controllers' desk system on top could change"* (Structural Designer)

The Attractiveness of Iterative Design Coordination

Programme administrators recognized upfront that parts of the base-building subsystems would change over time, and some degree of trial and error investment (Sommer and Loch 2004) was inevitable. This was put bluntly by a programme administrator:

> "The idea of building £4 billion worth of infrastructure over 5 years when the business cycles move at a different speed and not going around the loop a couple of times because the client changes his mind is nonsensical. We need to narrow the number of design alternatives to get a budget approved, but *we will not be able to get it right the first time — change is a fact of life*." (emphasis added)

We systematically found instances of this iterative strategy when the cost of reworking the base-building design was low relative to the benefits spelled out in the business case for the change. In the case of the main terminal building, for example, a radical change in the retail area layout driven by a business request to consolidate the 'shopping experience' caused major rework in the design of the backbone M&E subsystems. The iterative strategy got less attractive over time because of the gradual increases in the adaptation costs and risk of programme delay. As the Head of Development stated: "concurrent engineering is fine as long as you understand that the more you go through your programme of works, the more rigorous the management of change has got to be. There comes a point when we have to make a call and say 'you need to close that down'." Hence, managers would allow base-building developers to restrict the space of fit-out solutions in the late stages of base-building implementation, as they did when architects proposed a radical late change for the forecourt canopy.

The Attractiveness of Designing in Buffers in the Base-building Subsystems

We observed investments in design buffers to shield base-building subsystems from rework otherwise necessary to accommodate the upper bound of preliminary releases of fit-out information. This trade-off between sacrificing product optimality in the present to reap the benefits of cheaper rework in the future is not new (e.g., Eckert et al. 2004, Sheffi 2005). Tolerance margins, or buffers, are invariably designed in complex engineering and IT subsystems to absorb emergent changes that designers anticipate but find it hard to eliminate upfront, especially when the cost of building extra capacity is low against the high risks if the system fails (Sheffi 2005). Here, one respondent described investments in buffers as "providing more than what we need in anticipation it will be used at some point in the future." Of course, developers recognized that buffers came with an upfront cost without a guaranteed pay off, yet accepted this trade-off as part and parcel of the concurrent development process:

> "Over-engineering does not necessarily come free; it can come with a premium. You win some you lose some. Still, it is often better to make a design decision that keeps momentum on-site than to try to fine tune because material cost may be small, but prolongation cost to have someone standing around can be significant" (Design Manager for Main Terminal Building 2005)

Buffers were particularly attractive when the base-building adaptation costs would be high (in terms of physical rework cost and/or risk of programme delay) if working assumptions lacked reserve margins to accommodate foreseeable change in fit-out. This trade-off was clear in sizing the M&E backbone subsystems based upon assumed design loads. Developers estimated these loads by employing formulas and models based on theory of fluids, which require input information about both the consumption needs at the user-end, and the pressure losses according to number of bends, material specs, routing lengths, and fire safety requisites. Developers designed 25% redundancy on top of the design loads to size the capacities of the equipment and cross-sections of the backbone M&E routings running inside the vertical service cores (the first ones to be physically executed) to build adaptability to late changes in the floor arrangement drawings (e.g., increase in catering or toilette units). Yet, they applied an iterative strategy without buffers to design the M&E horizontal branches underneath the flooring as they expected fit-out uncertainties to be resolved by the time they had to start execution.

The application of a buffering strategy to the base-building definition did not eliminate the need to exchange information and coordinate design decisions with fit-out developers. Rather, we observed that base-building developers regularly checked the suitability of the buffers against favourable evolution of the fit-out design. Design buffers yet to be physically executed that turned out to be a waste of resources in the light of late, reliable information lent themselves to removal if the expected savings in implementation offset the negative implications from undertaking a late design rework cycle.

The Attractiveness of Modularizing the Interaction between Functional Subsystems

Our sample is rich both in cases where developers succeeded in decoupling the interfaces between the architecture of base-building and fit-out subsystems, as well as in cases where the architectures of the subsystems remained integral. In the case of the baggage handling system, for example, functional elements with modular interactions between each other, such as the baggage screening machines and conveyor belts, were available at the outset of development. This happens frequently when technology can only be provided by a small group of firms that form a modular cluster (Baldwin and Clark 2000) – less than five suppliers worldwide had capability to deliver such a large-scale baggage handling system. In other cases, developers designed the architecture of a functional element to get a modular interaction: the physical interfaces between the base-building subsystems of the control tower (mast and cab steel superstructure) with the fit-out subsystems going inside the cab, for example, were decoupled. Developers conceptualized a peripheral M&E core embedded in the steel walls of the mast connecting on top to three concentric distribution rings under the cab's hollow floor plate, as well as a self-standing steel podium sitting on top of the controller's floor plate. This base-building architecture was flexible to economically accommodate change in the configuration of the controller's equipment and IT cabinets inside the cab over time.

In other cases, however, the interaction between the architecture of the base-building and fit-out subsystems remained predominantly integral despite efforts to decouple some interfaces. For example, while the M&E subsystems were designed as a kit of modules pre-fabricated off-site, developers only succeeded in modularizing the interaction between the architectures of the electrical and retail subsystems. The electrical solution was based on a bus bar system — a sectional architecture in which most of the interfaces between physical components are of the same type (Ulrich 1995) — which made the electrical design adaptable to changes in the retail layout. In contrast, the interaction between the architectures of the mechanical and retail subsystems remained integral. As a result, the costs to adapt the mechanical design to late changes to the retail layout were very high to the extent some prefab modules had to be discarded and the parts later installed on site in a traditional fashion. As put by the logistics director for M&E "the fact of lot of piping is going to be done by couplings rather than site welding means it is easy to adapt, but once you fix the design of the modules to prefabricate off-site, you lose flexibility because many modules are custom-made and not interchangeable."

'Optioneering', or the Limited Life of Set-based Exploration for Base-building

In our field study, we did not learn of any instance in which base-building developers adopted set-based design. Rather, they invariably progressed on one design solution, even when fit-out developers released preliminary information in a set-based fashion, and limited rework risk through investments in buffers and modularity. Aware, however, of the merits of developing alternatives under uncertainty, upstream developers engaged in set-based exploration at the very early stages of design definition. In this 'optioneering' stage, they examined the performance of alternative solutions in terms of cost, programme, buildability, aesthetics, and adaptability to change. Yet, they would pragmatically choose one option to further develop and detail to move forward to physical execution on site, knowing that fit-out uncertainty would not be resolved until near, or after, the end of base-building implementation. A structural designer explained, for example, how the design for the cross-section of the control tower mast was frozen three years ahead of project completion when uncertainty was high regarding the cab internal configuration:

> "We did not develop parallel options. We initially looked to what we had to have in the cross-section layout and above — one or two lifts, a staircase, and service cores — and quickly reduced options: the square performed badly aerodynamically, the circle would make it difficult to have flat landings, and then we came with this triangle shape that allowed for a flat landing area in front of the lift."

We next summarize our empirical findings into a decision tree on resolving upstream base-building design under downstream fit-out uncertainty and ambiguity.

Results and Business Impacts

Key Findings

Figure 3 summarizes the choice for resolving base building under ambiguity and uncertainty about fit-out between the iterative and buffering strategies. The stylized decision tree shows an iterative strategy as the suitable choice when the fit-out information is ambiguous. Adaptation costs are limited if changes are circumscribed to a base-building subsystem that has a modular interaction with the fit-out subsystem, but can escalate if changes affect a base-building subsystem with an integral interaction to fit-out, unless base-building developers are allowed to constrain the space of fit-out solutions.

If the fit-out design is uncertain but not ambiguous, modularization of the interaction between subsystems is one option to limit the base-building adaptation costs. Functional elements with modular interactions can be available ex-ante (e.g., baggage conveyor belt case) or be developed (e.g., control tower mast and cab case). In the case of the control tower project, for example, modularity was combined with the overlapped approach in the face of the high risks to the business stemming from an inflexible base-building design: not only would adaptation costs be extremely high because the construction site was difficult to access (aircraft wing tips came within 2 meters of the edge of the site), but a delay would impact the timing for the airport operator to trigger a regulated increase to the airport levies.

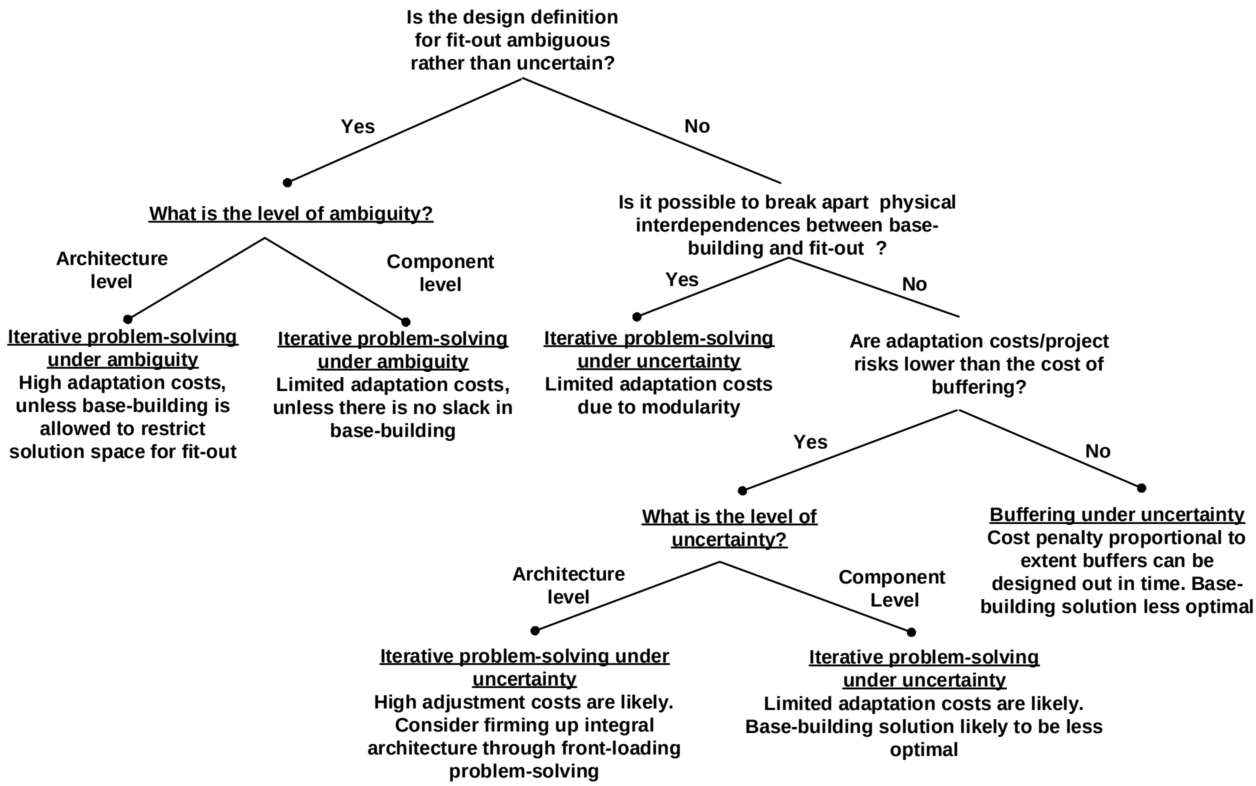

Figure 3 – Choosing between Iterative and Buffering-based Coordination under Extreme Overlap (adapted from Terwiesch et al. 2002)

If modularity is not an option because of complexity, a trade-off emerges between investing in a buffering or iterative strategy. Two nuances matter in assessing this trade-off: First, can buffers be designed out if uncertainties resolve favourably before the implementation of the base-building design? Second, does fit-out uncertainty exist at the architecture level where it is likely to lead to high adaptation costs, or at the component level where it is likely to lead to limited adaptation costs? A buffering strategy exhibits two trajectories, which differ according to whether buffers stay throughout or are removed in design definition. The buffers can only be taken away efficiently, i.e., with marginal rework, if uncertainties get resolved before the beginning of physical execution. Base-building developers, for example, designed out some buffers in the M&E backbone subsystem (e.g., removed provision of some dual power supplies) because the final floor arrangement drawings were released before the beginning of pre-fabrication of the related M&E modules. In contrast, they left the buffers in the cross-section of the service cores of the control tower mast.

Business Impact

Design briefs are documents that the client commissioning new infrastructure prepares at the project outset to communicate to the developers preliminary information about the operational and functional needs for the infrastructure. Our findings suggest that briefs need to better spell out the extent that preliminary information about fit-out subsystems is ambiguous or uncertain, or both, and when information is likely to become final. This will make it easier for base-building developers to map the most suitable coordination strategies needed to efficiently apply the overlapped approach. Further, if base-building developers are better informed about the reliability of information about fit-out subsystems, they can better investigate and tell the client whether it is worth investing in modularizing the physical interactions between functional subsystems/components given that this effort does not come for free. This can help the client’s business reduce the risk of delays and budget overruns that projects incur whenever late changes are made to base-building subsystems that are integral with fit-out subsystems. Informed decision-making likely will lead to better project management.

Conclusions

In infrastructure projects, some of the challenges to compressing the physical execution of base-building subsystems can be insurmountable due to the mammoth scale of the work, inadequate site accessibilities, scarcity of skilled labour, and complex issues such as stringent regulation in the domains of health, safety, and insurance underwriting. Yet, the speed of evolution in the needs of businesses and in the fit-out technology is unlikely to slow down. Here, we elucidate how base-building subsystems in integral infrastructures may be adaptable to incremental changes in fit out subsystems because of slack, but costly to adapt to radical changes. We also show the suitability of modularizing the interaction between base-building and fit-out subsystems to ensure an efficient application of the concurrent development approach. These findings suggest that clients, design consultants, suppliers providing integrated solutions, and product manufacturers want to invest more in developing base-building subsystems and components with architectures that interact in a modular way with the surrounding physical environment. Such efforts need to go beyond current efforts to prefabricate modules off-site into system solutions that exhibit decoupled, standard interfaces and simplified mapping between functions and physical elements. We summarize next the key lessons of our study.

Key Lessons Learned:

- Prefabrication of base building modules off-site does not mean that base-building subsystems have modular interactions with fit-out subsystems
- Base-building subsystems that are integral to fit-out subsystems seldom are economically adaptable to evolution in fit-out requirements
- Modularization of infrastructure subsystems does not come for free, but can pay off if operational requirements evolve over the infrastructure life-cycle
- Decisions to buffer base-building need to be informed by the reliability of preliminary information about fit-out subsystems and modularization costs
- Fit-out developers need to learn how to reliably exchange preliminary information, namely on the expected degrees of uncertainty and ambiguity

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The Project Culture – Forces behind the Optimum Project Performance

Jian Zuo & George Zillante

The Project Culture – Forces behind the Optimum Project Performance

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Abstract

There is a growing attention within the Construction industry to procuring facilities at low cost, with high quality and within a set time schedule. Construction projects were traditionally procured via the competitive tendering approach. Its competitive nature, compounded with the different objectives of the contracting parties and the practice of improper risk allocation, have led to adversarial relationships. This has resulted in poor project performance and confrontational disputes. This research employed a case study methodology to investigate how the collaborative contracting approach and its endorsed appropriate project culture can lead to better project outcomes and improved satisfaction of user requirements. The implementation of collaborative contracting and the development of an appropriate project culture led to all project team members concentrating on the same goal i.e. to achieve the best value for the project and the client/end users. The innovative KPIs and performance evaluation process were adopted in the project. Ownership of the project when combined with collective responsibility and collective decision making ensures the maximum commitment from all parties and leads to better user satisfaction The study also found that ICT support helps to achieve better satisfaction of user requirements by facilitating communication and collaboration amongst project participants.

Keywords: Project culture, collaborative contracting, value, performance metrics

Background

Industrial Context

The public image of the construction industry is generally poor. It has a long history of criticism for its poor performance with confrontational relationships and disputes among contracting parties (Jamieson & Thorpe 1996; Kumaraswamy 1997; Kanji & Wong 1998; Love et al. 2001; Dulaimi et al. 2002; Humphreys et al. 2003; Winch 2003).

A Construction project is usually procured by competitive tendering. Its competitive nature when compounded with the different objectives of the contracting parties and the practice of improper risk allocation, have created an adversarial relationship (Zuo and Zillante 2006b).

The traditional approach of clients dealing with risks is really a risk transfer strategy i.e. they try to transfer as much of the risk as possible to non-owner parties (ACA, 1999). This risk transfer approach is reflected in the traditional construction contracts, including lump sum and schedule of rates contracts (Quick, 2002). Being negotiated and amended in an adversarial environment, these contracts result in an even more inappropriate allocation of risk, detrimental to the time cost and quality objectives of the project.

For instance, construction projects are traditionally procured via a price competitive approach, where the tenderer with the lowest price generally wins the contract. The contractor often seeks to recover his/her loss due to the ill-apportioned risks during the contract by making a series of claims. This risk management strategy often fails and results in a construction industry plagued by disputes, time and cost overruns and overall poor performance (ACA, 1999; Quick, 2002). This traditional 'win-lose' approach is criticized for being responsible for the adversarial relationships between project team members and, as a consequence, the poor performance in terms of profitability, productivity and efficiency in project delivery (Rwelamila et al. 2000; Walker & Hampson 2003; Zuo and Ma, 2004).

The need for process improvement and cultural shifts has been advocated as a means of improving the effectiveness and competitiveness of the construction industry (APCC 1997, RCBCI 2002, Latham 1994, Egan 1998). More specifically, the need for a unified and positive project culture becomes an important issue for project performance. (Korzilius 1988; Newcombe, 1997, as cited in Walker, 2002, pp. 129).

Problem

The fragmented nature of construction projects does not encourage inputs from parties other than the design team. Construction projects are traditionally procured by the competitive tendering approach and participating parties generally try to pursue their own self interests. The differing objectives of these parties always result in conflicts and disputes, and lead to adversarial relationships.

The aim of open building manufacturing is to enable customers to purchase high quality at low cost whilst maintaining a high degree of design flexibility. Similarly, the literature claims that project culture is a very important factor for achieving better performance of construction projects; however there are few studies on the way that project culture contributes towards improving the satisfaction of technical requirements. As a knowledge-based industry, the construction industry requires better understanding of project culture issues and the impacts of those on the performance of construction projects.

Learning Objectives:

- Innovative procurement approach
- Value driven KPIs and performance evaluation
- The concept of project culture in the construction context
- The impacts of project culture on the performance of construction projects
- ICT support to achieve improved collaboration and co-operation

Approach

This research employed a case study approach to investigate how open building manufacturing related methods and techniques help to achieve better project outcomes and improved satisfaction of user requirements. These methods and techniques include:

- The innovative procurement approach
- Early integration of the client and end users
- Key Performance Indicators (KPIs) and performance evaluation
- ICT support

At the same time, the impacts of the project culture on the performance of the project were also investigated to target the knowledge based construction industry.

Eight project participants were interviewed. They were from the key participating parties namely: the Government agency, the client, the collaborative consultant, the managing contractor, the architect, the engineering consultant and two major subcontractors. They were chosen because (1) they had significant involvement with the project; (2) they were available when this research was conducted; and (3) the multi-source of information improves the reliability of the research.

The interviews were unstructured and each interview lasted about 1 hour. The interviewees were asked to illustrate how the above listed open building manufacturing related methods and techniques were adopted in the Lyell McEwin Health Service Redevelopment Stage A (LMHS A) project. They were specifically asked to point out how these methods affect the performance of the project.

Some project documents were evaluated, after the interview process in order to confirm the statements made by the interviewees. Those documents included: a) Tendering documents; b) High performance team building workshop reports; c) Project completion workshop report; d) Relevant government authorities' reports; and e) Contractor's work documents.

Analysis

1 Brief introduction of the project

As one of the major hospital facilities of the North Western Adelaide Health Service (NWAHS), LMHS hospital's facility comprises a range of old and newer buildings with almost 50% of existing floor space more than 40 years old. These areas of LMHS were very dysfunctional, costly to maintain and no longer met the health requirements and health service delivery models of current practice (Public Works Committee 2003).

In addition, population growth in the Northern suburbs is estimated to grow by some 22% in the next ten years thereby requiring improved access for health facilities in the area.

As the first stage of the redevelopment, stage A comprises construction of two new wards, a coronary care unit (CCU), the Women's Health Centre, administration and education areas, the Central Sterilising and Supply Department (CSSD), a new emergency area, an imaging area, an intensive care unit (ICU), a High Dependency Unit (HDU) and several operating theatres. It also includes the demolition of the old imaging department. This work will lead to a fully operational clinical and inpatient functional area (Public Works Committee 2003). The total capital cost of this project was AU$91.2 million.

2 Innovative procurement approach

In order to target the issues associated with the traditional competitive tendering process, an innovative procurement approach was adopted in the LMHS A project. Collaborative contracting serves to select the best participating parties for this project who are capable of delivering the desired results within the specified time and available budget.

Tenders were assessed against pre-determined selection criteria which included inter alia: the capability to work in a collaborative relationship; the capability to work in an operating environment; the capability to achieve the project objectives; and price, etc. The process comprised initial short listing, interviews, final short listing, workshops, selection of the preferred tenderer and negotiation for the finalisation of the contract. The entire process was facilitated by a collaborative consultant.

During the tendering process, the ability of the managing contractor to collaborate with the rest of the project team was allocated a very high priority. The tendering process focused on the selection of a managing contractor for reasons of quality, experience, teamwork and the ability to own the project objectives. Being different from the traditional tendering process, price was only a small factor in the selection process. All people interviewed as part of this research strongly recommended that this model should be used for the selection of contractors for complex and high-risk projects and that it had the potential to be used in all projects.

All interviewees emphasized that only 'best-for-project' participants should be selected because they could cooperate with other team members to achieve project objectives. According to interviewees, the high level of collaboration and co-operation among various disciplines and parties was achieved with the assistance of the collaborative contract and its endorsed project culture. Similarly, the contracting parties were very clear about their responsibilities in the project and this reduced the risk of possible disputes arising from misunderstandings about the project objectives and each party's roles.

It was acknowledged that, while the costs of this tendering process were significantly higher than the traditional process, there was endorsement for the introduction of the relationship contracting approach in the form of a collaborative contract as an investment in the management of long term project risk.

Traditionally, a hierarchical organizational structure is used for construction projects. In such arrangements, one party, usually the client sits on the top of the structure and dominates the process (see Fig. 1).

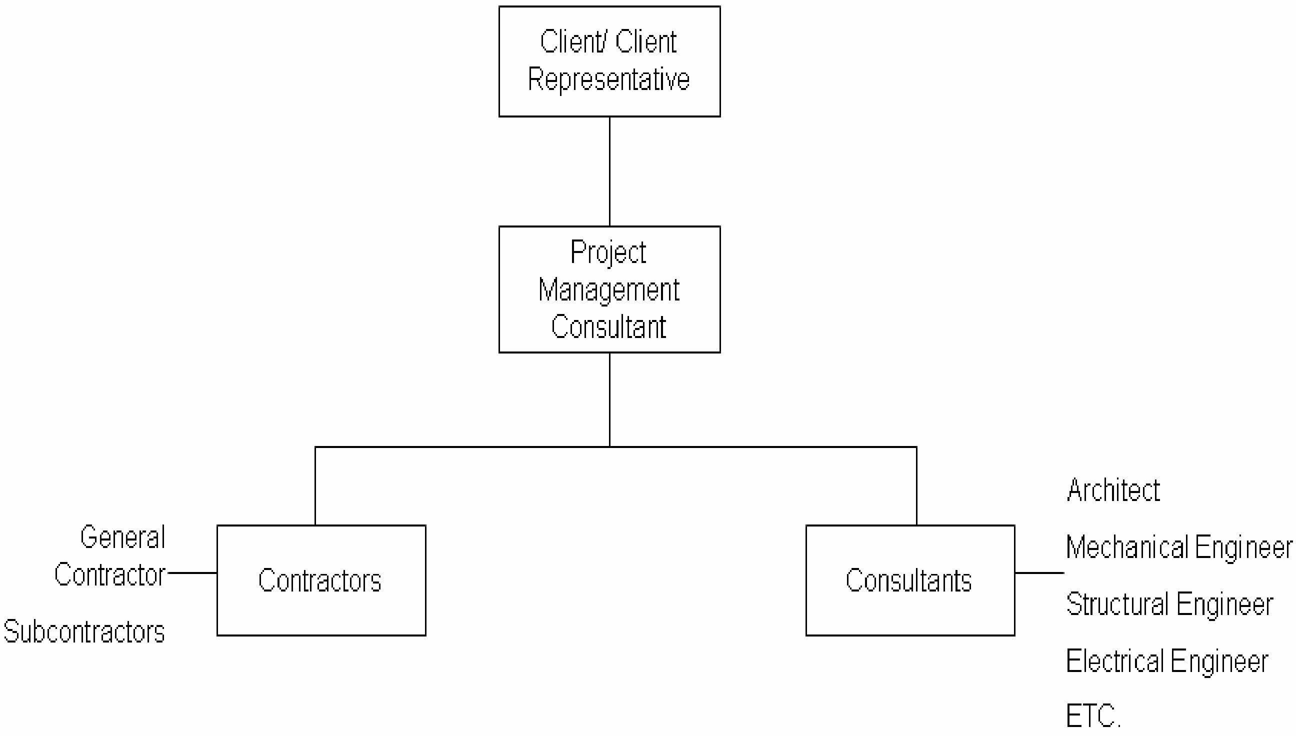


Figure 1 The organizational structure of a typical construction project with a project manager

In the LMHS A project, a non-hierarchical structure was established from the beginning of the project with all participating parties having an equal role (see Fig. 2). The client signed the direct contract with all consultants to ensure that all consultants had an equal say in decision making (Carr and Exton 2004). Under this system no party can dominate the team and all parties work together under the principles of relationship contracting. Similarly, all parties share ownership of the project outcomes by taking part in the decision making process. They share profits and risks and have common goals as objectives for the project which they work hard to achieve.

Figure 2 Relationships between participating parties in the LMHS A redevelopment

Traditionally a Project Manager is engaged to manage the whole project on behalf of the client (see Fig. 1). Even in a typical alliancing project, a project manager is employed to head the management team for day-to-day management of the project (see Fig. 3).

In the LMHS A project, there was no Project Manager role within the project team structure (see Fig. 2). This decision was made as it was seen that the usual hierarchical project management role was inconsistent with the objectives of collaborative contracting and equity among all stakeholders (Carr and Exton 2004). As the interviewee stressed: "…there is no position for project manager in the projects employing collaborative contracting…"

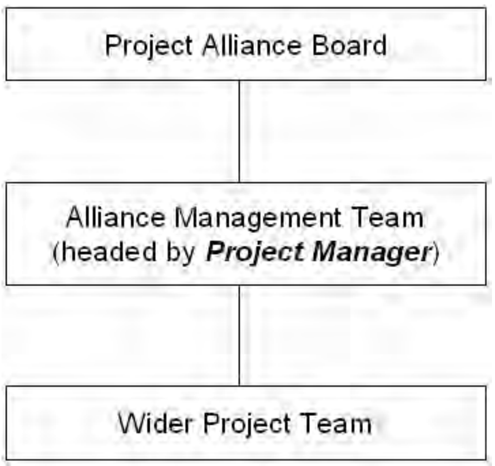


Figure 3 Typical team structure of an alliancing project, Source: Ross, 2001

According to interviewees, the project manager is not necessary (not a critical person) in relationship contracting projects because:

- The managing contractor does what is traditionally done by the project manager – programming and so forth;
- The architect acts as the coordinating consultant.
- Everyone is a 'project manager' by chairing the meetings
- The Government authority (DAIS) is the risk manager

The decision process is less bureaucratic and the final decision will not be made until it is agreed to by the whole team. When issues and / or different opinions arose, the following procedures were followed:

- A demonstration of the issues
- An Integrated Management Team (IMT) discussion
- Recommendations were made to the Executive Leadership Team (ELT) for action
- The IMT can debate with the ELT regarding how issues should be resolved

Under the above procedures, all participating parties had their say on the issues and how to resolve them. There were open discussions amongst all parties in the meeting after which all parties voted for the final decisions. This system allows for the client to be overruled as he/she has only one vote. This is an example of equity within the team structure which was designed from the beginning of the project. In actual fact the client and end users were very happy with this process and gained from it.

> "The project team management structure involves all participants in the project decisions through alignment and as a consequence ownership of the decisions is solid.
>
> The process and discipline of alignment in the team adds vale and improves the quality of the decisions.
>
> The project stakeholders, through their membership of the Executive Leadership Team, have improved the quality of project decisions and directions." (The Government agency's comments, Project Information Bulletin No. 16)

Because of this ownership, participating parties committed themselves fully to the project. All parties worked very hard and helped each other achieve the common goal i.e. to satisfy the user requirements.

According to interviewees, this innovative procurement approach facilitated the team building process as well as the management of the project team. The communication within the project team was both smooth and efficient. As well as being willing to help each other, all participants felt free to raise any issue of concern as well as giving early warning of possible problems.

3. Integration of the client and the end users in the delivery process

The client (Government authorities) and the end users (hospital staff) were integrated into the delivery process from the very early stages of the LMHS A project. As is illustrated in the following figure, both parties had key staff in the management team of the project. From the beginning of the project, both the Health Authority and the hospital staff were involved in the process of defining the requirements. They attended each meeting and expressed their concerns during the meeting. They were also involved in each performance evaluation meeting where they explained and clarified what their expectations were for the project and commented on the technical methods required to realize these requirements.

The Health Authority, the client of the LMHS A project, documented the hospital user engagement and acceptance as follows:

> "Overall the relationship between the team and the users has been very harmonious even when difficult issues were being addressed. The extent of working together that occurred through the of nine months period prior to the occupation and the equipping and commissioning has been far above the normal and has proven very effective. The work of the hospital redevelopment officer, although often under resourced, has helped this process. Similarly, deferrals, through cost management, of the very tight budget have contributed to the problems of forming the next redevelopment stage" (DHS 2005).

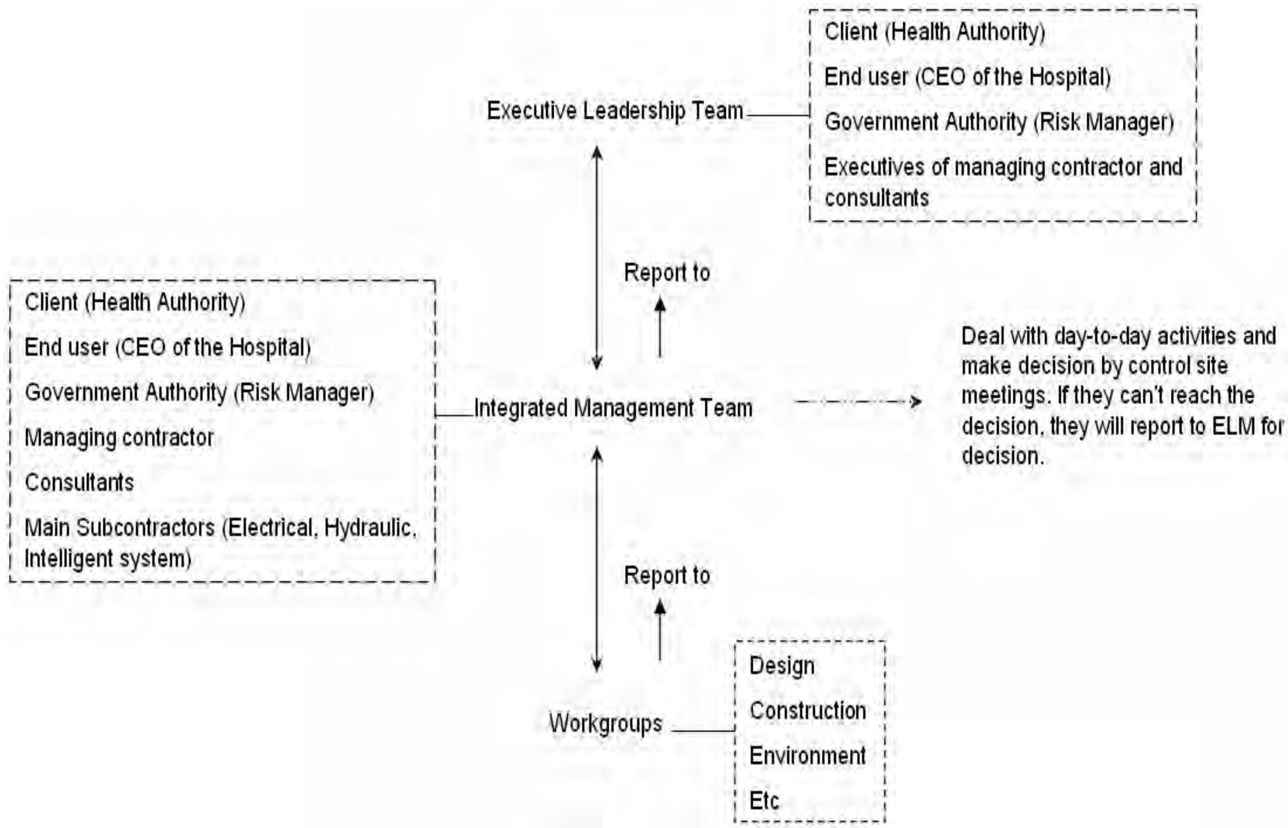


Figure 4 The management team of the LMHS A project

The principle of integrating the client and end users is manifested in the design and building of the operating theatres. The Redevelopment included constructing and equipping six operating theatres. Being at the centre of all major hospital facilities, operating theatres are very costly to construct, run and maintain.

In one team building meeting, the end users (heads of departments of the Hospital) placed the requirements to construct six operating theatres on the table and expected that these theatres would be built to a high standard and with low running costs. The delivery team went on to and refine and confirm the requirements during discussions with the end users. A brief that addressed all the requirements of the end users was then developed. With this knowledge the team could then propose solutions for each of the requirements. For instance, custom designed surgical equipment towers were used because of their ability to be manoeuvred from theatre to theatre thereby allowing all surgical specialists to have access to them. This provides for a high utilization of theatres thereby minimising down times and improving profitability. With the client and end users' inputs, the team constructed and commissioned all six operating theatres and satisfied all requirements. This process is illustrated in Fig. 5.

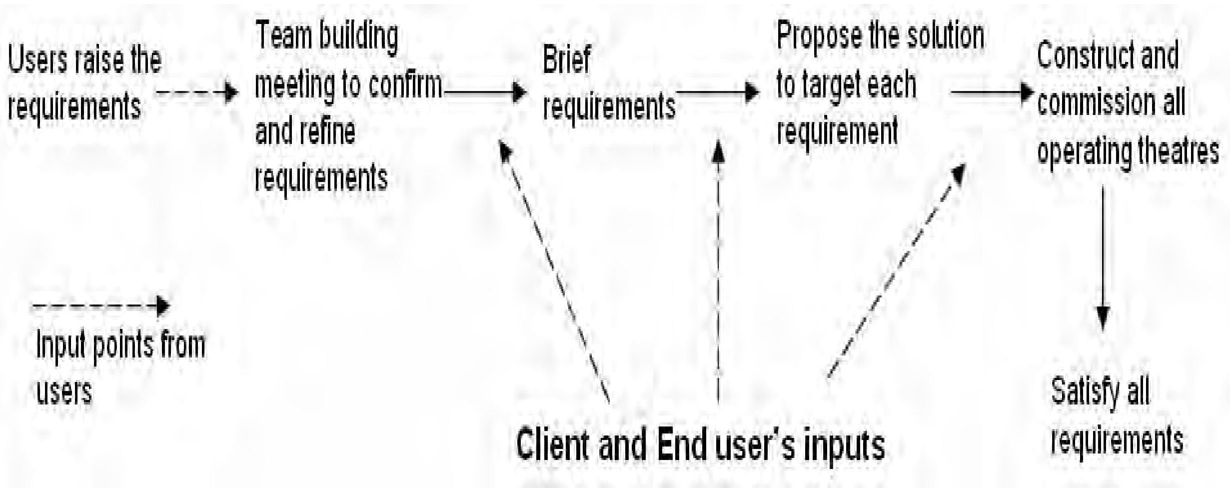


Figure 5 procedures used to confirm and satisfy the user's requirements

> "the delivery process for the Redevelopment allowed an integrated approach and the team balanced building capital costs, equipments standards and recurrent cost – a real 'value approach'"(Lyell McEwin Hospital Redevelopment Newsletter No 6)

The client was satisfied with both the process and the outcome of the delivery:

> "Compared with other teams there is significantly higher team cohesion and commitment to a common cause.
>
> The team has a real conscience that drives it to communicate widely, think of the community and find ways to widening the benefit of the project."(Client's comments, Project Information Bulletin No. 16)

4 KPIs and the performance evaluation

Key Performance Indicators (KPIs) affect the project culture through influencing how project participants work together during the project process. As compilations of data measures used to assess the performance of a construction operation, Key Performance Indicators are the methods management uses to evaluate employee performance of a particular task (Cox et al., 2003). Typically the actual performance is compared with the estimated performance in terms of effectiveness, efficiency, and quality in terms of both workmanship and product.

The way that participants behave within the project environment will be different and depends on the focus of management on different KPIs. This leads to different cultures. Xiao and Proverb (2002) point out that an organizational culture dominated by short-term financial consideration will have a negative influence on the quality performance of contractors; it leads to uncooperative, antagonistic and suspicious relationships with clients and other parties in the project.

In a typical project management system, the performance of each participant (or participating party) is evaluated and then rewarded based on their own contribution to the project. As a result, participants may compete with each other for their own benefits and individual objectives rather than the common goals (objectives of the project). This type of project culture is destined to be detrimental to the success of the project.

Under traditional relationship/alliance approaches, there is normally a financially related incentive framework for the team members to collaborate in developing a common vision and goals, to work together as a team to achieve successful outcomes, and to develop creative and innovative solutions. In the LMHS A project, this set of measures was extended by incorporating sustainability measures.

In the first workshop after announcing the successful tender, a certain amount of incentive funding was agreed to by all participating parties. A set of the Key Performance Indicators (KPIs) was also defined.

All major participating parties were responsible for evaluating the performance of the project against nine KPIs:

- Relationships and communication
- Time
- Cost
- Quality
- Safety
- Claims and issue resolution
- Environment and Ecologically Sustainable Development (ESD)
- Contract relations

Each KPI has several objectives to be evaluated by all participating parties. Each objective targets each contract clause. For instance, there are four objectives under the KPI for Relationships and Communication:

- Co-operation between parties
- Duty not to hinder performance
- Early warning
- Evaluation and monitoring

These objectives were evaluated by all participating parties by rating them from 1 to 5:

- 1 excellent;
- 2 above expectation;
- 3 meeting expectation;
- 4 below expectation;
- 5 unsatisfactory.

The group agreed on an action plan during the meeting, after discussing project objectives, comments, observations and suggestions for improvement.

Besides rating each objective, notes were also exchanged in order to improve the situation. For instance, at one stage of the project, the time KPI was rated as 4, which was below expectation. Comments were made that:

- One structural trade met tough targets
- Another structural trade performed poorly
- For the next part, steel delivery targets need to be more accurately determined
- Shop drawings and production for part 2 should continue through part 1 to ensure there are no problems with procurement (Project Performance Evaluation, 10 Dec 2002).

According to interviewees, this was a typical example of the collaborative project culture in the LMHS A project. The collaborative culture encouraged innovative ideas and solutions to be raised and applied during the project process. Up to July 2004, $2.83 million of added value was achieved, which is equivalent to 3.41% of the original budget of the project. Of this, 86.3% was ESD related. The managing contractor and the subcontractor that proposed these solutions were rewarded via a certain percentage of the incentive fund. Every participant was motivated to be innovative.

These performance metrics and the evaluation of the performance are driven by the perceived values of the customers (clients and end users) and other stakeholders.

All interviewees stressed that the KPIs adopted for the LMHS A project was different from other projects they had previously been involved in that had been procured via the traditional hard money contract. "… this is because the objectives of all parties have been aligned via collaborative contracting and positive project culture… we strive for a successful project, if the project is successful, we are all successful…". Because of the strong and early integration of the end users, the hospital's requirements were incorporated into the design right from the beginning. The active engagement of customers (clients and end users) enabled the delivery team to have a better understanding of the 'real' needs of the client, which in turn helped to achieve a better value for the project. Both the government agencies (as the client) and the hospital (as the end users) were extremely happy with the performance of the project and stated that in addition to the project goals significant value adding had also been achieved.

Similarly, all participating parties' goals had been aligned with the project goals from the beginning of the project via means of the collaborative contracting and the positive project culture. This 'win-win' approach also helped to achieve the value (business goal) of non-client parties. All parties enjoyed and shared the cost savings derived from the innovations.

The Lyell McEwin
Hospital Redevelopment
Building for the Future

Project Performance Evaluation

Date 10th December 2002
Attendees [redacted]

Refer to clause 6, ***Evaluation and monitoring***

Rating system

1 excellent
2 above expectation
3 meeting expectation
4 below expectation
5 unsatisfactory

The group should decide on an action plan during the meeting, after discussing project objectives, comments, observations and suggestions for improvement.

	Topic	*Contract Clause*	*Objectives*	STRUCTURAL TRADES		SERVICES TRADES		FAÇADE AND FITOUT TRADES	
				Rating this period	*Notes*	*Rating this period*	*Notes*	*Rating this period*	*Notes*
1	Relationships and Communication	3 4 5 6	• co-operation between parties • duty not to hinder performance • early warning • evaluation and monitoring						
2	Time	11 43 58	• time management • extensions of time • Completion by Contractual Completion Dates						
3	Cost	41 50 52, 54	• Variations • Prepayment • payments, final payment						

4	Quality	13 35 39 58 60	• achieve quality standards • assessment for innovation • timely Defects rectification • defect-free Completion • after Completion						
5	Safety	13	• occupational health, safety and rehabilitation management						
6	Claims and Issue resolution	Sched 5 61,62, 63,64, Sched 6	• Valuer • Claims resolution • Issue resolution • Expert Determination						
7	Environment and ESD	13	• energy, water, waste management, recycling, materails, air quality, noise • progress against benchmarks – energy, CO2, water, waste • practices and innovation • acknowledgement						
8	Contract relations	12 20-23	• industrial relations management • Consultant and Subcontractor performance						

Note: The names of attendees were not shown in order to maintain anonymity. The above performance evaluation form was used to evaluate the performance of the project on the 10th Dec 2002 but was not released on the grounds of maintaining confidentiality.

Figure 6 The performance evaluation form used in LMHS A project

Sustainability Achievements

Sustainable development was a major consideration in this project. Very strict Ecologically Sustainable Development (ESD) requirements were included within the documentation, tendering assessment, construction and operation. The redevelopment was awarded the 2005 Energy Efficiency / Environmentally Sustainable Award – SA.

An ESD Workgroup was formed with representatives from each participating party, e.g. the client, the consultant team and contractors. Some 90 ESD initiatives (e.g. open space, energy consumption, etc.) were incorporated into the design and documentation without additional cost (Carr & Exton 2004).

The ESD achievements as at Dec 2004 were as follows:

- The development footprint was reduced to the point where it exceeded the open space requirement for the local site zoning by 25%. Some 68% of the site is open space
- Every aspect of the building envelope and the essential shading structures were developed and tested throughout the schematic design and design development so as to achieve ESD principles.
- The roofs were pitched at the optimal 20° on the north facing slopes for maximum solar gains.
- The design provided for >90% solar availability to >50% of the total new roof surface so as to maximise solar power and heating opportunities.
- The energy consumption for the new hospital building was less than 1312 MJ/m^2 per annum. The delivered energy consumed was less than 15% of any other hospital in South Australia. The use of solar hot water alone reduced total energy consumption by 10%.
- Less than 50% of non-toxic demolition materials were dumped to landfill. All non-toxic materials were recycled during the demolition.
- More than 65% of construction waste was recycled (industry benchmark: 50%) (Project Information Bulletin No. 16, 13 Aug 2004)

According to the interviewees, the relationship contracting approach helped to develop a positive project culture characterised by co-operative behaviour and attitudes. This culture encouraged innovations, including ESD initiatives. As one government officer interviewee stated: "… the traditional incentive is only concerned with financial performance. This easily leads to confrontational relationships between participants as they fight for their own interests. That is why ESD is one KPI and why ESD is involved in the incentive scheme… Relationship contracting facilitates good ESD outcomes."

Community and subcontractors proposed good ideas to better implement ESD in the project. They seldom have this opportunity in projects procured via the traditional methods. Relationship contracting and its collaborative project culture, facilitate better synergies and better integration of solutions.

5 Project Culture and its impacts on the performance of the project

5.1 What is project culture?

There is no clear definition of project culture, especially in the construction context. However, drawing on a well-recognized definition of organizational culture (e.g. Schein 1985; Hofstede 1997), project culture may be defined as:

"*the shared values, basic assumptions and beliefs that the participants involved in a project hold that determine the way they process the project and the relationship with each other in the project environment*" (Zuo and Zillante 2005, p. 357)

Zuo et al. (2006) reported on research concerning project culture issues in construction projects that involved interviews of a number of industry professionals. All interviewees believed cultural issues at project level significantly influence construction performance by cultivating an appropriate attitude amongst participants. According to interviewees, a collaborative culture may be more easily developed and sustained if the project is procured via a relationship contracting approach rather than by a traditional 'hard money' contract.

5.2 Project culture of the LMHS A project

A collaborative culture was developed in the LMHS A project, with the process to develop such a culture starting during the very early stages of the redevelopment.

The principles of relationship contracting were incorporated in the procurement approach and then in the contract conditions. The tendering documents clearly defined that a collaboration arrangement between the client, the consultant team and the contractor would be required. This collaborative relationship focused the project team on achieving common project objectives so as to attain a 'win-win' result for all stakeholders and for the project.

There was also an innovative tendering process to select the 'best-for-project' participants. Price was one of the factors to be considered but was not a major selection criterion. Rather, the capability of the tender to co-operate with the rest of the project team was given the highest priority. The short listed tenderers were also given opportunities to display their capabilities to co-operate with other project team members and to satisfy the technical requirements such as in a virtual setting with face- to- face interviews. The selection panel then observed whether and how the tenderer satisfied each selection criterion.

According to both interviewees and Government, the 'best for project' participants were selected via this collaborative tendering approach. These participants had the capabilities to work together. They also understood the project's objectives, including Ecologically Sustainable Development (ESD).

A team building consultant was engaged to create a high performance team with an appropriate culture by coaching and training the participants. A set of favourable behaviours (discussed among all participating parties) was established from the outset and was reinforced during the project period through workshops and training. Features of the culture included no-blame, willingness to help, outcome oriented, etc.

All interviewees acknowledged the advantage of this collaborative approach in achieving exceptional project performance. In addition, they felt committed to the ownership of the project and its outcomes. Because the team as a whole was responsible for the outcome of the project, all parties worked collaboratively towards achieving exceptional project objectives. All participants freely discussed the issues that arose. It was a collective decision-making process whereby all participants voted on the resolution of issues. The client did not take the advantage of 'one-vote' to dominate the decision making of project activities any more. The managing contractor and major subcontractors were members of the management team together with the client and the consultant team. They took part in the decision-making process and made valuable recommendations on how to achieve better value for the project (the client) from the contractors' perspective. Similarly, they were members of the panel that was responsible for performance evaluation and monitoring.

Rather than trying to avoid their responsibilities, all parties demonstrated a willingness to help each other. A no-blame culture dominated the project: "We should not blame each other when encountering difficulties . . . Just as in a football match, if one team-mate loses the ball occasionally, the other team-mates will not blame him when he makes that mistake. Rather, they will encourage him to keep going" (Interview notes, June 2005).

The involvement of the managing contractor and major subcontractors in the design phase contributed to the improvements in constructability. Inclusion of critical subcontract trades as part of the design team allowed input on design decisions and prompted assessment of various proposals, prior to spending time on the development of options that may not have been best for the project (Project Information Bulletin No. 16, 13th Aug 2004).

All parties had ownership of the project by sharing both the risk and the reward. Being contracted in this way meant that all parties had to work together to deal with the possible problems encountered during the project process. This also ensured the maximum mutual commitment from all participating parties and individuals because all parties would either win or lose together.

There was an atmosphere of openness and honesty within the project team with early warning of any problems. As an interviewee remarked, "Keeping good relationships is at the heart of relationship contracting. This does not mean that participants will not reveal problems they discover during the process. Early warning of a problem is very important to keep the project running smoothly and, more importantly, healthy." In the LMHS Stage A project, there were occasions when the project participants spent more than three hours in meetings discussing issues until acceptable solutions were reached.

The comments made by one client representative is notable: "The same participants performed better in a relationship contracting project than they did in another project that was procured via the traditional hard-money contract … the poor project culture was very detrimental to that traditional project … the procurement method of fixed lump sum contract did not encourage a collaborative approach or lead to a strong team project."

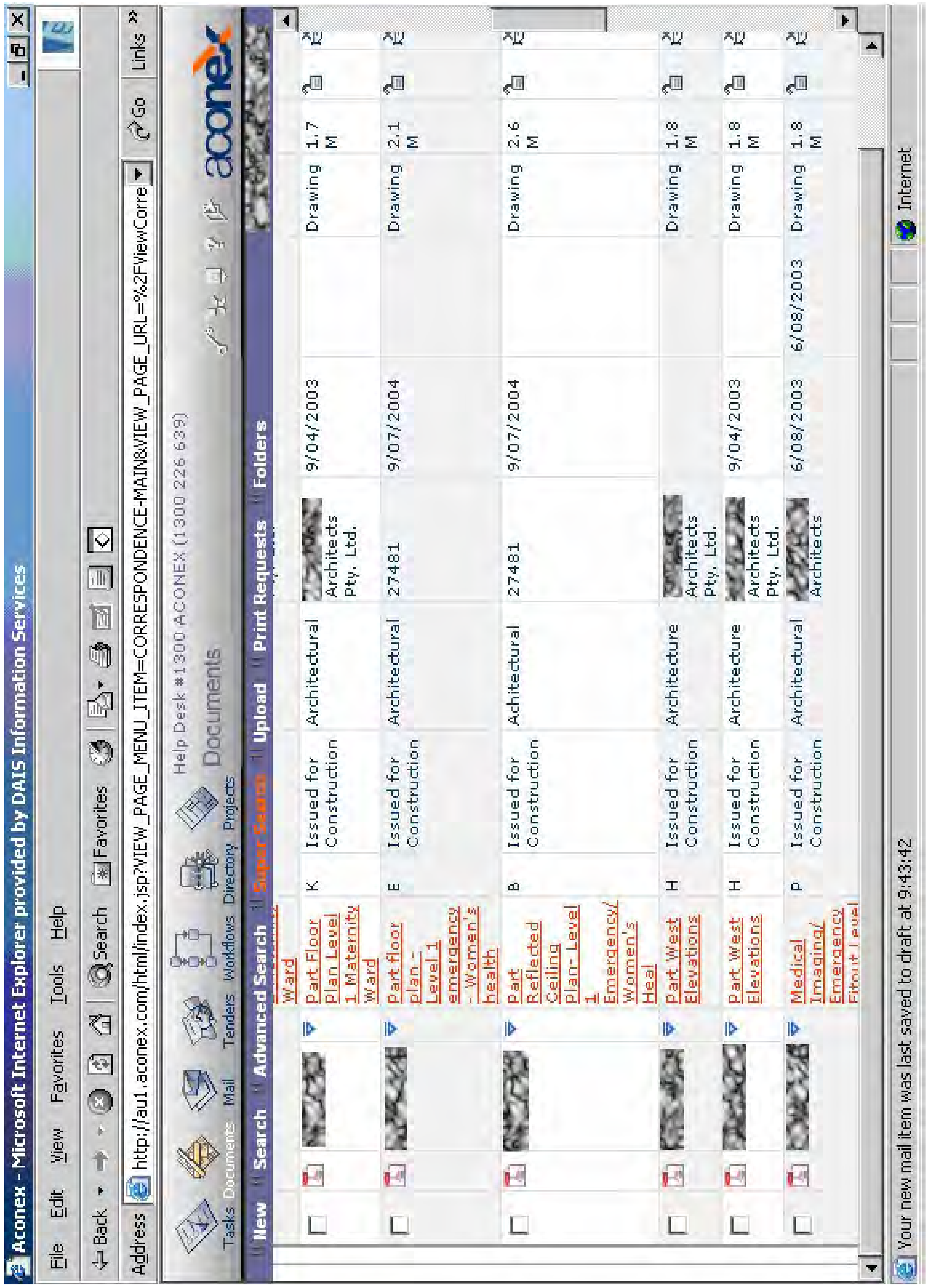
6 ICT support

ICT support can bring both tangible benefits and intangible benefits. Duyshart et al (2003) demonstrated that benefits of ICT support in the world-first alliancing construction project – National Museum Australia included:

- the achievement of improved communication and coordination of information between all project participants resulting in increased efficiencies, better-facilitated decision making and improved project control;
- the ability to increase flexibility for project participants by easily becoming a part of the project team through the use of ubiquitous, low-cost Internet and Web technology;
- the ability to increase savings in standard operating costs and approaches resulting from improvement in delivery processes, responsiveness, reporting and turnaround;

In the LMHS project, Aconex was chosen to provide a web-based communication and document management platform for all participating parties. Being registered with the Aconex system, participating parties (e.g. managing contractor, client, consultants, subcontractors) could access the project relevant information and documents such as drawings, mail and some tenders (see Fig.7 and Fig. 8). There were more than 200 project participants registered in the Aconex system which was used in the redevelopment.

As a tool that utilized the collaborative framework, Aconex enabled an open, efficient and unique ability for various participating parties to have direct two way communication with the client and consultants. This system also significantly reduced document printing costs and boosted collaboration.



Note: For confidential reasons, names and contact details of people and organisation in the project, actual document numbers and mail details are not disclosed.

Figure 7 Use of Aconex in LMHS A project (1) – Correspondence: provided by Mr. John Grinter

One key function of Aconex is the drawings register and maintenance that ensures drawings are available in real time. The access to drawings is controlled via the authorization and delegation of access rights. Aconex also provided functions to enable project participants to send, track, archive and generally manage documents like letters, memos, RFI's, instructions, samples submissions and minutes electronically.

Some statistics of using Aconex system, e.g. total mail sent, total recipients sent and received are illustrated in Table 1.

Table 1 Statistics of using Aconex, provided by Miss. Penny Stephens, Aconex

Total Mail Sent	**Total Recipients Sent**	**Total Mail Received**	**Total Registered**	**Total Docs Transmitted**	**File Size (GB)**
135	33691	79549	78613	59291	31345

The interviewees made generally positive comments about the implementation of the Aconex system in the redevelopment:

> "Aconex provides a cheap mechanism to exchange information, and document records are easily maintained. The system saves heaps of office space – we have about 10 CDs to store 40-45,000 documents." (Managing contractor, Source: Aconex website)

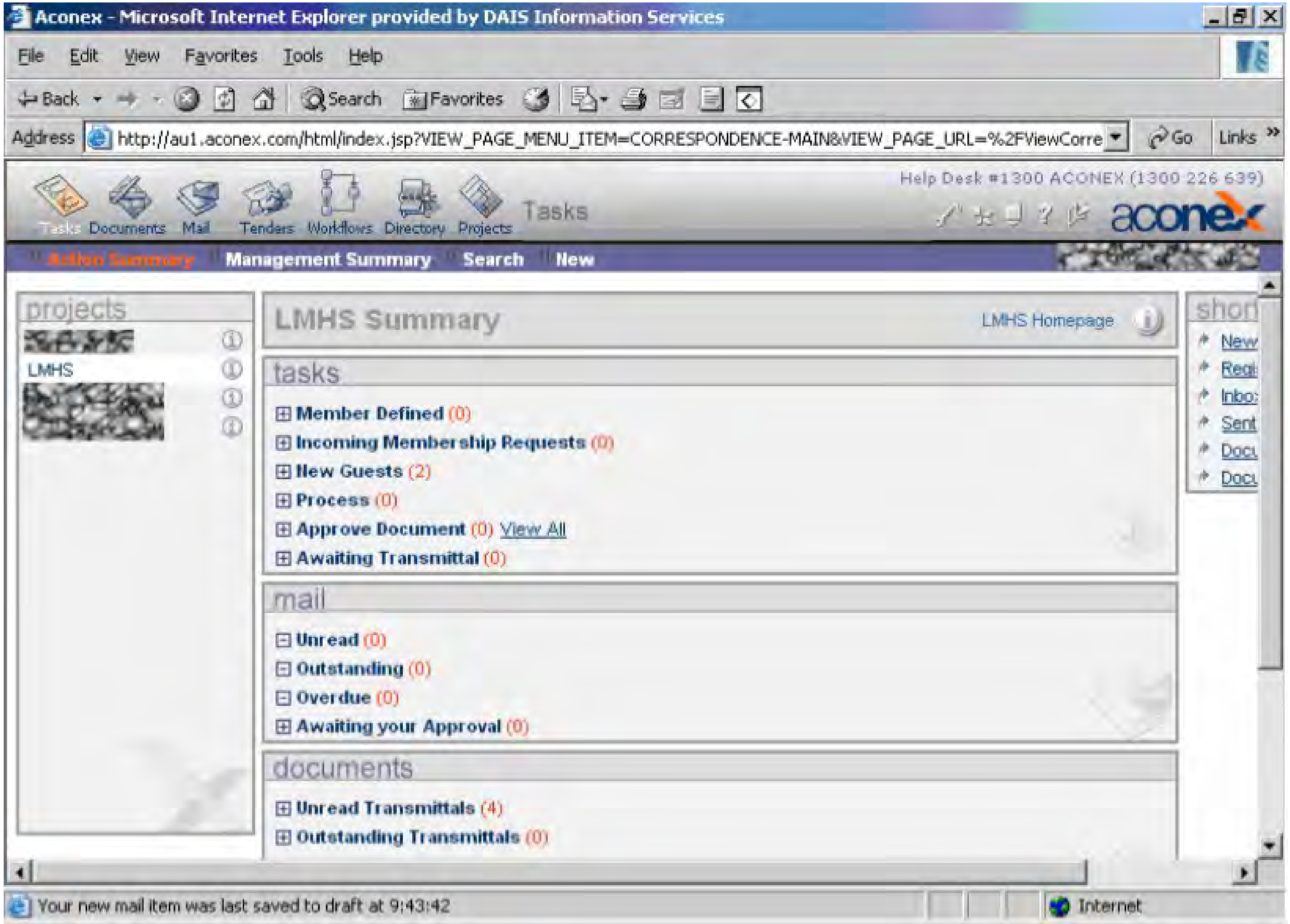
> "Aconex … emulates the more traditional collaboration process. There is also a high degree of certainty that, for example, all phases of a document will be managed correctly." (Managing contractor, Source: Aconex website)

> "Utilisation of an electronic drawing management and distribution system by not only the design team but also the subcontractors and client groups i.e. ACONEX. This has resulted in less printing than would normally be required by the project team and places the onus of additional copies on the respective trades. This proved to be efficient and was embraced by all participants" (Architect, Source: Integrated Management Team report Aug 2003)

> "(the system) is fairly user friendly, easy to use. It is a very good system to enable efficient communication… very easy to index and track project information i.e. emails, memos, etc. Generally speaking, it is better than other web-based project management systems that I have used." (Government Agency, from interview notes, Dec 2005)

The use of ICT support such as Aconex helps to achieve collaborative and efficient communications and improves the efficiency of dealing with project documents.

This system also facilitated the early and active integration of the client and the end users. Their comments on the design solution and the delivery options were communicated to the rest of the project team thereby resulting in a more flexible customer oriented design solution.



Note: For confidential reasons, names and contact details of people and organisations in the project, actual document numbers and mail details are not disclosed.

Figure 8 Use of Aconex in the LMHS A project – Project Summary: provided by Mr. John Grinter

Results and Business Impacts

Key Findings

The results indicated that both the collaborative procurement approach and its endorsed project culture help to achieve better project outcomes and improved satisfaction of user requirements with the assistance of: 1) collaboration and co-operation among various disciplines and parties; 2) more and early involvements from client and end users; and 3) inputs from contractors in the design phase (see Fig. 9). In the studied case, the open building manufacturing related methods, e.g. innovative procurement approach (business model and process), the value driven KPIs and performance evaluation, and ICT support contribute towards satisfying user requirements.

The collaborative procurement approach and positive project culture helps to facilitate the value management process and to achieve better value for both the project and the client (Zuo and Zillante 2006a). By minimizing waste, the project was able to achieve its high quality objective. Similarly, this enabled a high degree of design flexibility as well as encouraging design input from contractors. Innovations are encouraged from all parties. The result of all this value adding is that it can provide the client and end users with the opportunity to purchase the building at both a low cost and with a high quality.

Similarly, the collaborative procurement approach and positive project culture change the approach used to evaluate the performance of the project by shifting the focus from the financial perspective to the broader, user oriented sustainability focus. This not only improved the collaboration and co-operation among participants, but also enhanced the image of the project in terms of environmental friendly and sustainable redevelopment.

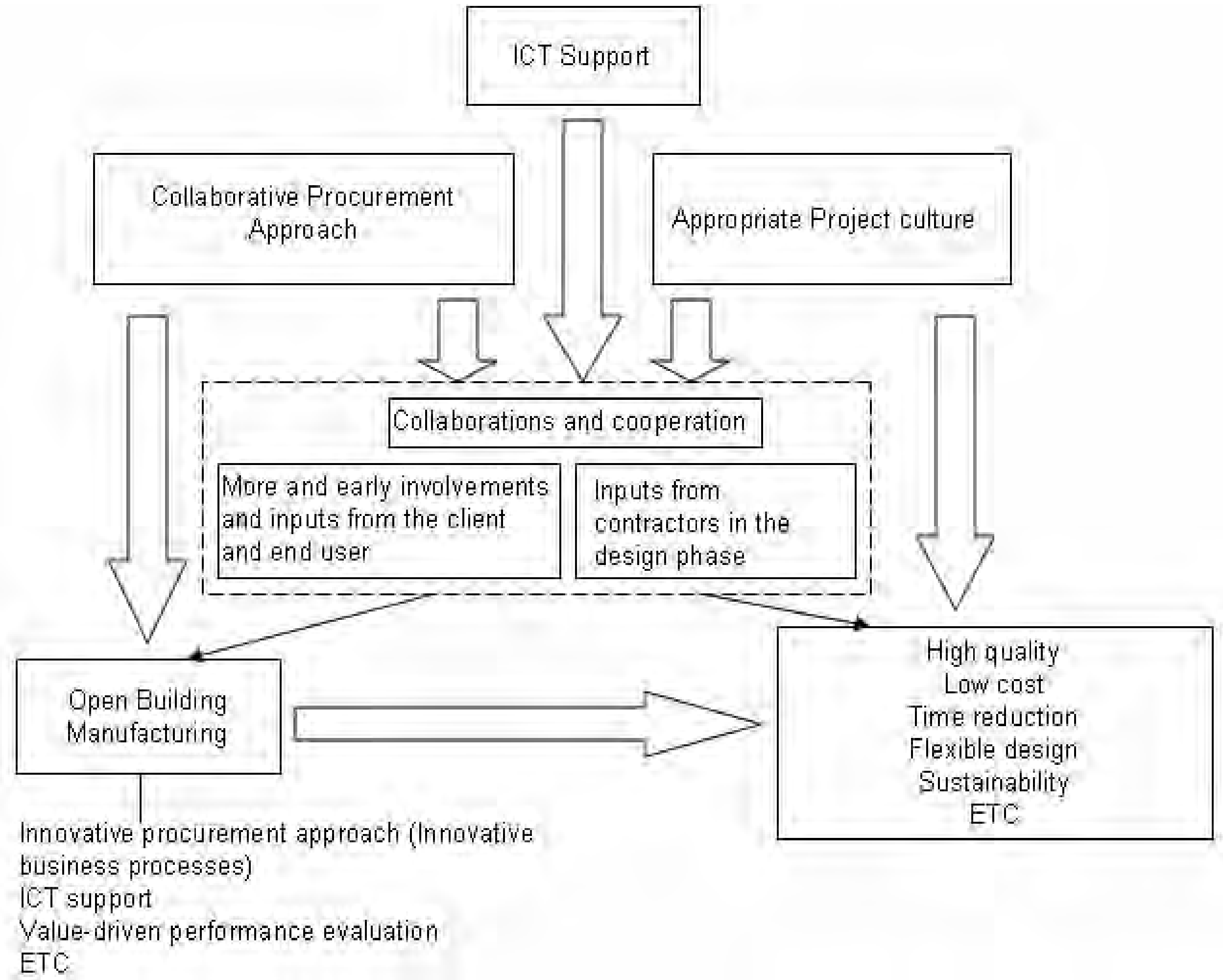


Figure 9 Findings framework

Business Impacts

The results indicated that both the collaborative procurement approach and an appropriate project culture help to achieve better project outcomes and improved satisfaction of user requirements thereby encouraging industry practitioners to use open building manufacturing methods and techniques such as the value driven KPIs and performance evaluation, and ICT support. This sends a clear message to industry practitioners – collaboration and co-operation between disciplines are very important in order to achieve better project outcomes. Collaborative contracting and appropriate project culture helps to foster collaborative and co-operative relationships among project participants. Accordingly this study encouraged industry practitioners to consider the impacts of collaborative contracting approaches and the creation of a positive project culture during the lifecycle of the project.

Some efforts are required for this to occur. Training and education are essential and will play a pivotal role in changing the mind sets of industry practitioners. It will not be an easy task to develop and sustain such a project culture during the lifecycle of the project and considerable resources, in terms of time, money, people, etc. will be required. Practitioners need to remember that this initial up front cost will create better returns as a result of better collaborative relationships and realized innovations.

Aconex is a good web-based system to provide ICT support and helps to enhance the efficiency of communication and to improve the collaboration and co-operation among participating parties. Industry practitioners should consider adopting Aconex or similar system in future projects.

Further research should be conducted to survey industry-wide practitioners and more cases should also be studied to see if the results can be generalized.

Conclusions

This research employed a case study approach to investigate the impacts of collaborative contracting and project culture on the performance of project outcomes. The results showed that both the collaborative procurement approach and the appropriate project culture significantly affect the performance of construction projects. The key elements of the culture in the LMHS A project include: ownership of the project and its outcomes, openness and honesty, early warning of problems, no-blame, willingness to help, mutual trust and respect, etc. Similarly, under collaborative contracting, participants tend to choose different sets of KPIs where more emphasis is put on non-traditional and soft issues, e.g. communication and relationships, sustainability, etc. The procurement approach adopted in the LMHS A project is very innovative. The ‘no Project Manager’ approach was successful and will be adopted in future major projects in the public health sector. ICT supports efficient communication and boosts collaborations and co-operation among project participants.

In summary, in the LMHS A project, the use of collaborative contracting and the developing of a positive project culture helps to achieve better project outcomes and a high level of satisfaction of user requirements. The relevant open building manufacturing methods, e.g. innovative procurement approach, ICT support, and value-driven performance evaluation play their roles towards these achievements.

Key Lessons Learned:

- Both the collaborative contracting and the positive project culture significantly affect the performance of construction projects.
- Relevant open building manufacturing methods, e.g. innovative procurement approach, ICT support, and value-driven performance evaluation help to achieve better project outcomes and improved satisfaction of user requirements.

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Authors' Biographies

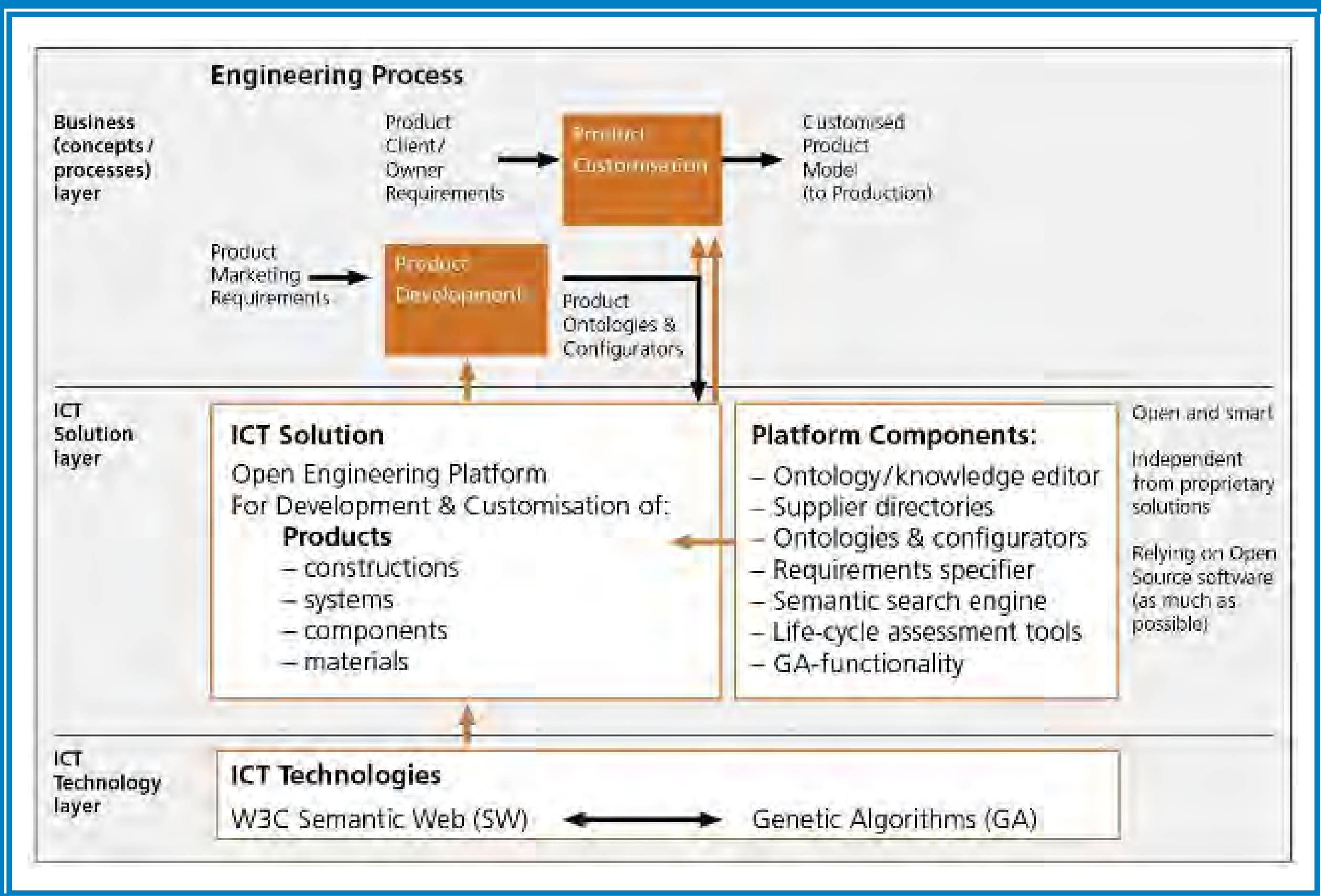
Jian Zuo obtained his Masters degree in Engineering from Wuhan University, in the Peoples Republic of China. Currently he is a PhD scholarship student at the University of South Australia. His main research interests relate to the impacts of cultural factors and procurement approaches on the performance of construction projects.

George Zillante is Associate Professor and Head of Building at University of South Australia. He has qualifications in Architecture, Urban & Regional Planning, Building Surveying and Business Administration and has worked (and continues to work) at the professional level in those fields. Over the years George has done a lot of work in the field of Building Legislation and this has resulted in his appointment to many Government Committees including, inter alia, Chair of the South Australian Building Advisory Committee, member of the South Australian Development Policy Advisory Committee, member of several Australian Building Codes Board Committees as well as representing the Australian Construction Industry on the International Association for the Professional Management of Construction. This interest in Building Legislation led George to establish the Centre for Building & Planning Studies at UniSA in 1993 and has resulted in several research projects dealing with the impacts of legislation on development and, more recently on Bushfires and Government Policy responses to the impact of Bushfires. George is also a member of several Professional Bodies (RICS, AIBS, AIQS, AIB etc) and serves on a number of Education & Accreditation Committees.

14

Using the LEGO™ Analogy to Engineer, Configure, and Optimise

SWOP Project Consortium



Using the LEGO™ Analogy to Engineer, Configure, and Optimise

The SWOP Consortium[1]

Abstract

Do you remember playing with LEGO? Assembling little blocks into a solution that fitted requirements of your imagination. You did not make the blocks but knew their capabilities and configured them creatively. The SWOP[2] project (Semantic Web-based Open engineering Platform, NMP2-CT-2005-016972) is doing much the same but with engineering and business "blocks" (parts of engineering or service products) that are parametric – so adaptable Lego blocks! SWOP is based on the new intelligent-internet - the Semantic Web. Solution approaches expressed as components, properties and rules can be stored, retrieved, applied, compared, assessed and optimised against end-user requirements automatically.

A benefit of the semantic, digitally modelled world is the ability to experiment at speed. Many problems in industry and business are simple in principle but complex and time consuming to optimise. SWOP introduces an optimisation engine based on the Genetic Algorithm (GA) approach which allows rapid analysis of numerous solutions that, en masse, map out the peaks and troughs of near-optimal solutions. The technique is not new but it has been difficult to join it to the real world. SWOP makes a semantic connection.

Four diverse industry cases are described, illustrating SWOP's aims to:

- *model product structure and knowledge, including configuration rules (assertions that must be held to and/or derivations that can be executed)*
- *improve flexibility of product customisation, reduce time and costs, and provide competitive advantage*
- *support supply chains with product knowledge distributed around the web*
- *compose products online based on client requirements as a customer relationship tool*
- *integrate with existing resource planning tools including the management of suppliers' catalogue information*

Keywords: business, configuration, semantic-web, optimisation, genetic algorithm

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[1] See contact details at the end of the chapter

[2] SWOP: Start date: 1 September 2005; End date: 31 August 2008; Budget: 4.15 M€; E.C. contribution: 2.3 M€

Background

Industrial Context: Configure, don’t create!

Many problems in industry and business are simple in principle but complex and time consuming in practice to solve due to there being many (potentially infinite) possible solutions with perhaps few that are near optimal. Often “a reasonable” solution is used rather than “the best” because of lack of time and the expense involved. There may also be other, even overriding, considerations than optimum engineering – like the availability of component parts that dictate the timely delivery of a solution.

Essentially the problem that SWOP tackles is universal in industry and commerce. If I am selling widgets that are identical in all respects other than their thickness (a spacer, say) then the problem is trivial and I have only to select a widget of the thickness the client wants – a perfect match. But if the widgets are part of a larger assembly with other components that require widgets of different sizes the problem becomes more complex.

Consider a heating system for a building and the selection of a boiler. The result will be influenced by the volume, shape and size of the building, the activities happening inside, the heating capacity, the boiler type and exhaust emissions, maintenance requirements, cost etc.. The heating engineer will go to a specialist heating supplier and express his requirements. The supplier may be one that simply has a fixed range of “off-the-shelf” boilers in a catalogue and he recommends some that seem to match or exceed requirements.

On the other hand, the supplier may custom design and manufacture boilers (especially for large industrial use). But even though custom produced, the supplier will design on the basis of systems and components that he has familiarity with – his LEGO blocks. There will be choices to be made and more than one way of configuring the required product solution. Even when a solution is determined (custom or from a catalogue) is it the best? Did I influence by my knowledge, my lack of knowledge or my shortage of time?

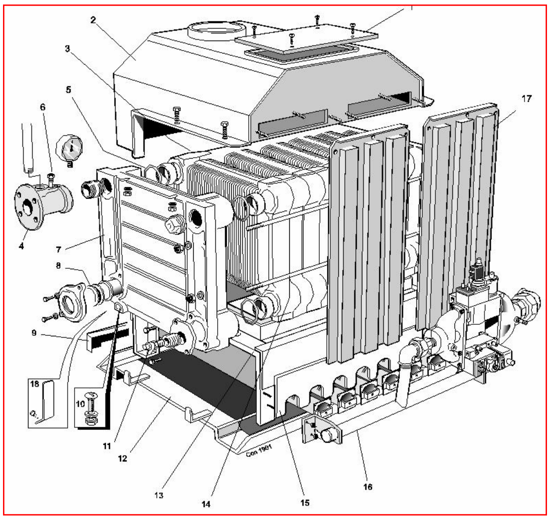


Fig. 1: Main elements of a commercial boiler system

A layman’s example, familiar to many, is the selection of a home computer. Competition is such that the custom specification of individual machines (as might have been done in the past) is too expensive. Instead, (and look at the DELL[3] computer web-site, for example) the customer is guided through an on-line process set by the supplier to configure a machine. Some of the rules involve sizing and choosing physical components and various performance criteria but some constraint rules are more hidden with marketing and pricing in mind. Total cost is continuously displayed so the customer can make sure it “fits his pocket” too. Of course, DELL is working (rather like LEGO) with mostly pre-determined components without much individual freedom, whereas SWOP will handle parts that may have many degrees of freedom.

It is a combination of something like the boiler and DELL examples that SWOP targets with the catch phrase “**configure, don’t create**”.

[3] DELL is a brand name of DELL Inc

Problem

There are four case studies of quite varied nature from four end user companies in SWOP:

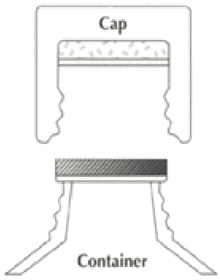
A. Saturn Engineering (Bulgaria) is an engineering design, product development and contract manufacturing company. It specialises in electronic and mechanical design, embedded systems, firmware and software development. Saturn provides a customer service to increase profits by reducing development risk and time of new products.

Examples of SATURN products are production line machines, container cap sealing machines, power supply for induction heaters, digital binoculars, sheet folding machines and medical and dental laboratory equipment. The focus for initial implementation will be the range of induction cap sealing equipment used across Europe and internationally.

The current process for deciding and approving a cap-sealing system configuration is long and inefficient, involving a chain of internal and external stakeholders - End User Customer, Sales, Saturn Engineering Division, Saturn Account Executives and Saturn Application Testing (QA).

CS350 Advanced Conveyor Cap Sealing System: 3kW output, very high line speeds (up to 100m/min).

Fig.2: Cap Sealing Machine



After removing the cap, the foil top remains bonded to the container.

Each time this process is repeated even for systems that have previously being tested and sold to the same or similar customers/applications. Reliable historical information is not maintained and analysed to support new decision making. The long and tedious product evaluation process slows down the sales cycle that is occasionally reflected in reduced customer satisfaction.

The time and effort for configuring and customising the equipment are not optimal and decisions are prone to mistakes. Under pressure of time, information may not be properly evaluated by a Sales person, which can later result in costly product recalls or upgrades at an end-user's site. There is a high cost involved in product customisation, with a need to maintain a significant inventory of pre-configured systems and often rework of existing products (reconfiguring).

The sealed containers cap sizes and shapes as well as the conveyor line speeds vary significantly.

- Cap sizes: from 12mm to 120mm in diameter
- Conveyor line speeds: from 3m/min to 100m/min
- Cap types: Flat, toll, sports caps, spout caps, flip-top caps
- Sealing axis: Vertical (bottles, containers), Horizontal (tubes)
- Foil types: Vary greatly in thickness, properties etc.

The SATURN/SWOP database will contain detailed configuration information about the target product type and its composition in terms of components and sub-components. Using this product composition knowledge the SWOP "engine" is able to find near-optimum solutions by combining the components according to specific rules and properties. The GA-based process produces the list of non-dominated solutions, along with their respective objective fitness values. It is then the responsibility of the user to favour some objectives if he wants to. For example, the delivery time could be prioritised over the price as the most important. There will usually be more than one factor that is important to finding a near-optimal solution. This is multi-objectives optimisation which is handled in SWOP via a so called Fitness Function (FF) that combines in a weighted way the various "axes of optimisation" into a single function. The definition of the FF requires company knowledge and experience. It embodies company technical *and* business know-how and is valuable intellectual property to be kept confidential.

The results produced by multi-objective fitness function approaches reflect far better real life situations, since when optimisation is tried against several criteria, most of the time (if not always) compromise in selection is required. Except with the greatest of luck, there will never be a single solution that will maximize the result for all criteria, and it will be up to a person eventually to put some priority on a given objective to pick a desired solution from among the several near-optimal ones found by GA's.

The system must find the optimal solution that fits customer needs by finding the closest configuration for the specified parameters. For example, if the input parameter is the price then it must find the closest offer to the specified price target (above and below the specified price).The system should if possible propose choices of configuration that meet users' needs.

B. TRIMEK (Spain) is a leading metrology (= the study of measurement) and inspection engineering company that designs and manufactures high-precision measuring machines. Machines must be competitive in terms of quality, added-value and cost. The initial requirements phase is an essential element of the life cycle of a process that starts with the active customer involvement and ends with the customer himself verifying his own needs.

A problem stage in Trimek's product modelling process is in the Sales Department's first contact with the client, when client's requirements are often gathered. A salesman's knowledge may be sufficient to make an adequate first assessment of a standard product, but in the case of special products the Application Department must first apply its technical knowledge to properly specify the product. Trimek wants to make this technical knowledge implicit in the salesman's first contact to offer a more responsive service as well as improving the specification process and raising the overall quality of product and services.

P9	Driving System	Single value from predefined set (manual, CNC, manual/CNC).
P10	Repeatability	Single value integer (m)
P11	Resolution	Single value float (m) from predefined set (0.5, 0.1)
P12	SW thermal compensation	Single value from predefined set (no compensation, automatic, manual)
P13	Linear Accuracy Specification MPE_E	Single value string (like "18+25*L/1000")
P14	Probing Accuracy Specification MPE_P	Single value float in microns
P15	Scanning Probing Accuracy Specification MPEthp	Single value float
P16	Scanning Roundness Accuracy Specification RONt	Single value float
P17	Temperature conditions	Single value from predefined set (like "20 degrees +/- 2K, 1.0 K/h, 1,0 K/m").
P18	Maximum 3D Speed	Single value mm/s.
P19	Maximum 3D Acceleration	Single value float mm/s^2.
P20	Air Consumption	Single value string (like "min. 6,5 bar 0,5, 150 l / min").
P21	Air Supply Pressure	Single value float bar.
P22	Electricity Consumption	Single value float Watt.
P23	Electricity Supply	Single value string (like "220V, 50 Hz 5%").
P24	Selling Price	Single value Euros.
P25	Lead-time	Single value weeks.
P26	Commercial margin	Single value Euros.

Fig. 3 above: Trimek SPARK machine.

Fig. 4 left: Some of the performance variables for a SPARK machine.

Trimek's focus will be the "SPARK" bridge-type measuring machine. It is available in different sizes to suit customers' needs and is wholly constructed from black granite, for high dimensional stability and precision movement. The measuring system of each axis is mounted on a thermally inert material making the machine fast and accurate even under temperature variations. The SPARK machine offers touch and optical sensors and comprises mechanical, electronic, software and hardware components specifiable by clients. Illustrating the kind of product optimisation needed, the criteria for best solution include:

Machine flexibility: Dimensions and ranges have influence on the usability of the machine. As a general rule, larger sizes make the machine usable for more flexible purposes.

Accuracy: Dimensions and ranges influence the accuracy of the machine. As a rule, larger sizes reduce overall measurement accuracy of machines. Also, resolution and the type of contact sensor influence accuracy.

Environment: The kind of floor (rigidity) in the place where the machine is to be installed and temperature control are important for accuracy when a piece is being measured.

Manufacturing cost: Smaller machines use less material, and are therefore less expensive.

Lead-time: The time to design the machine and set it up depends on several parameters, such as the machine resolution (the X-Y accuracy).

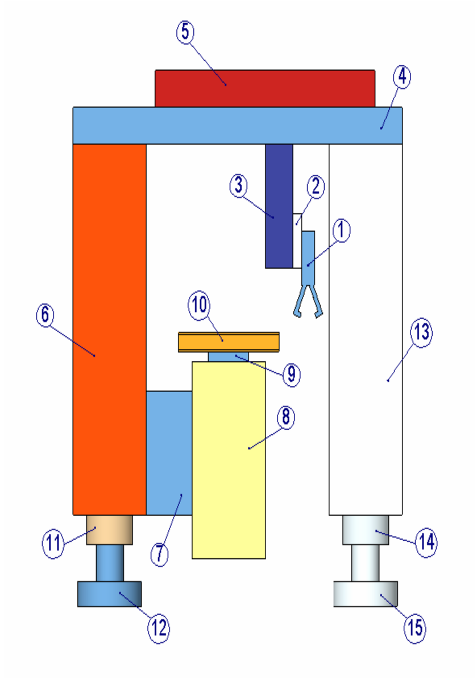
Commercial margin: Larger machines are more economic to manufacture.

C. Julius BLUM GmbH (Austria) is an international company that specialises in the production and distribution of fittings for furniture such as hinge systems, drawer runners and pull-out systems for kitchen cabinets in particular.

The company has localised manufacturing facilities all over the world but the main production unit is in Austria. BLUM's success has been based on the fact that all products of the hinge-, drawer-, and lift- systems have been and will be developed, manufactured, and assembled in-house.

But a prerequisite for this product innovation is process innovation. The linear assembly and special production machines used in the manufacturing process are vital to the company's competitive and innovative success. The development and configuration of machine tools, handling equipment and assembly operations is complex. Examples include:

- Stamping and deep-drawing dies (sheet metal processing)
- Plastic and zinc injection moulding tools
- Linear assembly and special manufacturing machines



Main components in a standard linear module. Up to 30 of these configured differently make up a manufacturing line.

1 Gripper Finger
2 Gripper Finger Plate
3 VTK, Vertical Axle
4 Flange Plate
5 HOZ, Horizontal Axle
6 Support Column
7 Spacer
8 Basic System
9 WT, Work Carrier
10 Product / Article
11 Foot Holder
12 Adjustable Foot
13 Support Column - optional
14 Foot Holder - optional
15 Adjustable Foot - optional

Fig. 5: A typical linear module

A linear assembly machine assembles a product from different individual components in a semi- or fully automated process at a relatively high manufacturing clock cycle. Up to 30 different linear modules are linked together, each performing individual linear operations. Fabrication and assembly processes (for new products) are typically configured 80% from standard, modular components with special tailor-made machines for novel new-product specific features (based on existing know-how, of course). Speed and efficiency are important to guarantee a timely market entry for new products.

BLUM intends to use SWOP solutions to improve internal engineering services and, more particularly, the internal design and configuration process of its linear assembly machines. The problem in the design and configuration of assembly lines is the know-how involved. On the one hand the knowledge is in the heads of experienced engineers. On the other hand it needs to be combined with additional data stored in different locations to design a functional and reliable machine. The number of possible sizes and combinations of the standard components is a special process configuration challenge in undertaking this.

BLUM wants to apply SWOP as a configuration platform that serves as a basis for conserving years of know-how (in the form of rules and principles). It hopes to offer its large team of design engineers a fast and secure option for equipment selection and configuration, reducing errors and reducing the number of optimisation cycles that presently are undertaken.

Ideally the platform should support two ways of working:

- first, after entering requirements to be a computation of possible solutions that maximise effectiveness
- second, a step-by-step approach controlled by the engineer at which after changing a parameter, the impact is immediately seen

D. ZÜBLIN (Germany) is a large building and civil engineering company. It intends to apply SWOP to the optimization of selected processes in tunnel construction using Tunnel Boring Machines (TBM). Such tunnelling is a complex process of interaction between:

1. Underground Conditions (geological situation, depth under-ground)

2. Surface Situation (under-water, inner-city)
3. Excavation Machine (TBM)
4. Construction Logistics (transportation, support)

1. and 2. are essentially input parameters and 3. and 4. have to be designed and optimised for those input parameters. It is not possible to reuse standard machines and solutions because the combination of input parameters is always quite different and efficient excavation and handling of spoil is vital to time and cost.

The selected SWOP focus is the separation of excavated soil. The separation is a well-defined process within the process line of tunnelling. It is required for underground excavations in soft soil containing a high fraction of fines such as clay and silt.

Fluid supported shield machines are widely used for driving through soft soil. Excavation is carried out by cutting and mixing the soil into a water-bentonite suspension which is pumped out of the tunnel to the surface. The suspension cannot be dumped or even stored for environmental reasons and parts of it might be classified as special waste. Considering the excavation volume of a large tunnel and the costs of special disposal, separation becomes a big issue.

The greater the proportion of ultra fine material in the subsoil, the more attention has to be paid to spoil separation. The requirements on the water content and/or the degree of purity of the separated soil material (respectively the disposal fees) then govern the limits of the economy of

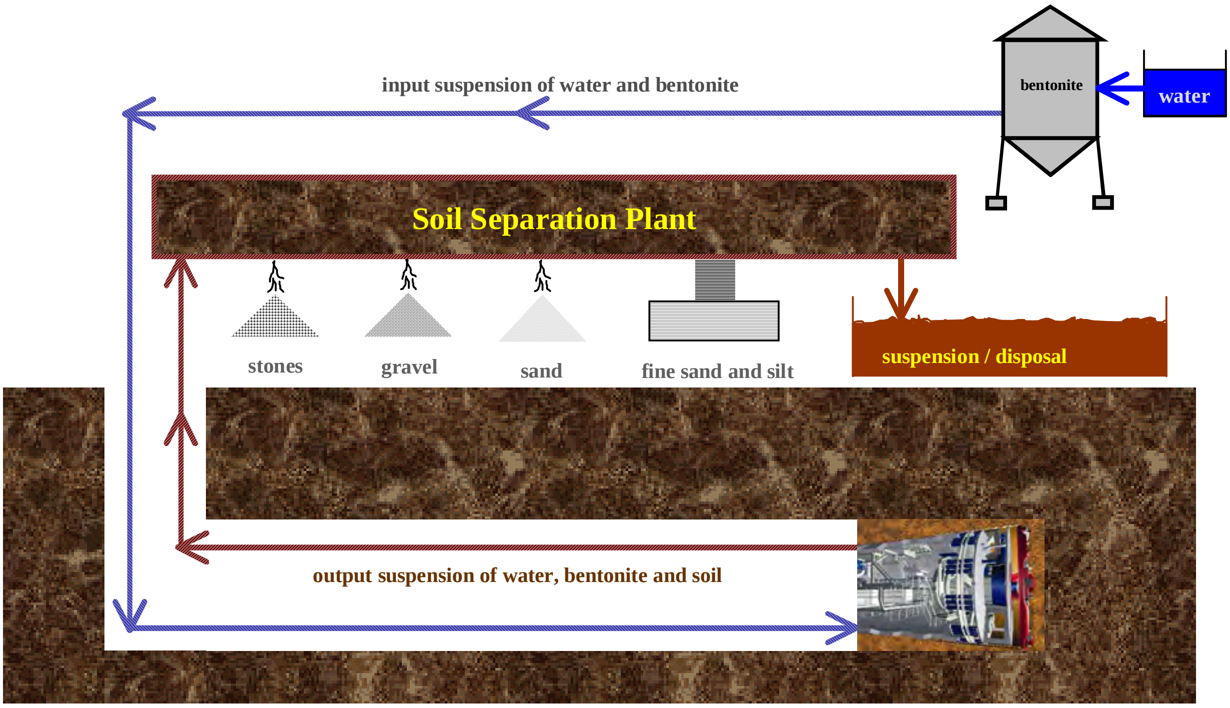


Fig. 6: Tunnelling and Separation Schematic

the method. The process of separation is a step-by-step mechanical and chemical procedure. The configuration of the separation equipment has to be well adapted to the incoming material. Because the geological conditions are never homogeneous the installations for the separation have to be "best fitted" for expected variety of soil conditions.

Currently this is a high-level engineering task covering a lot of different fields such as geology, civil engineering, chemical engineering and process engineering. There is no standard configuration for separation systems. The variety of soil conditions within a tunnel line is very individual. The separation system cannot be changed during construction time. It has to fit for all the different geological sections. This is the task of optimizing the configuration. We expect

SWOP to reduce the time spent for the configuration process and increase the quality of the results particularly in project phases where time is extremely short.

There are three main stages where the configuration of separation systems has to be specified: a) the quotation phase, b) implementation planning and c) system adaptation during use.

The quotation phase may be less detailed but correct pricing is only possible if the configuration is sufficiently detailed and complete. As time is particularly short in this stage it would be very advantageous to have a fast, reliable optimisation tool. In the phase of implementation planning things have to be specified in detail. Request parameters are then more precise and complete.

The first two options will be the most common cases for the use of SWOP. The third option is a later request during the implementation or from a running construction site.

Learning Objectives:

- Broadening understanding of what a Product might be
- Understanding the concepts needed to describe a Product
- Understanding how these concepts are realised via modelling
- Seeing the role of Semantic Web and the Web Ontology Language, OWL
- Understanding optimisation (getting better products) through the Genetic Algorithm method implemented at a semantic level
- To follow a simple example working in practice

Approach

First, note that the products in the industrial case studies described above are very varied – relating to machines, assembly lines and material processing. All are engineering examples although SWOP is equally relevant to services like a process plan with control properties (the product is an optimised “strategy”). Therefore, please think laterally about what a product is – it may be a physical result or a knowledge result.

Despite differences, what the examples have in common are i) a body of knowledge about the composition of the product (a semantic definition expressing the relationships between parts that make up the product), ii) rules about the (in)compatibility of elements (restrictions on how they are matched) and iii) information about the client’s requirements for the performance of the resulting product. Then there are measures of best performance that might include weightings of cost, capacity, speed, availability of parts etc. –whatever is relevant.

The SWOP approach is, in principle, simple:

1) Model the product (i.e. represent the possibilities of its nature by a digital description).
2) Model the rules that control the product (the restrictions on parts and interactions between parts that must be adhered to).
3) Combining 1) & 2) determines *valid* products.
4) Model the end-user customer requirements.
5) Explore the resulting valid model space to identify a) potential solutions that fit the requirements and b) from them, those that are near optimal.

What SWOP has proposed (and is presented in the next section) is a modelling approach covering 1) - 4) that makes the generic structure of a “product” explicit and acts as a template for defining the characteristics of particular types of product (as in the 4 case studies).

This product is expressed using a Product Modelling Ontology (PMO) - the set of relevant generic concepts that are together sufficiently powerful and expressive to model the ontology of products. Now, ontology is not necessarily a word familiar to end-users; it means “the way we understand something”. That something might be a cat, a LEGO block or a generic product.

Exposing some technical detail

SWOP asserts that there are 8 core, underlying concepts to a product that in fact constitute the PMO and can be understood by PMO compliant software:

a) Class
b) Property
c) Specialisation
d) Decomposition
e) Cardinality restriction
f) Property Unit
g) Property default value
h) Assertion/Derivation Rule

To explain these concepts the example of a staircase is followed. Although this is a ‘real thing’ taken from the Building & Construction industry the PMO approach is quite generic, industry/commerce independent and it can be applied to products within the widest interpretation of the word - from a process to a machine or to a city. But for now, we limit ourselves to a staircase, which is within the understanding of us all.

The 8 concepts are different aspects of the single “generic product” and as such fit together in a holistic definition of a product. This is made explicit through the PMO being expressed in the Ontology Web Language (OWL) from the World Wide Web Consortium (W3C). This is a very promising development based on the Resource Description Framework (RDF) and RDF Schema RDFS. RDF is a general-purpose language for representing information on the Web and the RDFS is a layer on top of RDF where a distinction is made between meta-concepts of classes and individuals. In RDF everything is a “resource”. Some software companies are now incorporating support for OWL in their software products.

1. Structure and Composition of a Product

Based upon the requirements from SWOP end users and the developed Semantic Web technology, the following 4 concepts were considered fundamental to the modelling of the form and structure of products (which could also be processes):

a) Class
b) Property
c) Specialisation
d) Decomposition

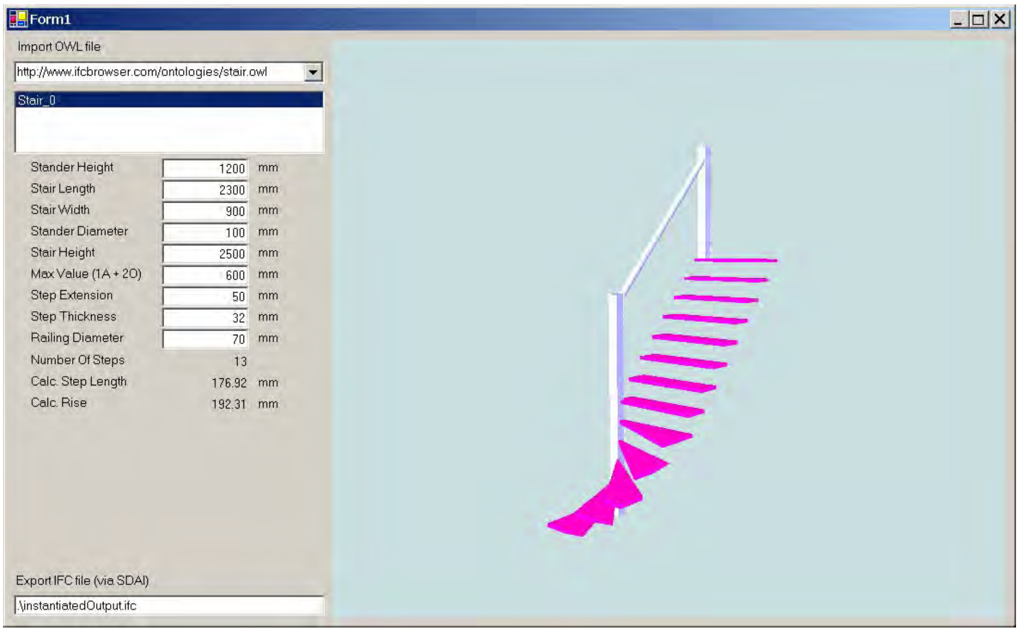


Fig. 7: Populated Staircase Ontology

a) Class

Class is already a developed concept in OWL. It is an abstract or meta concept. Actual products or processes (that you can touch or picture in your head) are **individuals**. An individual has characteristics inherited from the class but with properties that are valued.

Example: The staircase in figure 7 represents the **Class StairCase**. The class StairCase contains/defines all the freedom given to model StairCase; for instance the height, width and length of the staircase could be changed. An **individual StairCase** is an instance of a StairCase actually used somewhere. If this StairCase with the currently chosen height, width, length, etc. is actually placed somewhere it becomes an individual. In PMO terms it is **an individual of the class StairCase** (there is a specific relation between the individual and the class)[4]. A house of three floors normally has two individuals of the class StairCase. These could be two separate classes or one class StairCase with two individuals having, in most cases, slightly different values for height, length, etc.

b) Property

A property is already a concept in OWL, however its generic form in OWL does not correspond to what we mean by property within the PMO where we want to describe ‘parameters’. A subset of properties in OWL is Datatype Properties. These Datatype Properties exactly represent what is usually meant (in layman’s terms) by property.

Properties may be ascribed particular values, ranges or possible enumerations which instantiates the Class. A Property is related to a Class what means this related Class has this Property and all individuals of the Class are described within the “permitted” values of the Property. A Property

[4] **Classes** form the fundamental meta concept in OWL. They model the primary concepts with members as their ‘extension’. These are not “object-oriented classes” with methods but just reflect sets of members logically defined (like using predicates). The class members are ‘Individuals’ in OWL. It is important to interpret Classes and Individuals clearly: individuals are occurrences in reality one can (or could if they existed) point to; everything else is a class. This means a catalogue item is a class from which you can order three individuals. In product modelling a 3-level approach is generally preferred (“generic-specific-occurrence”) involving a generic class, a particular individual and a ‘variant’ in between (partially or fully specified) that can be placed in space or time several times.

has a type - real, integer, string etc. but cannot in itself (in isolation) be restricted. However in the context of a Class, **rules** can limit Properties to a subset of the domain.

Example: In the staircase example we see that several properties are defined and linked to the StairCase Class. Some of them are so restricted that the end user doesn't even have an option to change them. Other properties have several options but can be restricted. The default restriction for staircase height is for example 4000 mm. This is a default restriction and comes from Dutch laws, however if somebody from the UK wants to use this staircase class, but needs another value and/or more or less strict rules its easy to create a new PMO file that imports this staircase Class together with its Properties and only defines the differences in rules.

c) Specialisation

Specialisation is an existing OWL concept. It is a relationship between two classes, where one (super) class is the more generic version of the other more specific (sub) class.

Example: In the staircase example the class StairCase always has a 90º turn at the bottom. A more generic Class could contain all staircases with or without turns. On the other hand a more specific class could be all the staircases with a turn on the beginning and a height of 2500mm.[5]

d) Decomposition

Decomposition is a concept needed for product modelling that OWL does not directly support. Nonetheless, many parties see the need for decomposition and several solutions for decomposition exist as add-ons to OWL. PMO uses one of them taking into account the need to be as close to potential future versions of OWL that will support decomposition.

Decomposition is the breakdown of a Class into one or more Classes that the Class is composed of (i.e. sub-classes, but they are not given that name). All the decomposed Classes together do not necessarily make the original Class. Rather the correct configuration of the decomposed Classes makes the new Class. Further on how relations between the decomposed parts can be described will be presented. Also the influence between properties (one on another) can be described.

Example: The staircase is decomposed into a railing and a set of steps. The railing itself can be further decomposed in subparts. The dimensions of each step are dependent on the properties of the staircase. Also, all steps together with the railing do not make the staircase. Every decomposed Class should have dimensions based on the properties of the original Class (different dimensions of the steps) and also the actual configuration of the parts is important to get a valid StairCase. The rules on how to put a staircase together are linked to the StairCase

[5] **Properties** in OWL are rather special because of two characteristics:

a) They are 'first class' concepts meaning they are on the same level as the Class concept. In other modelling approaches, properties are secondary concepts. First there are entities … then properties that are typically directly associated with an entity (or class). It is not so in OWL. Classes and properties are considered equally important and are modelled separately; they are cross related as an action when relevant.

b) Properties in OWL do not just denote simple properties having a value according to some data type like height, width etc. but they also cover interrelationships between classes. Said otherwise: if classes are the nodes of an ontological network, the properties represent all the edges between them.

Consider the simpler Datatype Properties in OWL. For each property a domain and a range is specified. In the example, the domain is a Staircase so only a Staircase can have a StairHeight property. In principle if nothing is specified, all classes can have this property (so-called 'open world assumption'). Next a range is specified being the float datatype reused from the XSD name space. As well as floats, integers, strings and Booleans are possible, or more specific ones involving times and dates. In the case of strings discrete sets of allowed values can be entered.

Class. The rules of each decomposed part also apply and the creation of the Railing and the Steps are linked to the decomposed Classes and not to the StairCase Class.

2. Adding Semantic Richness

Although only 4 concepts have been defined, they are already enough to set up the structure of a product or process in a clear and descriptive manner. However what is missing is more detailed information needed to make the structure semantically richer and more useful to work with. The main detailed information that can be described in generic concepts is:

e) Cardinality restriction
f) Property unit
g) Property default value

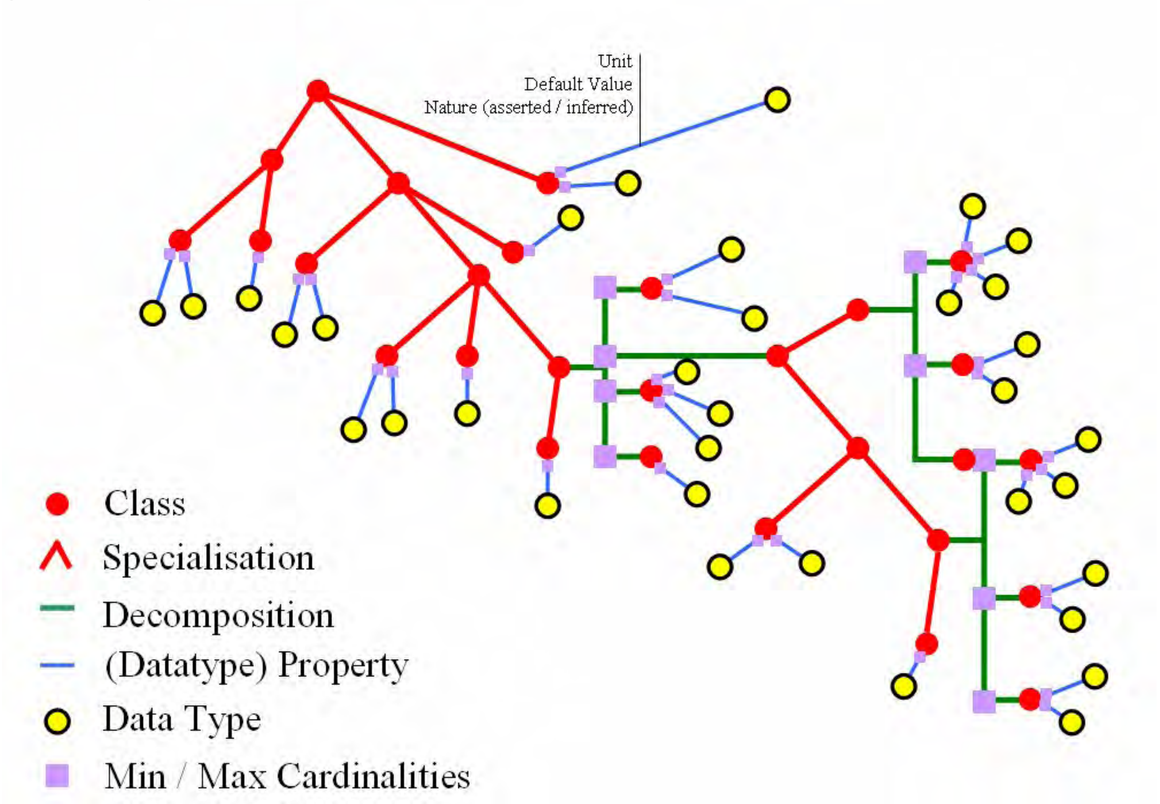


Fig. 8: Assembling the PMO LEGO pieces

e) Cardinality restrictions

Cardinality restrictions are optional. They impose restrictions on the number of Classes or the number of Properties that can be available.

Example for a Class: Cardinality restrictions on Classes are needed for decomposition relations. Take the example of the StairCase class. We might say that a StairCase needs to have at least 2 steps, this is a minimum cardinality restriction of 2 to the decomposition relation of StairCase into Steps. If we look at the Railing, we need always exactly 1 Railing, which means a minimum cardinality of 1 and a maximum cardinality of 1.

Example for a Property: If it is essential to have a property defined, this property is given a minimum cardinality of 1. It is essential for a StairCase to have a height.

f) Property unit

The **unit** of a property is a simple text field that stores the used unit ([prefix] + base unit).

Example: The StairCase Height Property is defined in millimetres. This means that the prefix is milli (‘m’) and the unit is metre (‘m’), so this will be ‘mm’.

g) Property default value

The default value of a property is a value used before the Property is actually assigned a value.

Example: The StairCase Length Property is used to calculate the number of steps. However when there is no value prescribed by the end-user (or Genetic Algorithm process) the default value 2300 will be used.

3. Power in Rules

h) Assertion/Derivation Rule

As figure 8 shows, the PMO supports the specification of the structure of a product or process. However a detailed description, geometry and restrictions are not limited to, or only defined by, the part of the PMO above which provides the total structure of the product or process and the Properties but not the rules and restrictions which also need to be taken account of.

Rules must be defined and added to the PMO to support the creation of product visualisation, for instance, as well as for storing formulae, technical calculation procedures, complex pricing issues and the like.

The PMO knows two types of rule:

- Assertion rules
- Derivation rules

Both types of rule will make use of Operations (see below) to configure formulae that can be (partly) reused and combined in an object-based manner.

Assertion Rules

Assertion rules are rules that must be always met. In effect they are rule functions that can result in outcomes that are either true or false and for valid product solutions the result must be true.

Example: in the Netherlands the height of a staircase may not exceed 4 metres. Accordingly, an Assertion Rule is added that says the staircase height must be ≤ 4000 mm. A related, more complex Assertion Rule is the definition of the minimum stride a person has to make which in the Netherlands is defined as the tread depth + 2 times the rise height being at least 600 mm. Thus the Assertion Rule added is treadDepth + 2*riseHeight ≥ 600mm.

Derivation Rules

Derivation rules are rules that represent the description of a certain product. When a product is defined a derivation rule describing this product will be executed. Geometry is one kind of derivation rule which allows a description of a product by visualisation. Important here is that visualisation is a possibility but not an essential requirement.

In PMO three kinds of Derivation Rule are defined:

a) *Nullary*
b) *Unary*
c) *Binary*

Every Derivation Rule contains an optional follow-up Derivation Rule (which can be a Derivation Rule of any kind).

A *Nullary* Derivation Rule does some action, but does not reference an optional follow-up set of Derivation Rules. A typical example is an assignment of a formula to a Property.

A *Unary* Derivation Rule does an action and then references just *one* optional set of Derivation Rules. A typical example is a WHILE-LOOP. If the condition for the WHILE-LOOP results in "true" it launches the referenced optional set of Derivation Rules. It then again checks the condition after the last Derivation Rule in the set is applied.

A *Binary* Derivation Rule does something and references exactly *two* optional sets of Derivation Rules. A typical example is an IF-THEN-ELSE statement. After checking if the condition for the IF-THEN-ELSE statement results in true or false it starts the appropriate referenced set of Derivation Rules. This Derivation Rule terminates after the last Derivation Rule in the set.

Operations

Rules, assignments and conditions can be much more complex than just assigning the value of a parameter or adding two values. Operations make it possible to build a complex formula based on small components in an object-based manner. This formula can be used by Assertion and Derivation Rules.

In PMO three kinds of *Operations* are defined: Nullary, Unary and Binary (as for Derivation Rules). Nullary Operations only give a fixed value back of a certain type. For example 4.2 (float), 12 (integer), true (Boolean) or "Hi" (character string).

Unary Operations reference exactly *one* Operation. They return a value depending on the result of the Operation they reference. Examples of Unary operations are Sines, Cosines, Minus (negative value).

Binary Operations reference exactly *two* Operations. They return a value back depending on the result of the two Operations they reference. Examples of Binary operations are Addition, Multiplication and Subtraction.

4. SWOP Semantic Optimisation Extension

Representing products by the PMO is one thing; finding best solutions is another. Problem complexity makes it difficult (even impossible) to know where to look. It is like being blind and exploring a strange place – unable to take in the big picture as a sighted person would and having to form a mind picture of the space by test-it-and-see. What is a best solution? It is often hard to define since it may reflect quite different requirements, some technical and some commercial. Examples of commercial requirements might be to have a product at the cheapest price or in the quickest time. Common sense says that to some extent these may be opposing requirements.

Computers do not tire, enabling exploration of many possibilities that help map out the territory to distinguish potential solution spaces from "blind alleys". One promising area of innovative research relating to this is Genetic Algorithms (GA), processes that mimic selection of species in nature (but which takes a much shorter time span!). Species evolve for fit to their environment according to many requirements, behaviours and rules very much in an unpredictable fashion with the best of species at any time (the most adaptable) surviving.

The GA analogy gathers the parameter values of each solution into a vector, which is seen as its "genome" representing the identity of this solution. Next individuals (i.e. solutions) are evaluated according to a fitness function which, when passed a genome vector, returns a measure of how well the corresponding individual fits the requirements. Based on these evaluations, a selection process is done, followed by a reproduction step that generates an offspring. This new population will be evaluated in turn, the whole process being iterated until a termination criterion is met, good solutions are found, or too many iterations have passed.

The power of GA may be appreciated through the classical “travelling salesman” problem. This “simple” problem requires finding the shortest route around the cities in a predefined set visiting each city only once (distance travelled is the fitness function). The obvious approach is to try every possible sequence of visits and compute for each the travelled distance. However, the number of combinations for N cities is factorial (N-1). For 25 cities this gives approximately $6.2*10^{23}$ calculations to be performed. A computer that can evaluate one million itineraries per second would take $6.2*10^{17}$ seconds - over $1.96*10^{10}$ years! Using a GA based approach, very good solutions are returned in less than a minute (see www.lalena.com/ai/tsp amongst others).

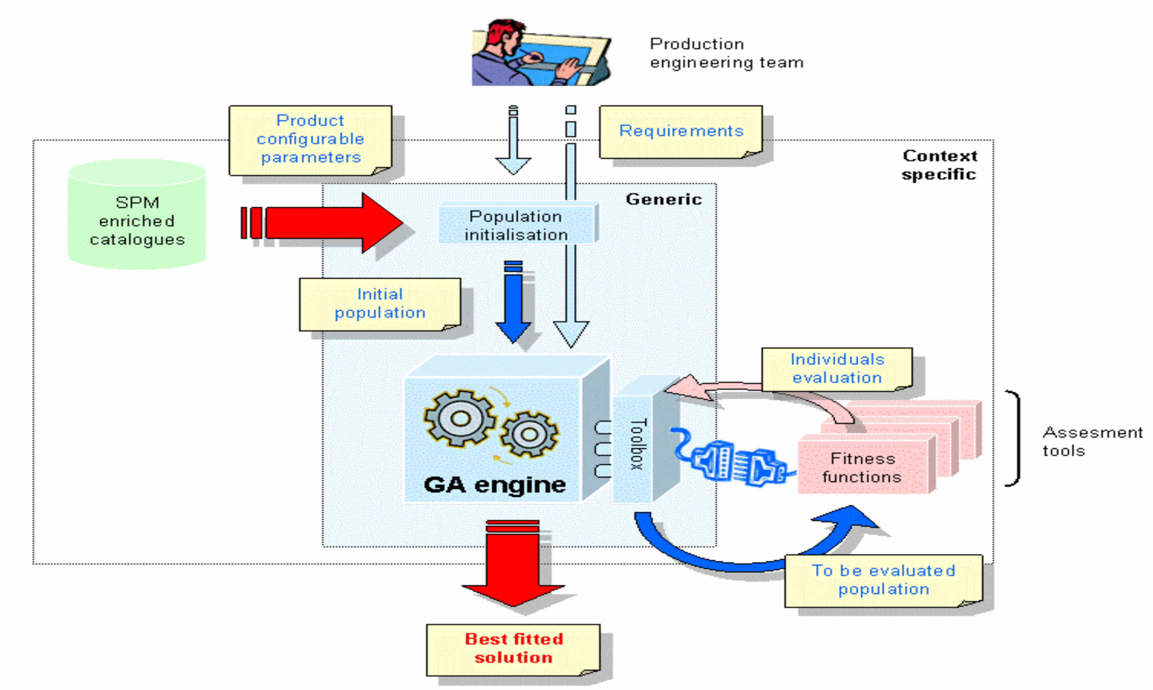


Fig. 9: Pictogram of GA functionality

Fig. 9 illustrates the functionality of the SWOP GA facility. The engine and associated tools are generic i.e. independent of usage context. The engine is no more than a manipulator of numbers that it does not understand – just numbers. The meaning of the numbers is in the usage context with the input requirements, the fitness function defining “best fit” (the optimisation) and the output results. The Product Modelling Ontology defines the context. So the GA engine is like a pump – it has a job to do but it knows nothing about the overall system beyond itself!

Global Architecture

The GA Module is one of the several "base building blocks" of the SWOP platform. It encapsulates all GA related activities and processes, and relies on pluggable data sources for exploration of product data. Figure 10 shows the global architecture of the GA Module. Basically, the GA Module is a "service" that performs optimisation tasks on Product Models. As shown, the module is used by API calls from client programs (be it GUIs for end-users or remote third-party applications). The diagram shows several "connectors" to product data sources.

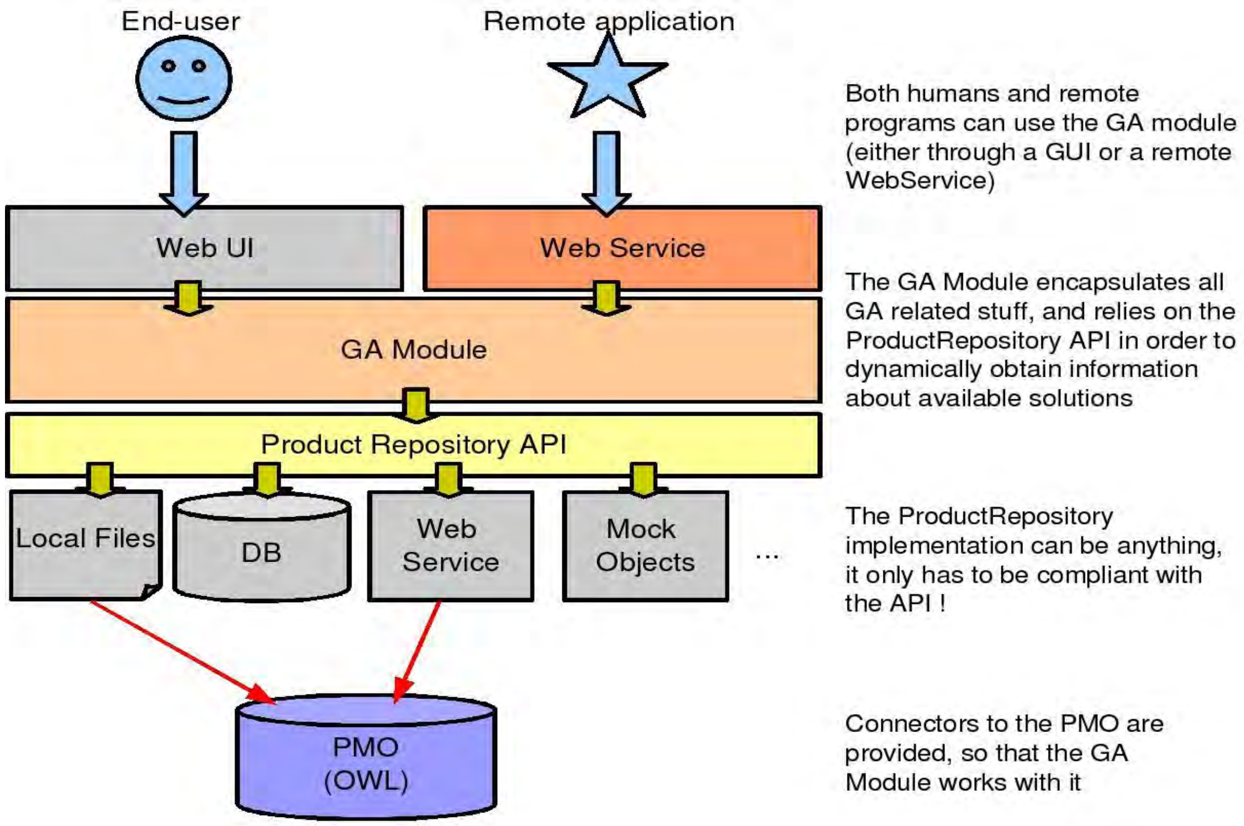


Fig. 10: Global Architecture of the GA Module

Typical usage

To clarify matters, consider a typical usage of the GA Module:

- Design-time (preliminary work, by "**system administrator**" or "**advanced**" users)
  - Configure the PMO, and feed it with company specific product models, etc.
  - Write additional connectors if needed and plug them in
  - Write fitness scripts and fine-tune GA routines
- Run-time (operated by "**regular end-user**")
  - Prepare customer requirements (set the values)
  - Launch run and obtain the results

Almost all is achieved via calls on the GA Module's exposed API (just like any other library), and by implementing connectors that comply with the Product Repository API.

Connector architecture

The GA Module pulls out data from *connectors*. Connectors are bridges between the GA and Semantic worlds. They allow the GAs to know about the products to be optimised, about component catalogues etc. Connectors can abstract all types of data source (PMO-OWL, proprietary SQL schemas, files, etc.). Joining a connector into the GA engine is by implementing a simple contract, under the form of Java interfaces and classes: the *Product Repository API*.

Product Repository

The primary information required by the GA Module is the decomposition of products (their components). The module uses this information in order to generate the early bound objects that represent each individual at evaluation time, allowing the user to access the product's components directly. Implementation of the Product Repository is done by implementing the *IProductRepository* interface (and related ones). Work is currently underway to implement the PMO connector. The GA Module already supports a set of property types (Booleans, doubles, integers etc.) and additional property types can be easily added.

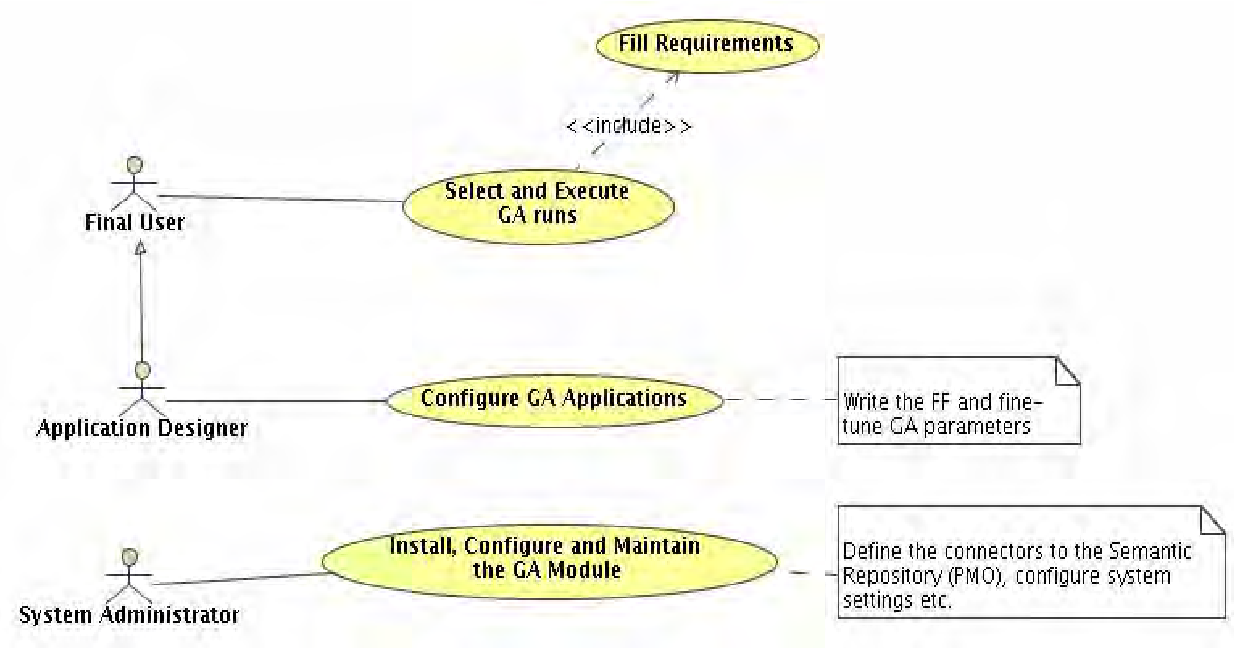


Fig. 11: Roles and actions in the GA process

Requirements specification

Requirements specification is also part of the *product*. Basically, the requirements specification is a list of the *properties* (name and type) that defines the available inputs that must be filled before evaluation; in essence, the conditions from the user/customer point of view that need to be satisfied by the product specification. Those requirements are linked by design constraints and rules to the technical product specification. While the technical specification is used inside the Fitness Function in order to evaluate the individuals with respect to the optimisation objectives, any valid individual must satisfy the product requirements. Requirement definitions have to be supplied by the connector (by implementing *IProduct.getRequirements()*).

Parts catalogues

When evaluating an individual, its genome is first represented by a raw vector of float or integer type, being enumerated values which correspond to a component in the product. This is how the genome is represented in the GA world. The GA engine does not know about Staircases (for instance), it only handles enumerated values and it is up to applications to convert "indexes" to parts id’s in (say) catalogues (e.g. 0=ST123, 1=ST456, etc.). The Product Repository API allows "feeding" the components of a product with the real properties (*values*, not only *definitions*), based on its index. This is done in the *IProduct.feedCom-ponentProperties(...)* method.

5. SWOP Configurators

The foregoing has focused on the two underlying technologies to SWOP (Semantics and Genetic Algorithms). These are implemented in SWOP via product configurators, software tools that manage the assembly of the LEGO blocks to satisfy requirements and optimise products.

Four relevant configurations domains are distinguished (figure 12)

- the context or 'client situation' of the product to be configured (in case of an industrial tool typically including his product and his environment (country, voltage etc.)),
- the client's or sales view on the product (the black box view). From the producer's perspective this is his 'front-office',
- the white box view of the product, including all design details on materialisation,
- a process-oriented view on the product on how to manufacture it.

Typically a product configurator is developed for one or more of these domains. In an ideal scenario all domains are addressed in an interrelated way. However for simplicity it seems wise to start in one specific domain and extend it in a controlled way to other domains.

In SWOP we distinguish between two main layers in the 'design' phase:

- Product Engineering, and
- Product Configuration

In the *Product Engineering* phase a reference product is "designed" for a new product type usually making use of existing, externally provided, parts. This parametric product description embodies all possibilities and impossibilities with respect to the client product. This description is the back-office PMO. It is used as a reference in the actual design for a specific client.

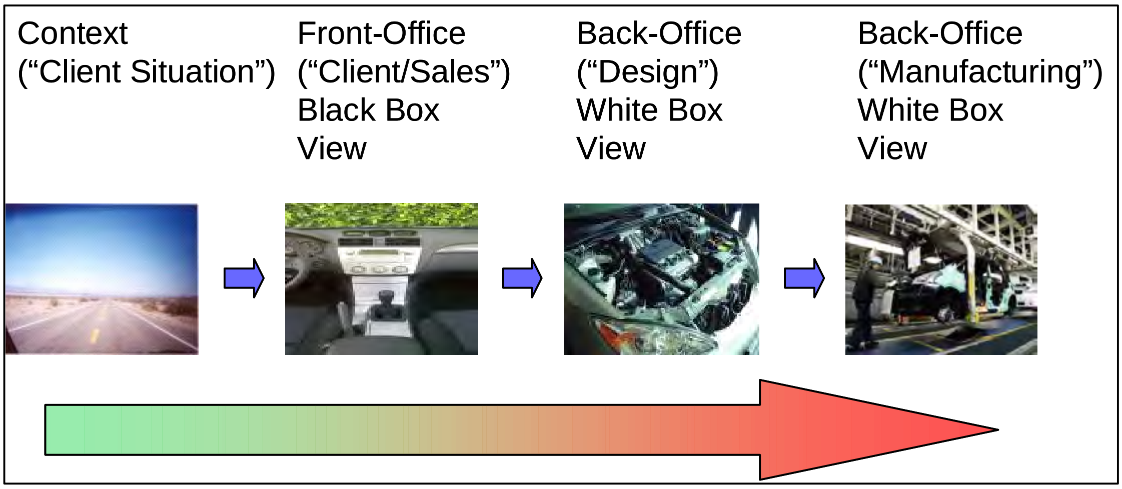


Figure 12: Stereotype configuration/ontology modelling domains

The *Product Configuration* phase is the front-office sales and client requirement phase. Here products are configured by considering the client/sales requirement. The PMO properties are given values and processes like GA optimisation applied. Sales staff and potentially clients use software that guides them through the process of configuration – hence the software is called a Product Configurator (remember the simple DELL example early in this chapter). This configurator is driven by the PMO and is relatively generic software (at least in its functionality).

But the activity of developing a product configurator requires support. SWOP will provide a tool to assist in this. This Product Engineering level tool can be regarded as a configurator for configurators with the choices and constraints for a product being input and its (often externally supplied) parts, and a specific web application is automatically generated to be used by a client to configure his product. The configurators are the tangible tools for end-users.

Results and Business Impacts

What has been presented is based on work undertaken during the first year of the SWOP project. It takes into account the business requirements of the four industrial partners and early prototypes of the SWOP platform, the configurators and the Genetic Algorithm optimisation engine. Inevitably the findings at this stage relate more to demonstrating the practicality of the SWOP approach than evaluation of intended end results of the project. R&D on end user scenarios is now being undertaken and first reportable results are expected in Spring 2007.

Key Findings

Design and production engineers, sales executives and customers know that the process of matching products to product requirements is a rather repetitious one. More or less the same process (with some decision points to complicate matters!) is followed on each occasion. For most product types (other than novel ones) the types of requirement, the product characteristics and the rules/constraints are all well known. It is just that, in other than trivial circumstances like choosing a product from a simple catalogue, the process can be lengthy and involve some trial and error judgements. SWOP's thesis is that products, requirements and rules can all be modelled semantically, allowing the power of the computer to be brought to bear.

One of the early barriers in the project was the difficulty for partners (especially, but not exclusively, the end users) to see that there were common features – indeed generic ones – in all the business cases proposed in SWOP and more widely. This realisation gave birth to a Product Modelling framework containing relatively few concepts that could represent the Product Modelling Ontology of physical and service products of all types. This generality also opened up the prospect of relatively generic approaches and tools, driven by a particular product PMO, to explore solutions in what are often complex solution spaces for a product. SWOP believes that even product configuration tools (configurators) that need to talk the language of lay people (salesmen, customers) can have generic parts that communicate to the user via the particular PMO. This work is currently underway in SWOP.

On the more technical side, OWL (with one or two extensions) is proving to be a good vehicle for representing the needed semantics and presenting to the Web.

Business Impacts

SWOP focuses on a product modelling framework based on the next generation of the internet (the Semantic Web), where pre-engineered design solutions automatically can be stored, found and assessed. From any location, users will be able to search the internet for proven components, and configure and assemble them into a complete, near-optimal design solution to meet requirements. This should speed up the specification and delivery processes, leading to faster-to-customer products, and should lower costs and raise individual competitiveness.

SWOP's semantic based configuration with GA optimisation will enable a company to achieve greater flexibility in product customisation to customer requirements, with products able to be composed online to client requirements as a customer relation/management tool (if that suits the kind of business model). Moreover, by interfacing to existing corporate systems, it should also be possible to optimise the planning and management of current resources (technical and human), the management of suppliers /subcontractors and optimise cost and lead times.

Conclusions

The main scientific and technical objective of SWOP, and its primary deliverable, is a Semantic Web-based Open engineering Platform (SWOP) that will greatly improve complex product development (including both physical products and services), product customisation processes, and the intelligent link between them as illustrated in figure 13.

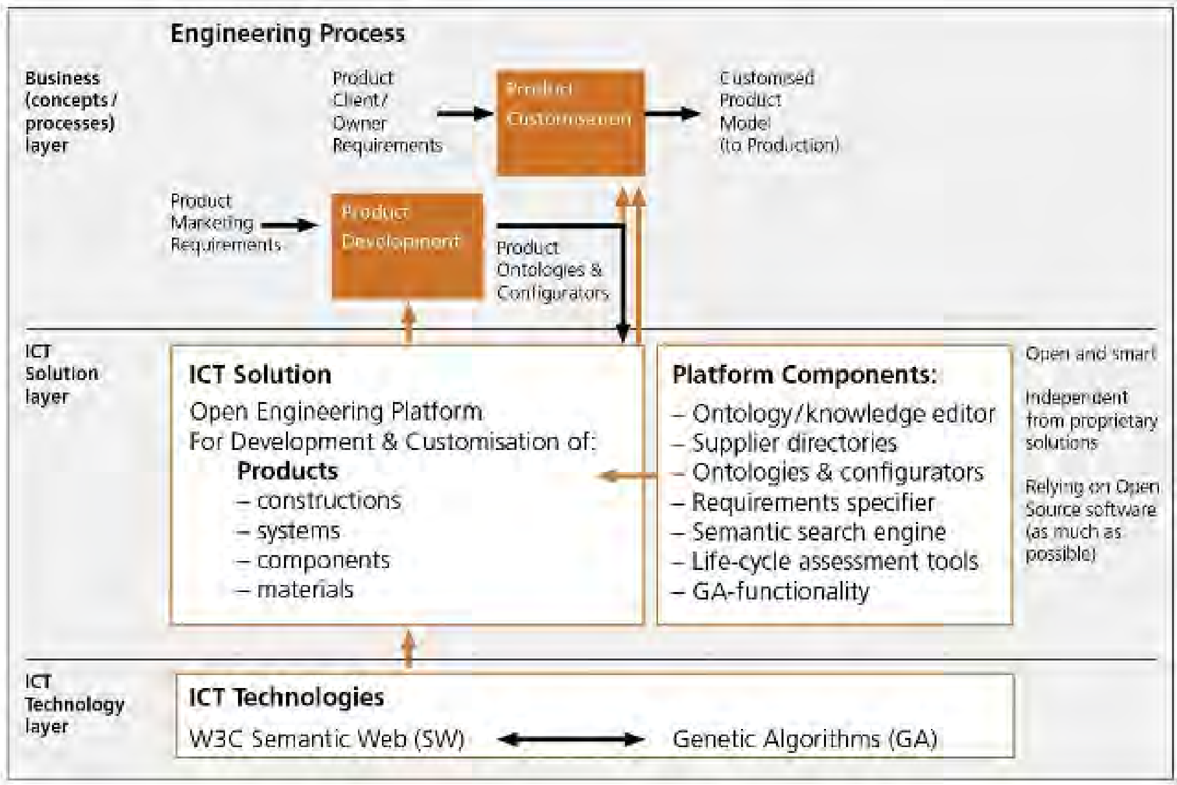


Fig. 13 SWOP Platform Architecture

Progress to date (one third into the project duration) is very encouraging and there are promising preliminary results. By autumn 2007 (two-thirds point) there will be demonstrable, implemented business examples. These will be the primary proofs of the SWOP concept upon which exploitation plans will be based.

Key Lessons Learned:

- Semantic modelling is the basis for efficient and effective virtual engineering and commerce
- Product configuration is a business matter as much as a technical one
- The possibility to tightly bind back office design and production to front office sales, marketing and customer relations
- The importance of the Semantic Web and the Web Ontology Language, OWL
- The appropriateness of the Genetic Algorithm method implemented at a semantic level to some classes of problem

The SWOP web-site may be found at www.swop-project.eu. Public information on the project will be posted there, but those interested in more detail are in the first instance invited to contact the Project Coordinator IAT via holger.eckstein@iat.uni-stuttgart.de or the Technical Manager CSTB via marc.bourdeau@cstb.fr. The SWOP project has international cooperation with the University of Toronto, Canada and CSIRO, Australia.

The reported work draws on contributions from all SWOP consortium members and many of the individuals depicted in this group photograph. Contact details are provided below.

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Cutting Construction Waste by Prefabrication

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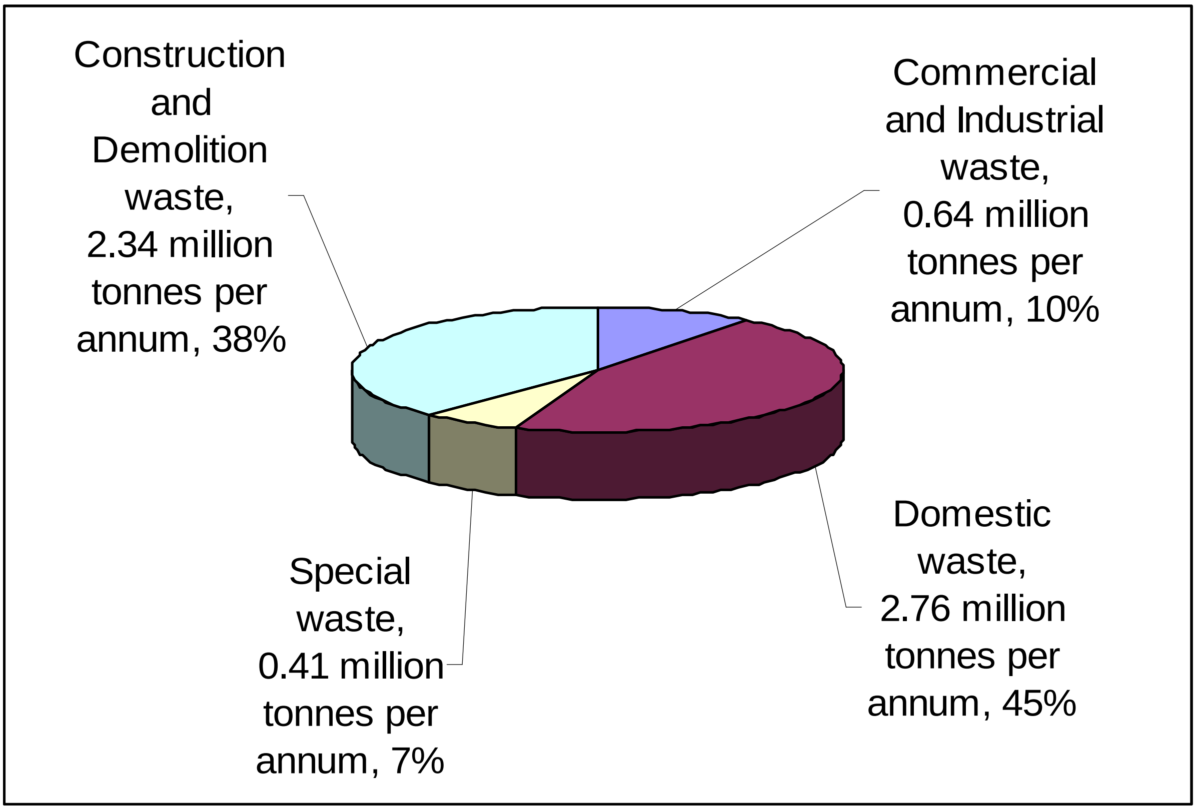

Cutting Construction Waste by Prefabrication

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Abstract

Open building manufacturing aims to provide a high degree of design flexibility and at low cost. It is commonly combined with high efficient industrial production. Use of prefabrication to reduce waste generation and to lower the cost is one of the best methods in open building manufacturing. As construction waste has become the major source of solid waste in Hong Kong, thousands of tons of solid waste are produced every year from construction and demolition activities. Increasing generation of this waste has caused significant impacts on the environment and aroused public concerns. Therefore, the minimization of construction waste has become a pressing issue. This chapter aims to: i) reveal the status of construction waste; ii) investigate the effectiveness of prefabrication in terms of waste reduction in replacing the traditional on-site production; iii) examine the factors that help minimizing construction waste by the adoption of prefabrication; and iv) explore the situations of waste reduction after adoption of prefabrication in comparing with on-site production. From the findings of a structured survey, waste from "poor workmanship" can be greatly reduced by adopting prefabrication in construction. Furthermore, after the adoption of prefabrication, waste generation can be greatly reduced in various on-site production activities including plastering, timber formwork, concreting and reinforcement. Especially in plastering, the waste reduction can be achieved with 100% efficiency. Case studies are also used to demonstrate the effectiveness in the use of prefabrication to minimize construction waste in Hong Kong. It can be concluded that using prefabrication of building components is one of the effective technologies of waste minimization.

Keywords: Open building manufacturing, mobile factory, prefabrication, on-site production, Hong Kong.

Background

Industrial Context

Open Building Manufacturing

Open building manufacturing is an approach to the design of buildings which recognized internationally to represent a new direction in architecture and also helps the ordinary built environment grows, regenerates and achieves wholeness (Kendall, 2006). The open building manufacturing can be a tool to achieve over time in a given building, the goal of income mixing and community stability (Kendall, 2006), which enables a more dynamic balance between physical assets and changing household income over time.

Therefore, the open building manufacturing poses new challenges and opportunities for architectural and engineering knowledge, as well as business practices, construction management, the building trades, supply channel logistics, and information technology (Kendall, 2006). This approach can also balance production efficiency and consumer choice in housing (Kendall, 2006) and provide a high degree of design flexibility and at low cost. It is commonly combined with high efficient industrial production.

There are many methods can help achieving the aims of open building manufacturing. Use of prefabrication to reduce waste generation and to lower the cost is one of the best methods in achieving the concepts of the open building manufacturing. The following sectors are mainly focus on how to use prefabrication to lower the cost and build a more comfortable life for the construction industry.

Construction and Demolition Waste Levels

Advocacy of waste management for construction activities, environmental protection, and the recognition of the contribution of waste generated from construction and demolition work has recently been promoted in Hong Kong (Shen and Tam, 2002). The construction industry plays a vital role in meeting the needs of society and enhancing the quality of life (Shen and Tam, 2002, Tse, 2001). However, the responsibility for ensuring construction activities and products that are consistent with environmental policies needs to be defined and good environmental practices through reduction of waste need to be promoted (Environmental Protection Department, 2006).

The environmental deterioration resulted from construction in Hong Kong has become a pressing issue. Hong Kong generated as much as 14 million tons of construction debris in 2001, of which about 3 million tons (21.4%) of construction and demolition (C&D) materials were disposed of at landfills, while the remaining 11 million tons (78.6%) of C&D waste was transported to the public filling areas for reclamation use (see Figure 1). Construction debris resulting from construction and demolition work constitutes a large proportion of solid waste as shown in Table 1. Figure 2 shows that the C&D waste contributes an average figure of 38% to all waste at public filling areas during the period from 1991 to 2001 (Environmental Protection Department, 2006). To manage such a huge quantity of C&D waste, the Hong Kong government adopts a policy of disposing of the waste to either land reclamation or landfills. For decades, landfills have provided a convenient and cost-effective solution to the wasteful practices of the industry (Mills *et al.*, 1999). Ferguson *et al.*'s study found that more than 50% of the waste deposited in a typical landfill in UK came from construction waste (Ferguson *et al.*, 1995). Similarly, according to Rogoff and Williams's study, 29% of the solid-waste in the USA are construction waste (Rogoff and Williams, 1994). Wong and Tanner's study pointed out that the landfills in Hong Kong, originally expected to last 40 to 50 years, would be filled up by 2010, even if there were adequate alternative outlets for C&D materials (Wong and Tanner, 1997).

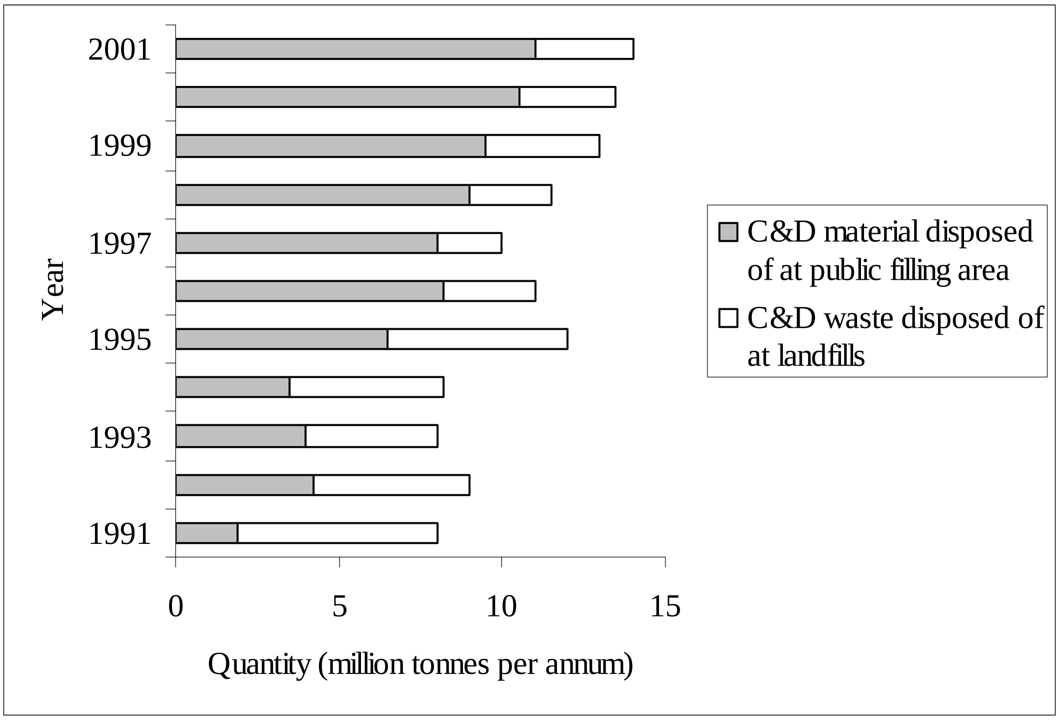

Figure 1: Solid Waste Disposed of at Landfills and Public Filling Areas (Environmental Protection Department, 2006)

Table 1: Comparison of Proportions of Construction Solid Waste (Construction Materials Recycling Association, 2005, Environmental Protection Department, 2006, Hendriks and Pietersen, 2000, Poon, 2000)

Country	Proportion of construction waste to total waste (%)	C&D waste recycled (%)
Australia	44	51
Brazil	15	8
Denmark	25-50	80
Finland	14	40
France	25	20-30
Germany	19	40 to 60
Hong Kong	38	No information
Japan	36	65
Italy	30	10
Netherlands	26	75
Norway	30	7
Spain	70	17
United Kingdom	Over 50	40
United Status of America	29	25

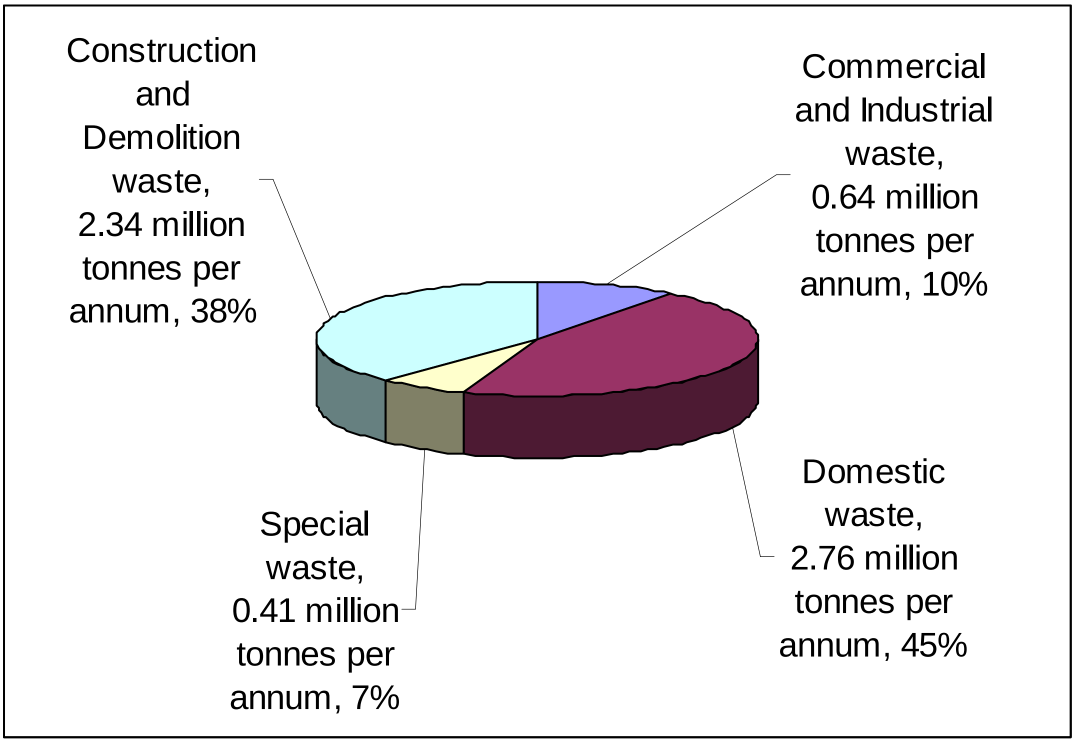

Figure 2: Average Share of Construction and Demolition Waste at Public Filling Areas from 1991 to 2001 (Environmental Protection Department, 2006)

Waste Minimization Methods

Although waste generation is serious in the construction industry, there are many possibilities in disposing C&D waste, from recycling to incineration and landfilling. Five waste management actions have been recommended by Waste Reduction Framework Plan (Waste Reduction Framework Plan, 1998): (1) Waste avoidance: waste should not be produced in the first place, for example, packaging should not be used unless essential; (2) Waste minimization: if waste production is unavoidable, the quantities should be minimized. Essential packaging, for example, should be designed to minimize the materials used; (3) Waste recovery, recycling and reuse: the recovery, recycling and reuse of suitable waste materials should be maximized; for example, using a producer responsibility scheme to recover waste packaging for reusing; (4) Waste bulk reduction: if it is not possible to recover, recycle or reuse the waste materials, the volume of residual waste should be reduced before final disposal, this might involve incineration or composting; and (5) Waste disposal: wherever possible the residue left after bulk reduction will be used for construction purposes or reclamation in preference to being dumped in the landfills.

There are several measures in implementing waste management under government initiative:

(a) The Waste Disposal Ordinance [Chapter (Cap.) 354], enacted in 1980, along with its subsidiary regulations, is the principal legal framework. The other ordinances include Waste Disposal (charges for disposal of waste) Regulation, Waste Disposal (designated waste disposal facility) Regulation, Town Planning Ordinance (Cap. 131), and Building Ordinance (Cap. 123) (Environmental Protection Department, 2006).

(b) The environmental protection issue was started to be addressed in a white paper by the Hong Kong government since 1989, which laid down the framework for a comprehensive 10-year plan to fight against construction waste and other pollution problems, including a commitment to review its progress every two years.

(c) In 1995, the Hong Kong government launched the green manager scheme, requiring every governmental department to appoint a green manager to take the lead in managing the environmental performance of individual organizations (Environmental Protection Department, 2006).

(d) The government drafted a Waste Reduction Framework Plan (WRFP), which was launched on 5 November 1998 (Waste Reduction Framework Plan, 1998) attempting to change the waste treatment habits of the public, and acknowledging the low environmental awareness in Hong Kong.

(e) In 2003, the Buildings Department (BD) of the Hong Kong Special Administrative Region (SAR) issued a practice note for authorized persons and registered structured engineers entitled "Use of recycled aggregate in concrete" (Buildings Department, 2006). This technical guideline can be applied for prescribed mix concrete (20P) and designed mix concrete (25D to 35D) in adopting 100% and 20% recycled aggregate respectively.

(f) Civil Engineering Department (CED) of the Hong Kong SAR commissioned a pilot recycling plant at Tuen Mun Area 38 with a view to supply recycled aggregate to a number of public works projects.

(g) The Circular (Ref: 15/2003) (Environmental Transport and Works Bureau, 2006) on "Waste management on construction sites" issued by the Environment, Transport and Works Bureau of the Hong Kong SAR in 2003, which strengthened the government initiatives by stipulating the implementation of "Waste management plan" and "Pay for safety and environment scheme" for public construction projects.

(h) It is proposing in charging HK$125 per ton of waste dumped into the public landfill areas to encourage recycling and reusing construction waste.

On-Site Production and Prefabrication in Construction Activities

The construction industry in Hong Kong is characterized by labour-intensive on-site production activities. The on-site production activities include in-situ concreting, timber formwork, bricklaying, plastering, screeding, tiling, rebar fixing and bamboo scaffolding. All these activities from transportation, mixing, installation and fixing need to be done on-site. This method has been used for many years, in which it receives different versions of feedback. Advantages in using on-site production include materials suitable for particular site conditions and flexible design arrangements. However, disadvantages in using on-site production are time consuming and quality varied by frontline workers and site supervision staff. These practices have been criticized by the industry and the public in general for poor safety records, failure regarding timely construction and unacceptable quality performance.

As a result, the use of prefabrication has been strongly advocated in the industry, as it can help improving site safety by providing a cleaner and tidier site environment, enhance quality by producing elements under factory conditions and eliminate site malpractices. Further, factory production can reduce waste and can encourage recycling of construction waste, leading to environmental protection and sustainability of the industry.

The Use of Prefabrication in the Hong Kong Industry

Prefabrication is defined as transferring the stages of construction projects from the field to an off-site production facility (Tatum, 1986). The Hong Kong Housing Authority of the Hong Kong SAR has adopted small scale prefabrication since 1988 (Cheung *et al.*, 2002). The prefabricated elements include precast facade units, staircases, drywall and semi-precast floor planking while the structural elements still remain cast-in-situ. Their experience in using prefabrication is positive in terms of quality, time, safety; some good responses are listed as follows:

- Site tidiness is obviously improved, resulting in the reduction of site accidents;
- The speed of construction can be improved by moving some critical site casting activities to precast works;
- The external outlook of building structures can be varied by changing the combinations of modular units;
- The in-situ grouted joints can minimize the occurrence of water leakage; and
- The quality is much improved by prefabrication. The former quality breakdowns like the de-lamination of external mosaic tiles and water leakage along external window frames have been seldom recorded in prefabricated construction.

Problem

From the last section, it is clear that the waste generation from construction and demolition activities is a pressing issue, which constitutes as one of the major proportions of the total waste generation. All these investigations demonstrated that construction business is a large contributor to waste generation and it is possible to protect the environment through managing construction waste properly. Therefore, the aim of this chapter is to explore the possibility to reduce construction waste by prefabrication.

Learning Objectives:

- Revealing the status of construction waste;
- Investigating the effectiveness of prefabrication in terms of waste reduction in replacing the traditional on-site production;
- Examining the factors that help minimizing construction waste by the adoption of prefabrication;
- Exploring the current waste reduction situations after the adoption of prefabrication in comparing with on-site production construction;
- Exploring why prefabrication is one of the effective methods in cutting construction waste;
- Recognizing the hindrances in using prefabrication; and
- Investigating how to use prefabrication more effectively for construction activities.

Approach and Analysis

Factors in Minimizing Construction Waste by Using Prefabrication

The best way to deal with material waste is not to create it in the first place (Environmental Protection Department, 2006, Gavilan and Bernold, 1994, Snook *et al.*, 1995). Hence, to reduce construction waste, prefabrication has been considered as one of the effective and efficient ways (Ting, 1997). Several major causes of materials waste, including concrete, steel reinforcement, formwork and brick / block, were investigated (Shen and Tam, 2002, Tam *et al.*, 2005, Tam *et al.*, 2006), which are tabulated in Table 2a&b.

Table 2a: Causes of Material Waste

Application of construction material	Causes	Specification
Stone slabs	Cutting	Lack of tuning between sizes of different products; imperfections of the product; waste-causing choices in design; lack of knowledge about building during the design stage
	Shape	Imperfections of products; choices made in design about specifications of the product; method of transportation
	Quality	Choice of a low-quality stone slab in design; lack of influence of contractors and lack of knowledge about building during the design stage
	Order too much	Lack of possibilities to order small quantities
	Storage and handling on construction site	Unpacked supply
	Cracking during transportation	Unpacked supply
Concrete	Ordering too much	Required quantity of products unknown due to imperfect planning
	Loss during transportation	Required quantity of products unknown due to imperfect planning
	Scraping off	Method to lay the foundations of a building
Mortar	Scraping out	Negligent practice
	Mortar in the tub	Negligent practice
	Atmospheric influence	Negligent practice
	Specifications of the mortar	Short processing time
	Messing	Negligent practice; quantities of supply too high

Table 2b: Causes of Material Waste

Application of construction material	Causes	Specification
Roof tiles	Sawing consequent from the design of the roof	Attention not paid to sizes of the products used in design; designers not familiar with possibilities of different products; types and sizes of the different products do not fit
	Cracking during transportation	Negligent handling by the supplier
Reinforcement	Cutting	Use of steel bars of sizes that do not fit
Formwork	Cutting	Use of timber boards of sizes that do not fit
Brick / Block	Cutting	Use of sizes that do not fit
	Damaged during transportation	Unpacked supply

Cheung *et al.* also identified six major causes of material waste on on-site production activities, including: i) cutting; ii) over ordering; iii) damage during transportation; iv) lost during installation; v) poor workmanship; and vi) change of design (Cheung, 1993).

To assess the significant levels on the causes of material waste, an interview survey was conducted which collected thirty-one construction senior practitioners, who asked to comment on the levels of waste reduction in various reasons for the reduction in comparing prefabrication with other on-site production activities including concreting, bricklaying, plastering / screeding, tiling and rebar fixing. The practitioners included senior project managers, project managers, architects, senior quantity surveyors and engineers, with about 15 to 25 years on-site experiences. Respondents are asked to response on the significant level on five levels of scale, from “1 − least significant” to “5 − extremely significant”. The results are shown in Table 3.

According to Table 3, it can be found that “poor workmanship” is considered as the most important cause leading to the waste of plastering / screeding, with a weighted average score of about 3.40 and tiling score of about 3.21. In concreting and bricklaying, “poor workmanship” is considered as the second important cause with weighted average scores of about 3.55 and 2.95 respectively. On explaining the importance of workmanship on these trades, for example, plastering needs applying various layers and thus improving the performance of the outlook; therefore, one of the interviewed engineers explained that the techniques of the workers directly affect the final quality of plastering work. As the quality of these trades is based on the performance of the workers, improving the quality of workers by training, certification and skill development is essential in cutting construction waste. “Damage during transportation” in bricklaying is the major cause of waste, which can be reduced or eliminated by replacing site bricklaying with drywall panel systems.

Waste in tiling caused by “cutting”, “over-order” and “poor workmanship” can be reduced after using prefabricated building components. However by simple applications of modular dimensioning on tiling, a potential reduction in waste can also be achieved. The reduction of waste in rebar is considered moderate. However rebar is of less concern in waste minimization as it is recyclable.

In general, the major causes of construction waste, namely, “cutting”, “over-order”, “damage during transportation”, “lost during installation”, “poor workmanship” and “change of design”, can be effectively reduced by adopting prefabrication.

Table 3: Response on Reasons Leading to Waste for Various On-Site Production Activities

Trade	Causes	Interviewees’ response					Mean
		Least significant “1”	Fairly significant “2”	Significant “3”	Very significant “4”	Extremely significant “5”	
Concreting	Over-order	10%	10%	15%	35%	30%	3.65
	Damage during transportation	20%	35%	10%	10%	25%	2.85
	Lost during installation	20%	25%	20%	10%	25%	2.95
	Poor workmanship	15%	15%	15%	10%	45%	3.55
	Change of design	40%	20%	15%	13%	12%	2.37
Bricklaying	Cutting	30%	25%	15%	10%	20%	2.65
	Over-order	40%	25%	15%	15%	10%	2.45
	Damage during transportation	15%	15%	15%	10%	45%	3.55
	Lost during installation	20%	25%	20%	10%	25%	2.95
	Poor workmanship	20%	25%	20%	10%	25%	2.95
	Change of design	10%	35%	30%	15%	10%	2.8
Plastering / screeding	Lost during installation	22%	15%	23%	20%	20%	3.01
	Poor workmanship	10%	20%	15%	30%	25%	3.4
	Change of design	30%	15%	30%	20%	5%	2.55
Tiling	Cutting	15%	15%	30%	30%	10%	3.05
	Over-order	10%	15%	37%	25%	13%	3.16
	Poor workmanship	6%	25%	25%	30%	14%	3.21
	Change of design	25%	25%	35%	10%	5%	2.45
Rebar fixing	Cutting	19%	4%	50%	25%	2%	2.87
	Over-order	30%	25%	25%	10%	10%	2.45
	Poor workmanship	55%	10%	15%	10%	10%	2.10
	Change of design	32%	30%	23%	10%	5%	2.26

Comparing Waste Levels between On-Site Production and Prefabrication

Adoption of prefabrication technology is mainly confined to public housing developments in Hong Kong, which have the resources and expertise to risk introducing new technology while the technology has not been widely accepted by the private sector (Tam, et al., 2005, Tam, et al., 2006). To examine the advantages of prefabrication to private developments, four private building projects in the forms of hotel, residential tower and two commercial buildings are selected for this study, which have applied, to a certain extent, some prefabrication techniques. Details of the four projects are tabulated in Table 4.

By interviewing project managers of the four projects, the levels of prefabrication are identified. Table 4 shows the various prefabrication elements for the projects. The most common prefabricated elements are facade and staircase units. During construction of the precast facades, aluminum window units were cast monolithically so that any water leakage through joints can be minimized. “Lost” form (permanent form) for the entire external load-bearing wall and precast balcony were adopted for Project 2. Plastering, tiling and scaffolding work were minimized, thus enhancing site productivity. Precast balconies were pre-finished with tiling in the prefabrication yard adopted a semi-precast technique in which the final structural portion of the unit was cast in-situ with the supporting beams. Projects 2, 3 and 4 adopted a dry wall system for internal partitions onto which a thin layer of skin coat of 1-2mm thick was applied before the final painting, thus reducing site construction waste arising from the traditional on-site production activities.

Off-site building services fabrication was used as the prefabrication technique for Project 4. About 95% of building services were fabricated off-site, including integrated lighting and air-conditioning outlets, low-glare fluorescent lights with electronic ballasts, direct digital control variable air volume system, heat absorbing and solar reflective double-glazed curtain walls, semi-precast sprinkler heads, fully recessed lighting unit and suspended acoustic ceiling panel. The project manager suggested that significant cost savings could be achieved by this.

To examine waste levels, the four projects with some level of prefabrication in compared with similar projects but using the traditional on-site production approach, which were identified with the help of the four project managers. Data were collected through a series of structured interviews with the project managers, our site observations and recording. Four major site operations including plastering, timber formwork, concrete and reinforcement were investigated in this study, that exclude the off-site trades at the prefabrication yards and other auxiliary services such as additional transport and hoisting facilities.

Table 4: Details of Projects with High Level of Prefabrication

Project title	Project 1: Hotel redevelopment	Project 2: Residential	Project 3: Commercial-A	Project 4: Commercial-B
Gross floor area	9,514 m^2	56,756 m^2	181,310 m^2	31,140 m^2
Scope of the project	A 31-storey hotel comprising 3-level podium and a 28-storey guestroom tower.	Two blocks of residential buildings of 48-storey high and one level podium.	An 88-storey office and a 5-storey car park.	A 36-storey grade A office building including a 2-storey podium and a 1-storey of mechanical and electrical (M/E) floor.
Construction methods	A conventional method is adopted for the guestroom tower, while prefabrication is used for the podium.	For the podium, it adopts the conventional method, while prefabrication is applied to the residential towers.	Car park construction adopts the conventional method, while the 88-storey office tower uses prefabrication.	Semi-precast elements at typical floors, in which it splits into two portions, one by in-situ construction and the other by prefabrication.
Prefabricated building components	➢prefabricated slab ➢staircase ➢precast facade ➢system formwork	➢precast facade ➢lost form ➢precast balcony ➢staircase ➢dry wall system	➢structural steel frame ➢unitized curtain wall system ➢system formwork for corewall and mega column ➢superdeck material platform ➢precast staircase ➢dry wall system	➢precast staircases ➢precast plank ➢semi-precast beam ➢jump lifts ➢off-site prefabricated building services components
Cycling time	7 days cycle	4 days cycle	7 days cycle	4 days cycle
Location of prefabrication yard	Yuen Long	Dong Guan	Mainland China	Mainland China

Waste levels of building materials can be defined as the remains of the materials delivered on site after being used. This can be described in Eq. (1) and Eq. (2) for projects with prefabrication and projects using the traditional on-site production approaches:

$$W_p = \frac{M_{Dp} - M_{Up}}{M_{Dp}}(100\%) \qquad \text{Eq. (1)}$$

$$W_c = \frac{M_{Dc} - M_{Uc}}{M_{Dc}}(100\%) \qquad \text{Eq. (2)}$$

where

Wp and Wc denote the percentage of material waste for projects of prefabrication and projects of the traditional on-site production respectively;

MDp and MDc for material delivered on site for projects of prefabrication and project of the traditional on-site production respectively; and

MUp and MUc for material used for built works for projects of prefabrication and project of the traditional on-site production respectively.

Improvements in waste levels are measured by a relative index, denoted as 'W' in Eq. (3):

$$W = \frac{W_c - W_p}{W_c}(100\%) \qquad \text{Eq. (3)}$$

The relative indices of the various trades for these projects are summarized in Table 5.

Waste resulted from hacking off concrete from grout leakage and dislocation of formwork; excessive plastering to hide surface unevenness and excessive site mixed mortar was completely removed for Projects 1, 3 and 4. For the hotel project with prefabrication, only 1mm to 2mm skim coat instead of 15mm to 20mm plastering was used, yielding 100% of waste reduction in plastering. Furthermore, timber formwork was reduced by about 73.91% to 86.67%, causing significant reduction in timber scraps. Compared with the traditional on-site production construction methods, steel formwork was used in prefabrication yards; the increase in times of reuse results in significant reduction in material waste. Waste resulted from concrete was also significantly reduced by about 51.47% to 60% as the prefabricated products were cast off-site. Although waste of steel bars can be reduced from about 35% to 55.52%, the saving was not significant as steel bars from construction sites can be recycled.

Table 5: Relative Indices on Improvement in Waste for Various Trades

	Traditional on-site production			Prefabrication			W
	M_{Dc}	M_{Uc}	W_c	M_{Dp}	M_{Up}	W_p	
Project 1: Hotel							
Plastering (m^2)	7,200	6,800	5.56%	600	600	0.00%	100.00%
Timber formwork (m^2)	16,500	14,000	15.15%	2,350	2,300	2.13%	85.96%
Concrete (m^3)	7,700	7,000	9.09%	1,360	1,300	4.41%	51.47%
Reinforcement (ton)	1,370	930	32.12%	350	300	14.29%	55.52%
Project 2: Residential							
Plastering (m^2)	250,000	180,000	28.00%	600	580	3.33%	88.10%
Timber formwork (m^2)	400,000	285,000	28.75%	2,000	1,850	7.50%	73.91%
Concrete (m^3)	50,000	45,000	10.00%	500	480	4.00%	60.00%
Reinforcement (ton)	6,500	6,000	7.69%	400	380	5.00%	35.00%
Project 3: Commercial-A							
Plastering (m^2)	5,000	3,000	40.00%	400	380	5.00%	87.50%
Timber formwork (m^2)	6,000	4,000	33.33%	1,500	1,400	6.67%	80.00%
Concrete (m^3)	2,200	2,000	9.09%	500	480	4.00%	56.00%
Reinforcement (ton)	1,250	1,000	20.00%	200	180	10.00%	50.00%
Project 4: Commercial-B							
Plastering (m^2)	9,500	8,000	15.79%	700	700	0.00%	100.00%
Timber formwork (m^2)	16,000	10,000	37.50%	2,000	1,900	5.00%	86.67%
Concrete (m^3)	13,500	12,000	11.11%	1,000	950	5.00%	55.00%
Reinforcement (ton)	4,500	4,200	6.67%	500	480	4.00%	40.00%

Results and Business Impacts

To identify the material waste levels between the traditional on-site production and prefabrication construction in Hong Kong, it has been found that the various on-site production activities can effectively reduce the waste after using prefabrication. Furthermore, standardized designs should also be adopted to facilitate the use of prefabrication, thus reducing the material waste.

Although significant reduction in waste levels was recorded in using prefabrication in this study, there were several hindrances in the development of prefabrication as described by the interviewees.

- The congested roadwork in Hong Kong affects timely delivery of prefabricated components, which would impinge on the progress of the tight construction schedule;
- Lack of experience of the labour and the frontline supervisory staff in handling prefabrication takes a longer learning curve/time before arriving at planned cycling times. Designers and consultants are very cautious and thus very demanding in managing prefabrication works. Proper training and education in this area are strongly required; and
- High land costs also form one of the major difficulties in locating prefabrication yards in Hong Kong.

Prefabrication will only be successful when contractors and developers can enjoy cost savings. Interviewees suggested that cost was the key factor at this critical moment of economical downturn. Prefabrication will only bring cost saving when the following issues are addressed:

- Fully mechanizing the construction process using heavy plants;
- Turning construction into an assembling industry rather than on-site production; and
- Use of recycle materials for the prefabricated components.

In addition, three main stimulators are required in encouraging the use of prefabrication (Ho, 2001, Poon, 2000, Ting, 1997):

- Environmental issues: when more stringent environmental control and regulations are forthcoming, prefabrication is one of the ways to facilitate long-term waste minimization and reduction;
- Construction costs: introducing more productive and lean construction methods can reduce the construction cost effectively and reduce the burden encountered by the high initial investment (Shen and Tam, 2002);
- Government incentives: granting relaxation to the gross floor areas for projects employing prefabrication elements (for example, discounting the area occupied by facade units) (Environmental Protection Department, 2006) will encourage the use of prefabrication. Moreover, tighter control on workmanship, allowable tolerances, homogeneity, and allowable rework will favour the adoption of prefabrication.

Conclusions

This chapter has shown that the adoption of prefabrication can effectively reduce construction waste. It has demonstrated that the causes of waste generation by “cutting’, “over-order”, “damage during transportation”, “lost during installation”, “poor workmanship” and “change of design” can be greatly reduced after adopting prefabrication. “Poor workmanship” was found to process the greatest saving as it is the major cause of waste generation for on-site production activities, especially in plastering/ screeding and tiling work.

Four private building projects with high levels of prefabrication are used as case studies to illustrate the effectiveness of prefabrication in waste minimization. It has been found that up to 100% of waste can be reduced in plastering. Timber formwork could reduce waste from about 73.91% to 86.87%. Waste resulted from concrete can be reduced from about 51.47% to 60%. Waste of steel bars can be reduced from about 35% to 55.52%.

It should be noted that waste can be significantly reduced in using prefabrication rather than the traditional on-site production activities. However, there are various hindrances encountered in the adoption of prefabrication, including the long haulage of prefabricated components, the lack of experiences of the industry, and high land costs in locating prefabrication yards.

Suggestions have been made to help pushing the use of prefabrication, including implementing more stringent environmental control and regulations, highlighting the savings resulted from the more productive lean construction methods, and granting relaxation to the gross floor area for projects are required to change the attitude of the construction industry.

After all, the prospects of using more prefabrication techniques are very promising, because prefabrication will ultimately help to lower its high construction cost through mechanization, standardization and industrialization.

Key Lessons Learned:

- High waste levels are generated from construction and demolition activities;
- Waste minimization methods are necessary to implement in reducing the serious waste generation;
- 'Poor workmanship" was considered as the most important cause leading to the waste;
- The most effective waste reduction trade after using prefabrication is plastering, which can nearly eliminate waste;
- Site condition, labour skills and land costs are the three main hindrances in using prefabrication in construction activities;
- To effectively use prefabrication in construction, the construction industry should:
  - i) Implement more stringent environmental control and regulations;
  - ii) Highlight the savings resulted from the more productive lean construction methods; and
  - iii) Granting relaxation to the gross floor area for projects employing prefabrication.
- Prefabrication is one of the effective methods in waste minimization.

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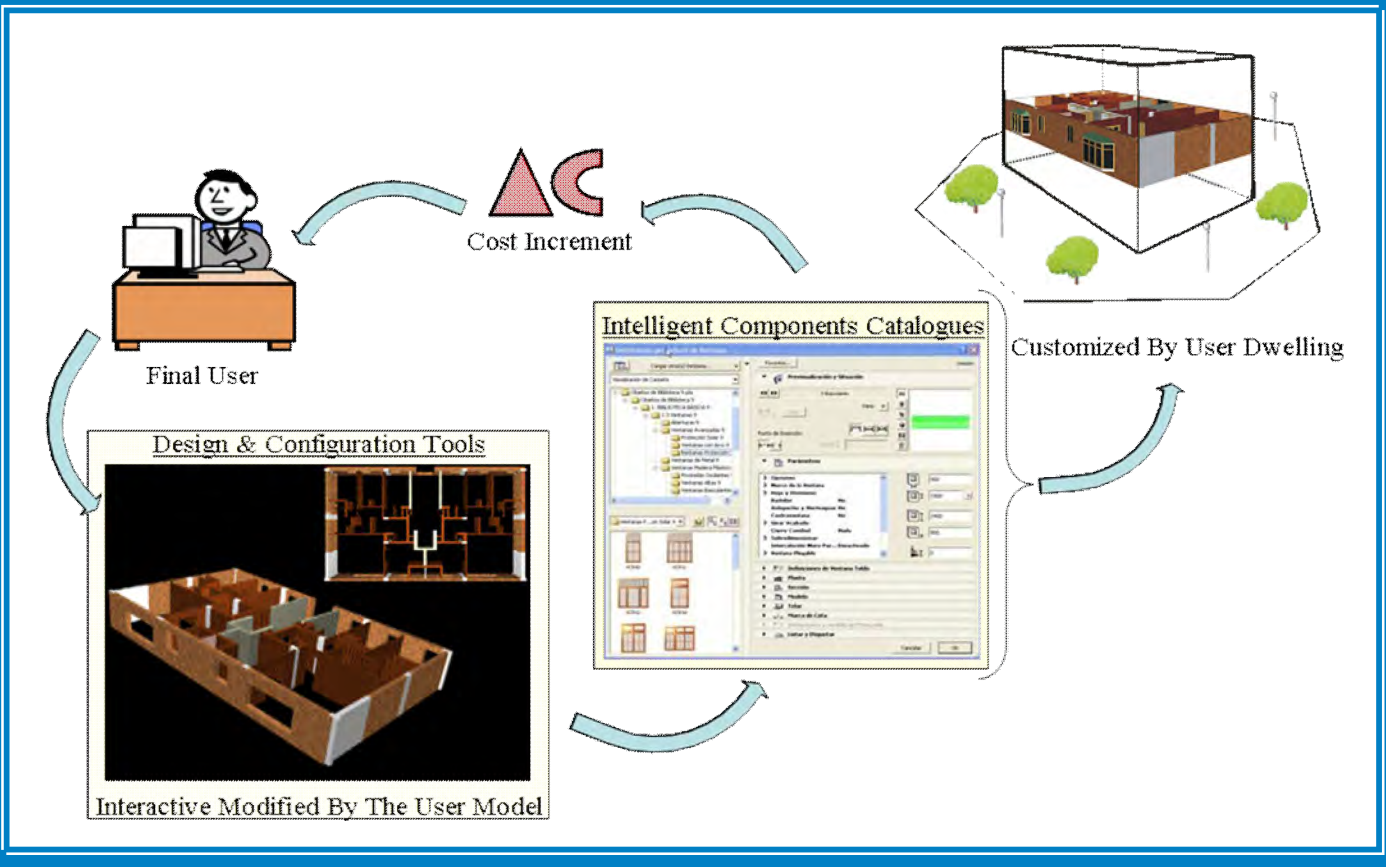
16

User-Oriented Interactive Building Design

S. Martinez, C. Barcena, C. Balaguer,
J.M. Navarro, C. Bosch & A. Rubio



User-Oriented Interactive Building Design

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Abstract

The objective of the chapter is to present the 3D VR-based environment for basic design of the apartment buildings. The key issue of the system is the user-in-the-loop philosophy which permits the interactive modification of the building design. The user is able to choose the preferences in order to select their best apartment design: number of bedrooms, bathrooms, distribution, sizes, sun-orientation, etc. And all with a simple click of the mouse. This user-oriented design need to have in account (in automatic way) numerous restrictions during the design, with the overall objective of obtaining, at the end of the design process, the feasible and realisable result. The friendly-user interface and internet-based facility of the system make them extremely easy to use.

Keywords: User oriented building, architectural design, virtual reality.

Background

Industrial Context

The concept of marketing orientation was developed in the late 1960s and early 1970s at Harvard University and at a handful of forward thinking companies. It replaced the previous ‘sales orientation’ that was prevalent between the mid 1950s and the early 1970s, and the ‘production orientation’ that predominated prior to the mid 1950s. Since the concept was first introduced in the late 1960s, it has been modified, repackaged, and renamed as "customer focus" or "customer driven". (Wikipedia contributors, 2006).

The marketing orientation considers the end user satisfaction as one of the main objectives. The product success depends on a great extent of the customer satisfaction. In order to achieve this goal the industry has took into consideration the role of the end user from different points of view.

The first role is the user involved on the product final configuration. The customer can select different finishing options of the product and personalize it to his preferences or necessities, but the user is involved into the process only at this final stage. It can be seen into the automotive industry where the most of the companies have car configuration tools and the final user personalizes his car finishing and features.

The second role is the user as an active part of the production process. Until now, the end user has been involved into the process development by mean of tests to improve the design or the performance of the product. Customer opinion is taken into account but he can not decide directly about the design.

These two roles were not applied into the building sector but, in the last years, there are building companies where the customer can configure some finishing aspects of his dwelling.

Problem

Within the actual building market the user is out of important stages of the construction process and he cannot decide about a lot of aspects of his future dwelling. This implies that the degree of satisfaction of the final user of a dwelling is determined by the joining between the user desires and the market offer.

The building construction process in Spain is very complex and has no participation of the final user in early stages (Balaguer, 2003). It can be seen that in a traditional process of a private developer the end user is only involved in the final part of the process, where no decision from his side will be taken into account (figure 1).

PRIVATE DEVELOPER IN SPAIN

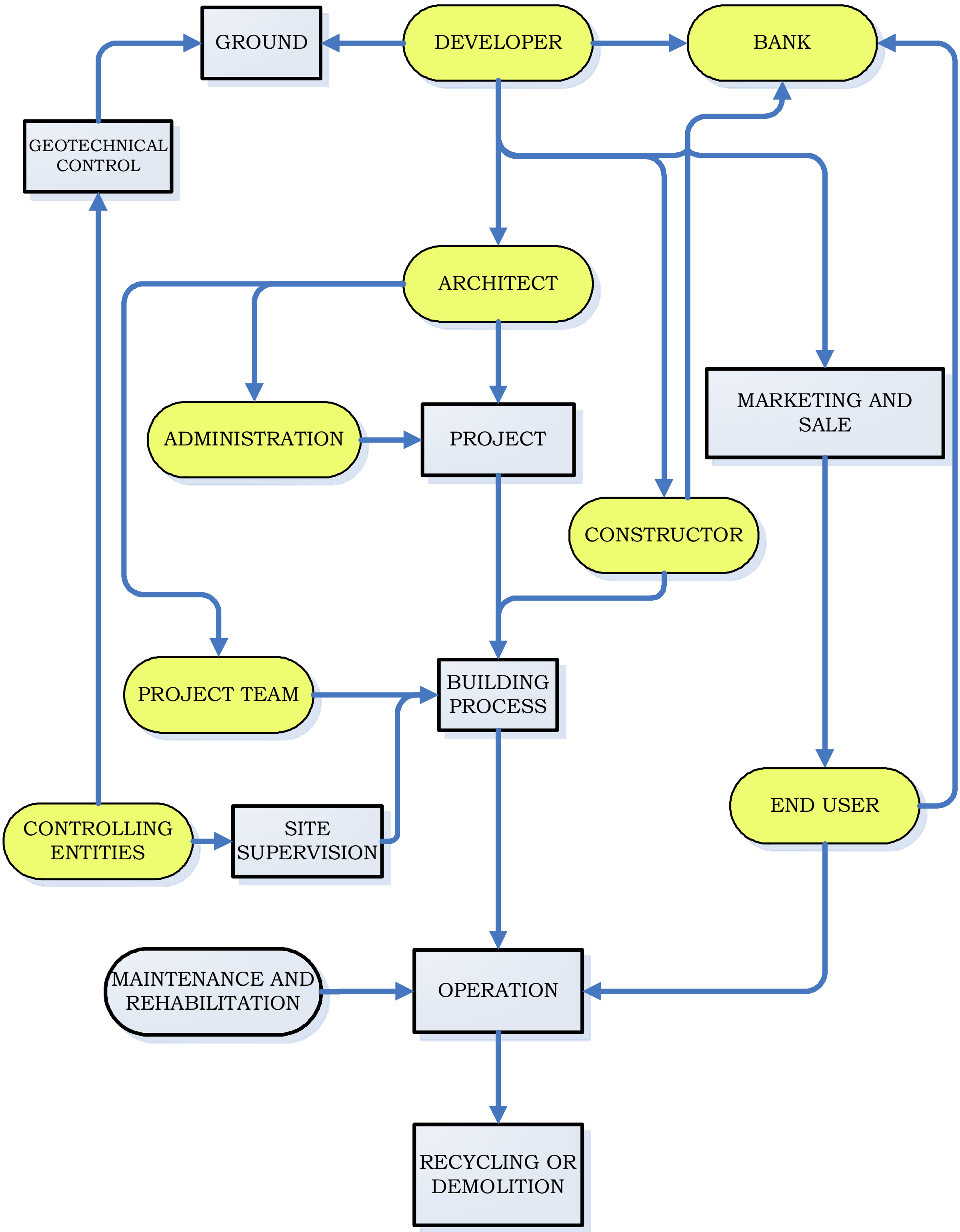


Figure 1. Private Developer Building Process

The objective of this investigation is to introduce the end user of a dwelling into the whole construction process, from the first phase of design to the end of the cycle of life of the building. In that way, the final user would be the centre of the process and his level of final satisfaction would be increased.

Learning Objectives:

- The end user role into the building process.
- How the end user can take part into the construction market.
- Guide to develop a configuration tool for dwelling personalization.

Approach

Building design

In this first stage of the work the end user will be introduced into the architectural design of a multi storey building, more specifically, in the personalization of his own dwelling. The main difference is the consideration of the customer as another stakeholder into the constructive process.

The significant change that the project wants to introduce is the user-in-the-loop philosophy in building construction, from design to the final cycle of life of the building (figure 2). In this way, the user can participate in all the stages of the process to get a final product according to his preferences (Balaguer, 2000).

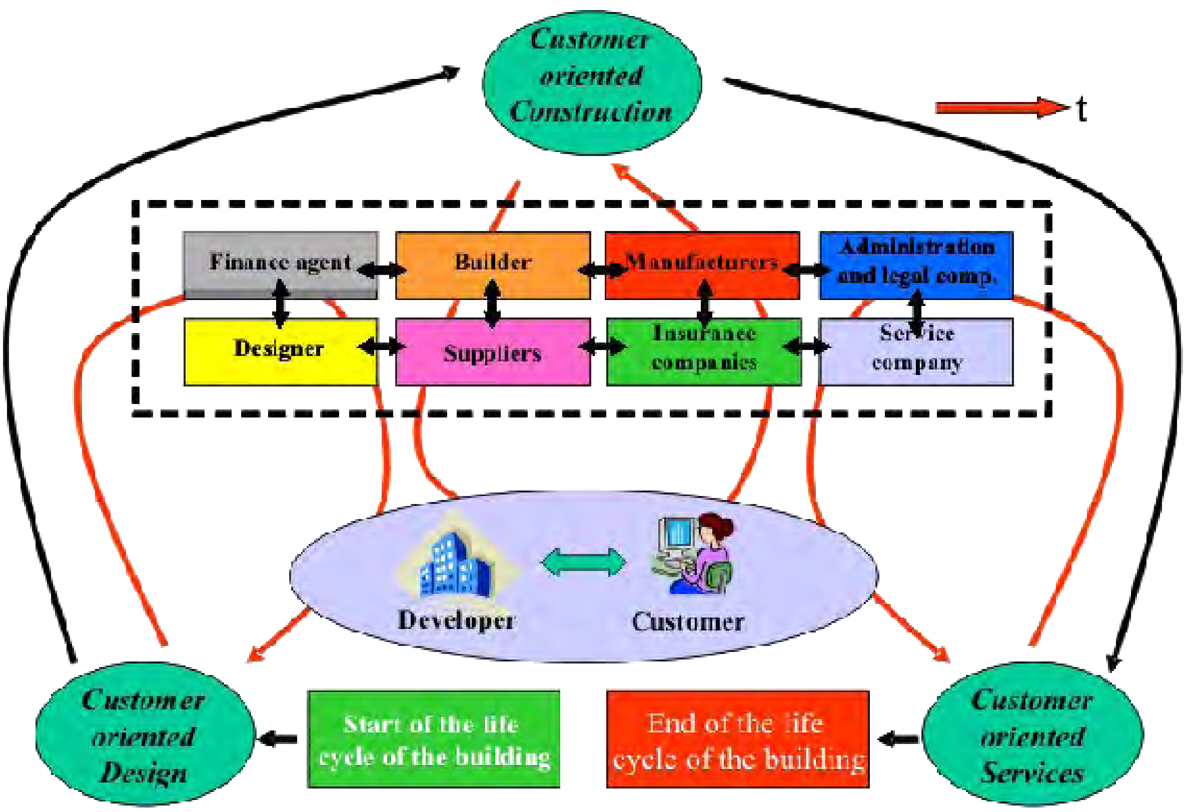


Figure 2. User-in-the-loop Process Model

The architectural design starts from a dwelling template obtained by mean of a questionnaire. This template reflects some general aspects which defines the user recommended dwelling. These features, like number of rooms, distribution, total home surface or desired room types, are represented by the template and it is the guide to follow by the architect. The design step joins the templates derived from all users into one entire customized building.

Once the building design stage is over, the user will be involved again in the process by making modifications on the previous design modelled in 3D. This architectural model will be introduced into a virtual environment in which the user will make modifications according to his preferences and with the limitations of predefined designing constraints.

In this virtual reality environment designed, the end user will see his dwelling and will be able to modify some aspects of the architectural design, as can be number of bedrooms, bathrooms, distribution, sizes, sun-orientation, etc. according with his preferences. This interactive design will maximize the user final satisfaction.

Virtual Reality Environment

The virtual reality environment can be taken into consideration according two points of view. The first is from the side of the hardware systems and the other point of view is from the user interaction type with the system.

The hardware systems can be classified depending of the sense of immersion, or degree of presence it provides (Biocca, 1992). There are three different levels of immersion that the systems can provide:

1. **Non immersive systems**

These systems are so called ‘desktop systems’ because the virtual environment is viewed through a virtual reality browser by utilising a standard high resolution monitor. Interaction with the virtual environment can occur by conventional means such as keyboards, mice and trackballs or may be enhanced by using 3D interaction devices such as a SpaceBall™ or DataGlove™.

The non immersive system has several advantages as for the designer as for the end user. The main advantages are that they do not require the highest level of graphics performance, no special hardware and can be implemented on a domestic PC system. This means a low cost virtual reality solution which can be used for many applications.

The main disadvantage issue is the 2D interaction devices, not designed specifically for 3D applications, which limit the perception of the user.

2. **Semi immersive systems**

A semi immersive system is composed mainly by a wide field projection system. They can be, for instance, large screen monitors, large screen projector systems or multiple television projection systems. These systems increase the feeling of immersion or presence experienced by the user. However, the quality of the projected image is an important consideration. It is important to calibrate the geometry of the projected image to the shape of the screen to prevent distortions and the resolution will determine the quality of textures, colours, the ability of define shapes and the ability of the user to read text on-screen.

These systems are more complex and much more expensive than desktop systems. For these two reasons, it is difficult to use these virtual reality devices out of determinate environments, as they can be professional simulators or entertainment areas, where the most important thing is the sense of immersion.

3. **Fully immersive systems**

A fully immersive virtual reality system tries to replace a real environment by a computer generated environment and some of the user senses only have perceptions from this virtual world. To achieve full immersion the user has to employ a head-coupled display which is either head mounted or arranged to move with the head. A sense of full immersion is achieved because the display provides a visual image wherever the user is looking. Consequently, a head coupled display provides a 360° field of regard. The field of view of a head coupled display is also very important and it is essential to note that the sense of immersion will be a function of the quality of the display provided in terms of resolution, field of view, update rate and image lags, etc. (Kalawsky, 1996).

The main advantage of these systems is the degree of perception achieved by the end user but, for this reason, the computational cost is higher than in other systems because the necessity of achieve a real perception of the virtual environment.

The other possible classification of the virtual reality systems is depending on the level of the user's participation and interaction with the virtual environment. Virtual reality applications are also subdivided into passive, explorative or interactive environments:

a. *Passive environments.*

The passive environment is only a projection that the user can see. The user cannot interact with the virtual reality world so, the perception is limited to the sense of the sight.

b. *Explorative environment.*

The basis of the system is the same as the passive systems but, in this case, the user can navigate through the virtual reality environment.

c. *Interactive environment.*

The last type of systems and virtual worlds is the interactive one. In these systems, the user as well as navigate also can interact with the environment. There are objects into the world with interaction properties as can be displacement by the user, etc.

Analysis

User Oriented 3D Building Design

The user dwelling design starts from the architectural building design made by and architect's office. In order to accomplish with the user-in-the-loop philosophy, this basic architectural design must be made following several rules that will be fixed during the ManuBuild project development. These rules and the main features of the user dwelling are defined by the templates the architect must use into the design. Mainly, the design should be carried out following the Open Building philosophy.

With this architectural design and with input data about the environment of the building, the 3D user oriented model will be built.

3D Model Construction.

The first step is the construction of the virtual reality environment where the designed building model will be placed. The environment model has two main parts (Sadek, 2005):

- The terrain information.

In order to make a realistic 3D model it is necessary to do a terrain model. The building models will be placed on it taking in account the geospatial orientation and the terrain profile. The basic process is shown in the figure 3.

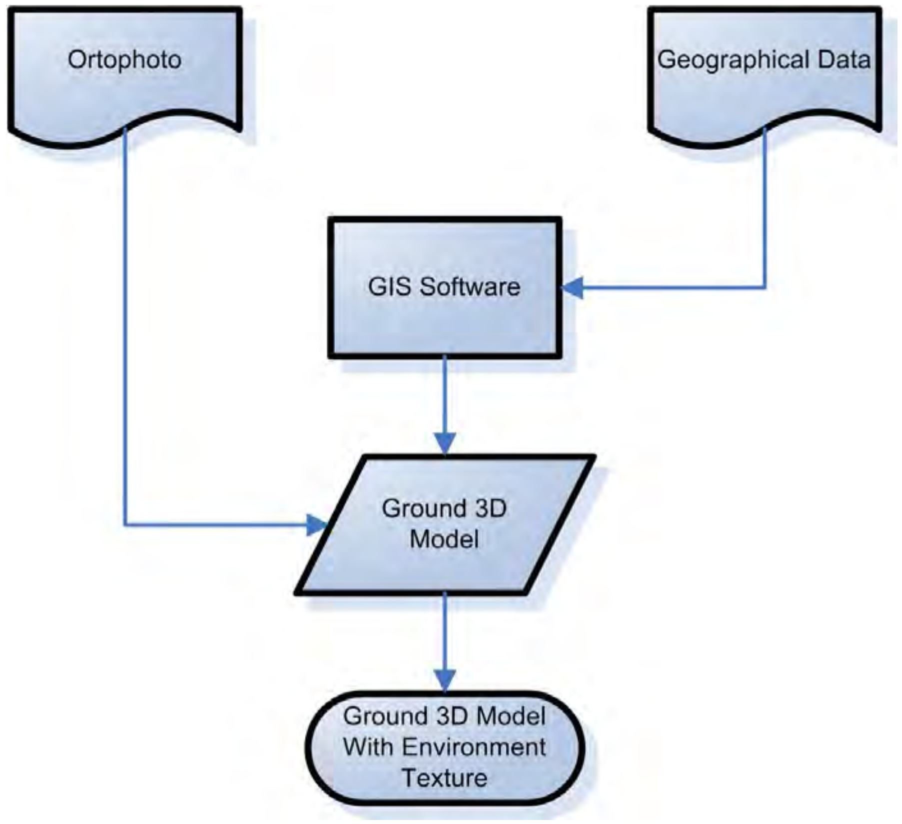


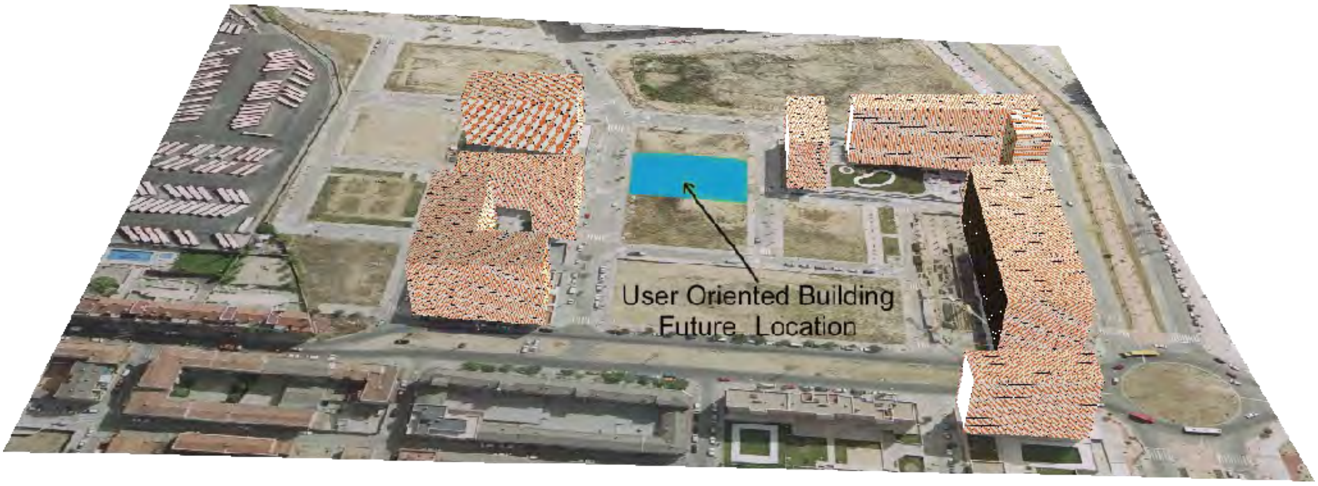
Figure 3. Basic 3D Terrain Model Generation Process

The input data for constructing the terrain model is an orthophoto of the work area and geospatial data (topographic map and a contour map).

In this step GIS (Graphic Information System) software is used. A DEM (Digital Elevation Model) will be created with the contour map. This DEM file contents the elevation points of the terrain corresponding with each pixel of the photograph map. With these elevation points a 3D model of the terrain profile will be generated.

The orthophoto will be use as texture of the 3D terrain model. It will also provide information of the situation of the different objects surrounding the user oriented building location (other buildings, streets, trees, etc.)

(a) (b)



(c)

Figure 4. (a) 3D Approached Model from (b) Real Photograph and (c) Whole 3D Model.

- The surroundings object models.

Once the 3D terrain model is obtained, the following step is reconstructing the environment. In order to do this, it is necessary to have 2D photographs of the objects and apply photogrametric techniques. This procedure consists on matching common points from different 2D views of a 3D object. The photographs must be taken with a calibrated camera or with a camera with known characteristics in order to make a correct geometric reconstruction.

With software like PhotoModeller^{TM} it is possible to make 3D models of objects from their 2D photographs. The models of the buildings of the neighbourhood will be modelled in this way. Other objects, like trees or streetlamps, will be modelled with object obtained from a 3D objects library.

The figure 4 (a) shows an approach to a 3D model produced from several 2D photographs like (b). The final result is the whole 3D environment model (c). All of them are located in the Carabanchel district, in the city of Madrid.

Interactive Modification of the Building Design

The following action is integrate the architectural design of the user oriented building into the 3D model. In this stage starts the participation of the final user who can achieve the first actions to configure his dwelling.

The process of configuration starts selecting the area desired within the city and then the specific building. The final user can navigate trough the 3D environment and can see the building where his dwelling will be situated. The user will be able to see all the surroundings of the building and, with this information, he will be able to select some general aspects like orientation, floor, etc. This process is showed in figure 5.

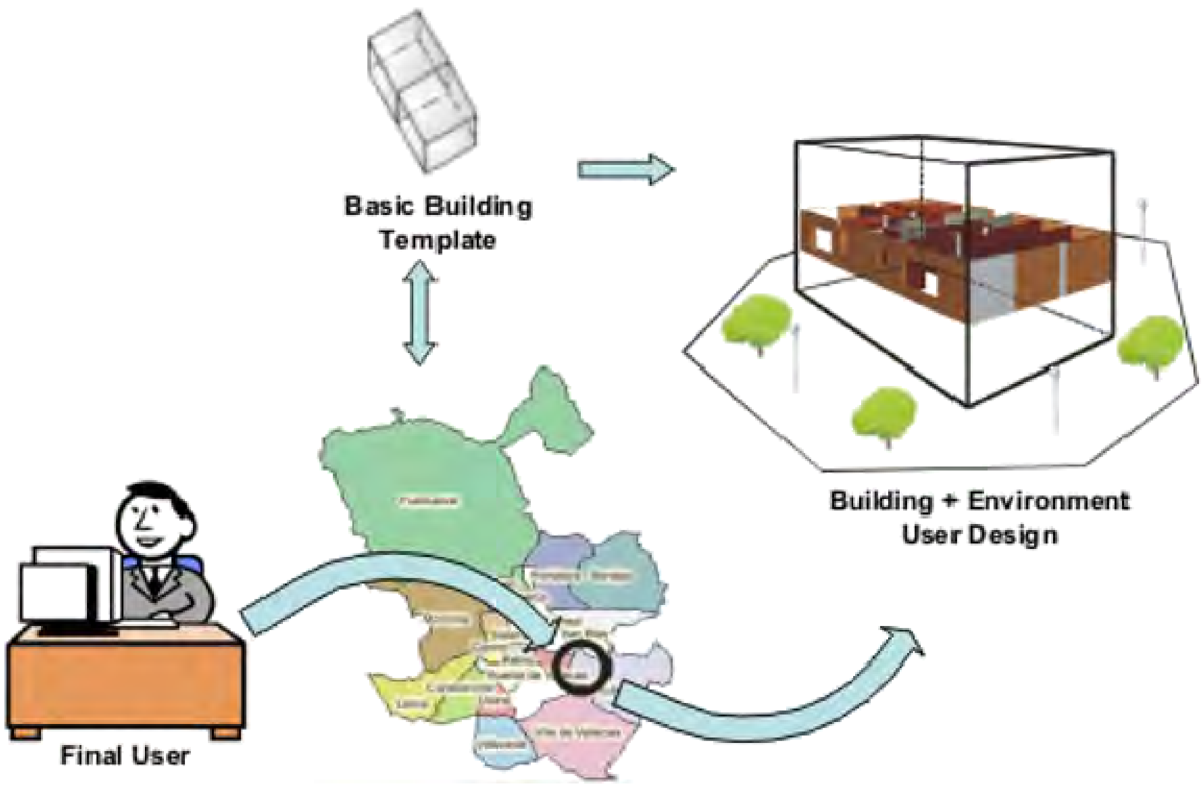


Figure 5. Area Selection and Environment Configuration

Once a particular location of his dwelling is selected the user starts the configuration of the interior side.

The user will have a list with the possible architectural modifications permitted and will be able to do them according to constraints that the designer of the 3D building model will put on it. For example, the user can move a wall but it cannot be situated a position where there is a window.

Another step to obtain the fully configured by the user dwelling is selecting the elements of the dwelling such as doors, windows and the qualities of them. This will be possible due to the connection of the system with a data base containing the different constructive elements and their suppliers. This data base is called 'intelligent component catalogue'. All these configurations will modify the final price of the dwelling, very important information to the user that can decide to maintain or change the configuration and his desires. This process can be viewed in the figure 6.

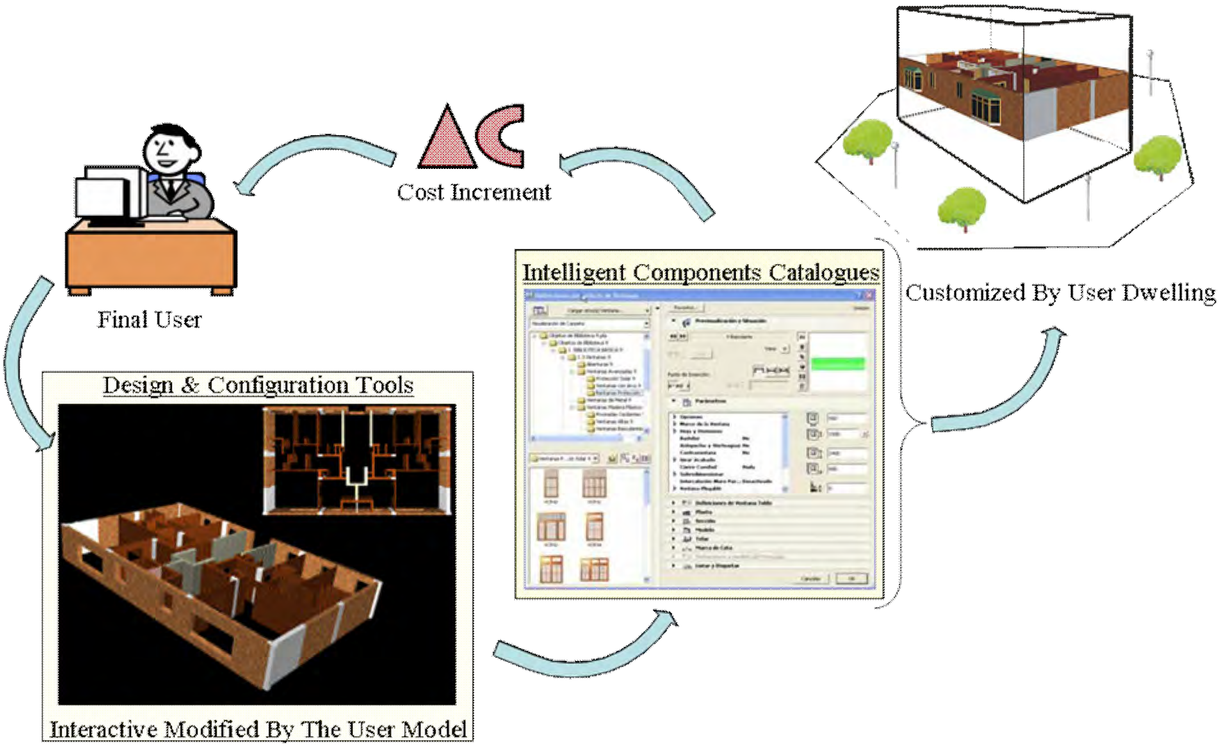


Figure 6. Dwelling Configuration Loop

VIRTUAL REALITY INTERFACES

It is necessary to develop two different kinds of virtual reality interfaces, one for designers and another for the final user.

The two main differences between them are the complexity and the functionality. While the designers interface must allow total control of the virtual world, the end user interface only allows to navigate and to modify the list of objects determined.

For designers, it is possible to select an immersive and interactive system. This system is more powerful providing more capacities to the designer.

By the other hand, it is more difficult for the user to have access to an immersive system. Due to this, the end user interface will be an interactive desktop system. The user can interact with the virtual world in order to configure his dwelling according to his preferences. At last, this interface must be web based in order to be accessed from any user location.

Results and Business Impacts

Key Findings

The main advance exposed in this research is the user in the loop philosophy. From the building sector's point of view the customer was rarely taken into account in the construction process. The building developers considered the user as the final link in the chain. The user satisfaction depended on finding one dwelling that could fit in as much as possible with his desires.

The new placement of the user increases the satisfaction because the customer can decide about his own dwelling from the first stage of the process. Moreover, all the process is oriented to the end user: design, construction and services.

This idea must be supported by appropriated tools which are not only informatics systems but also building standards or laws. This chapter makes an overview of the software tool that the customer must use into the design stage. First, the software provides a frame of the dwelling by mean of the building templates in an early stage of the construction process. Once the architectural design is over, the configuration tool permits the dwelling personalization. Two important aspects are the continuous contact with the suppliers of materials, furniture, etc. and the possibility of cost control.

Business Impacts

The main impact for the construction business is the user in the loop concept as a way to make better buildings and with more satisfaction for the customer. The configuration software is the tool in which this concept is applied.

The configuration tool is also the channel of communication between the different stakeholders involved in the process. The customer can select between multiple suppliers, banks to obtain financing, legal support, etc. Due to this, the configuration tool is the mean to open new business channels and new ways of relationship into the building market.

Conclusions

One of the most important changes introduced by the project and by this work is to take into consideration the user, from the beginning of the construction process to the end of the cycle of life of his dwelling.

Using virtual reality technologies and web based applications it is possible to make a visual design, more suitable for every kind of end user. The usability of the system is not depending on the user skills or his location.

The development of the system is in an early stage. The first work to do is to develop an interface for designers that it allows to create fully virtual environments from a limited number of data sources in a simple and automatic way.

The second step is the development of program that translates the 3D model from the designers' environment to the final user model. This software must apply the constraints to the model in such a way that all kind of building designs can be used.

The following logical phase is the web based virtual reality interface development for the end user. The interface must be designed to be used on a domestic PC and by end users with different skills. This interface should be connected with the components data base.

Key Lessons Learned:

- The customer satisfaction in the building market must be the main objective.
- The end user as an active part of the process.
- Relationship improvement between stakeholders involved in the building process.
- New technologies applied in the building market.

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Open Building Manufacturing

Core Concepts and Industrial Requirements

Edited by:
Abdul Samad Kazi, Matti Hannus
Samir Boudjabeur & Adrian Malone

The construction industry is primarily characterised as a craft-based one producing one of a kind products and services. Other manufacturing sectors such as aerospace and automotive sectors in comparison primarily rely on standardised components that can be configured and assembled to provide a specific product or service.

Open building manufacturing is an attempt to bring some of the salient features of efficient manufacturing to the construction sector. This should allow for significant savings in construction and maintenance costs, fewer errors and rework, more choices and value to the customer, new products and services that can be configured and assembled in mobile factories at construction sites, etc., as is reported in different chapters in this book.

This book contains 16 chapters, clustered under the themes of concepts, industrial requirements, and solutions and applications for open building manufacturing.

Concepts: The chapters under this theme cover the vision for open building manufacturing as seen by the ManuBuild project consortium, lessons learned on building concepts from industrial best practices, classifications of industrial building systems, and different approaches to the understanding and use of different concepts in open building manufacturing.

Industrial Requirements: The chapters under this theme focus primarily on different requirements for open building manufacturing. They cover different perspectives to building manufacturing architecture, stakeholder requirements, the need for open building maintenance, the need for use of stochastic process modelling to support open building manufacturing services, and the need for training and education to close the skills gap.

Solutions and Applications: This theme presents different initiatives in the form of solutions and applications of open building manufacturing concepts. The chapters present the operationalisation of open building manufacturing, how project culture influences performance, use of the Lego™ analogy for product and service engineering, reducing waste through prefabrication and user-oriented interactive building design.

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