Open Building Manufacturing

Key Technologies, Applications, and Industrial Cases

Abdul Samad Kazi, Matti Hannus, and Samir Boudjabeur

ManuBuild

Open Building Manufacturing

Key Technologies, Applications, and Industrial Cases

Edited by:

Dr. Abdul Samad (Sami) Kazi, Matti Hannus, and Dr. Samir Boudjabeur

Published by: ManuBuild

ISBN 978-951-38-7144-4 (Print)
ISBN 978-951-38-7146-8 (Electronic)

Table of Contents

Table of Contents iii

Preface iv

Chapter 1:
Newways: An Industrialised Kit of Parts 1
A.Fuster, A. Gibb, K. Beadle, S.Austin, and P. Madden

Chapter 2:
Value-Oriented Industrial Building for a Sustainable Future 19
S. van Nederveen, W. Gielingh, and H. de Ridder

Chapter 3:
Evolvable or 'Future-Proof' Infrastructure Design: Integrating Modularity and Safeguards 31
N. Gil

Chapter 4:
The Long Tail and Innovation of New Construction Practices - Learning Points from Two Case Studies 49
C. Thuesen, and C.C. Jonsson

Chapter 5:
Flexible and Innovative Manufacturing – Two Case Studies 65
J. Zuo, G. Zillante, and M. Smeaton

Chapter 6:
Industrial Management Approaches for Improving Building Services Works in Hong Kong 85
S.K.M Wan, ;.M. Kumaraswamy, and D.T.C. Liu

Chapter 7:
Investigating the Feasibility of Industrialised Low-Cost Housing in South Africa 103
A.A.E. Othman, and S.M. Conrads

Chapter 8:
Development of Digital Learning Environments for the BC industry 129
R.Beheshti, E. Dado, and M. van de Ruitenbeek

Chapter 9:
Virtual Reality Interactive Learning Environment 153
W. Nadim, M. Alshawi, J. Goulding, P. Petridis, and M. Sharp

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 22 partners from 8 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.

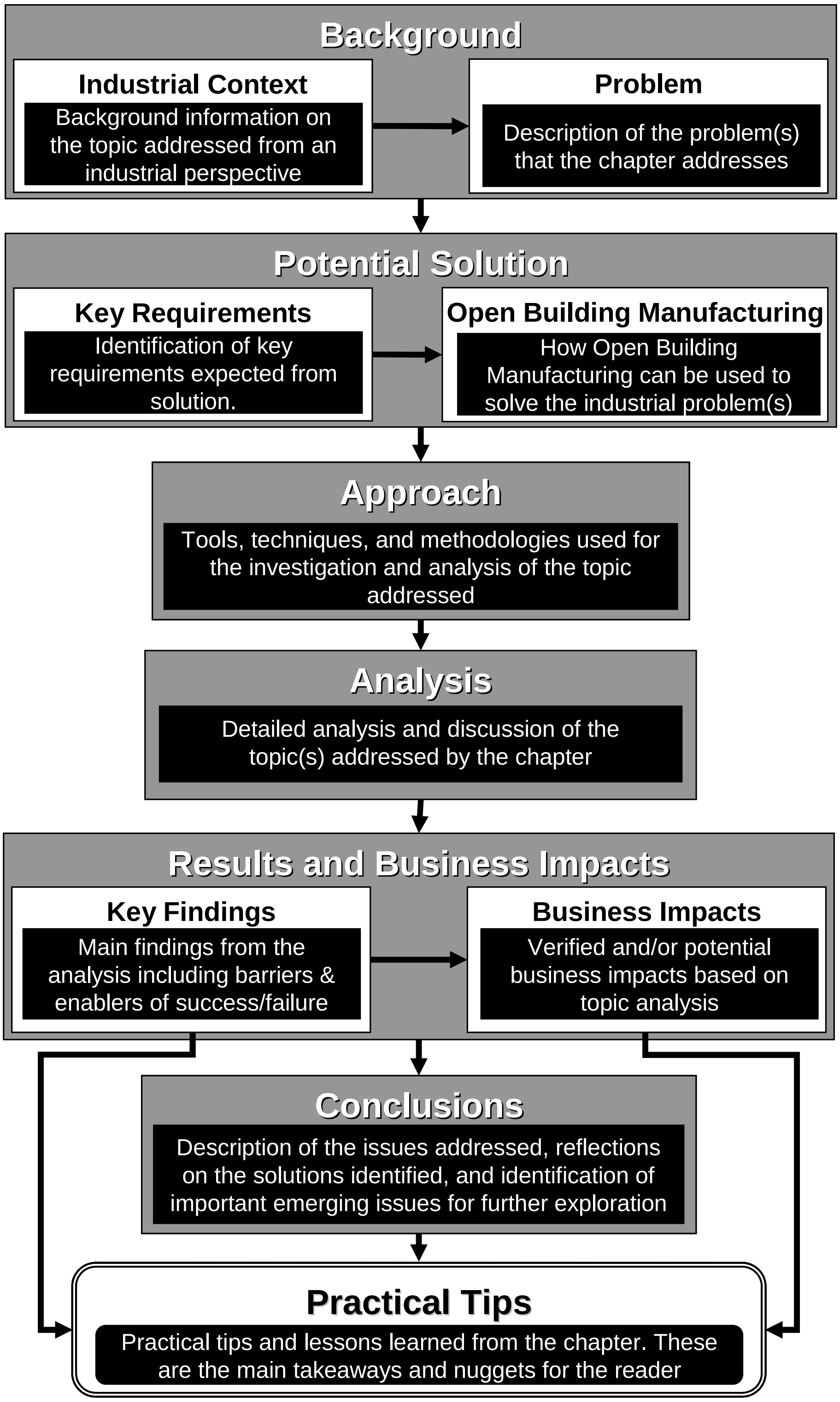
Open Building Manufacturing: Key Technologies, Applications, and Industrial Cases

This book, “Open Building Manufacturing: Key Technologies, Applications, and Industrial Cases” is the second book launched by the ManuBuild project consortium to follow-up its first book entitled, “Open Building Manufacturing: Core Concepts and Industrial Requirements”. The aim of this book, “Open Building Manufacturing: Key Technologies, Applications, and Industrial Cases” is to showcase some of the recent developments in the area of open building manufacturing.

The portfolio of chapters in this book present new ways of industrialised building design, value-oriented industrial building concepts, future-proof infrastructure design, learning environments, and a set of industrial cases studies covering: innovation and new construction practices; flexible and innovative manufacturing; industrial management approaches for improving building service works; and industrialised low-cost housing.

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, key requirements, open building manufacturing solutions, approach, analysis, key findings, business impacts, a set of conclusions, and most importantly, a set of practical tips.



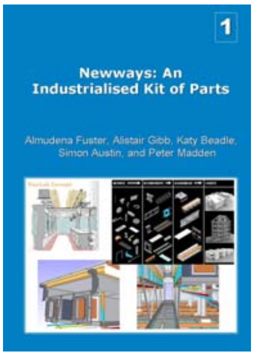
Overview of Chapter Structure and Content Flow

Portfolio of Book Chapters

Newways: An Industrialised Kit of Parts

A.Fuster, A. Gibb, K. Beadle, S.Austin, and P. Madden

This chapter reports on research exploring the adaptability of complex, framed, non-domestic buildings, through both academic research at Loughborough and practical real-life applications such as GlaxoSmithKline's (GSK) Newways pre-configuration strategy. Newways is the development of an on-demand delivery supply-chain of mass-customised operational facilities, capable of deploying assets into GSK up to eight times faster than existing processes.



Value-Oriented Industrial Building for a Sustainable Future

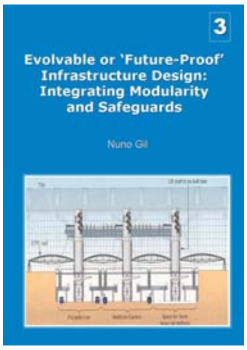
S. van Nederveen, W. Gielingh, and H. de Ridder

This chapter explores three main themes: value orientation, industrialisation and open building manufacturing, and, life cycle orientation and open building manufacturing. It advises on exploring opportunities for remanufacturing of building components in other building facilities when the host building facility no longer needs them, or is no longer used. The chapter advocates extending the concept of open building manufacturing to open building remanufacturing.

Evolvable or 'Future-Proof' Infrastructure Design: Integrating Modularity and Safeguards

N. Gil

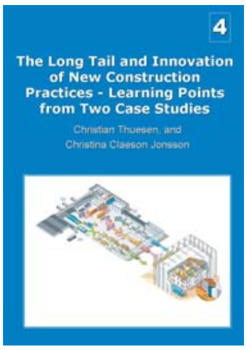
This chapter advocates understanding the importance of modularity as a strategic approach to building in flexibility in infrastructure design. It argues that modularity and safeguarding are at the heart of efforts to design future-proof infrastructures, i.e., design affordable infrastructures that can economically adapt to change over time.



The Long Tail and Innovation of New Construction Practices - Learning Points from Two Case Studies

C. Thuesen, and C.C. Jonsson

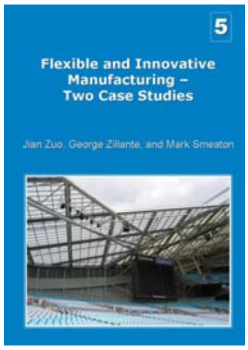
This chapter presents two different development initiatives aimed at delivering customisable residential buildings in a standardised way. While one was trying to implement a huge flexibility through industrialised manufacturing processes, the was aiming to constrain the flexibility in traditional construction - focusing on delivering value to the customers and to reduce costs.



Flexible and Innovative Manufacturing – Two Case Studies

J. Zuo, G. Zillante, and M. Smeaton

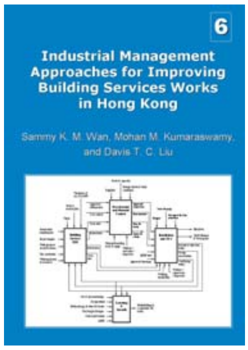
This chapter reports on the application of the principles of open building manufacturing to small scale projects. In particular, it focuses on the systems used for prefabrication, transportation and on-site assembly. It reports on how open building manufacturing was used to make substantial savings in re-configuration projects and in minimising safety risks involved with constructing at heights.



Industrial Management Approaches for Improving Building Services Works in Hong Kong

S.K.M Wan, ;.M. Kumaraswamy, and D.T.C. Liu

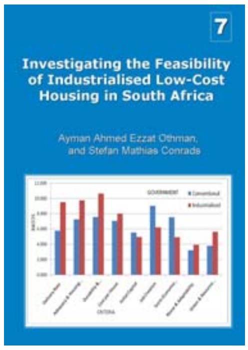
This chapter reports on the use of different industrial management approaches for improving building services in Hong Kong. It advocates adoption of a 'material tracking system', 'dynamic coordination buffering' and 'self-governing' multi-skilled work teams with reference to a 'dynamic production cell', which if implemented as envisaged, could herald a new era of 'industrial construction' with a revamped and far more efficient production system.



Investigating the Feasibility of Industrialised Low-Cost Housing in South Africa

A.A.E. Othman, and S.M. Conrads

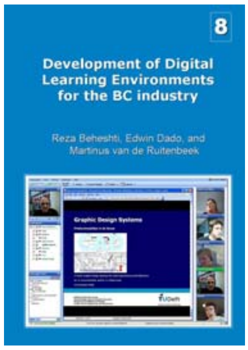
This chapter explores the feasibility of industrialised building systems as a means to solve housing problems in South Africa. Some of the key benefits of industrialised building systems over conventional building systems for social housing include delivery rate, production control, quality control, adequacy of services, and repairability.



Development of Digital Learning Environments for the BC industry

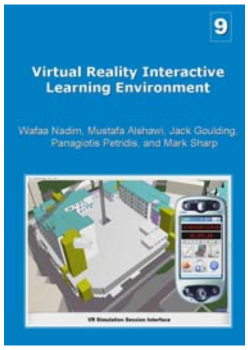
R.Beheshti, E. Dado, and M. van de Ruitenbeek

This chapter lays the foundation for next generation learning environments in the construction industry by illustrating how both human and virtual actors may participate in the role of teachers (or experts) within digital learning environments. It advocates the application blended modes of learning and training to prevent purely digital learning/training systems from becoming impersonal



Virtual Reality Interactive Learning Environment
W. Nadim, M. Alshawi, J. Goulding, P. Petridis, and M. Sharp

This chapter discusses how a virtual reality based interactive learning environment maybe used to supporting experiential learning. It advocates that interactive learning environments have the potential to enable experiential learning in a safe and controlled learning environment, with minimal disruption to the working environment, as it can facilitate "any time, any place learning". The chapter presented the development, testing, and validation of a VR interactive learning environment for Open Building Manufacturing training.



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.

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 technologies, applications, and industrial case studies on open building manufacturing that are reported in this book.

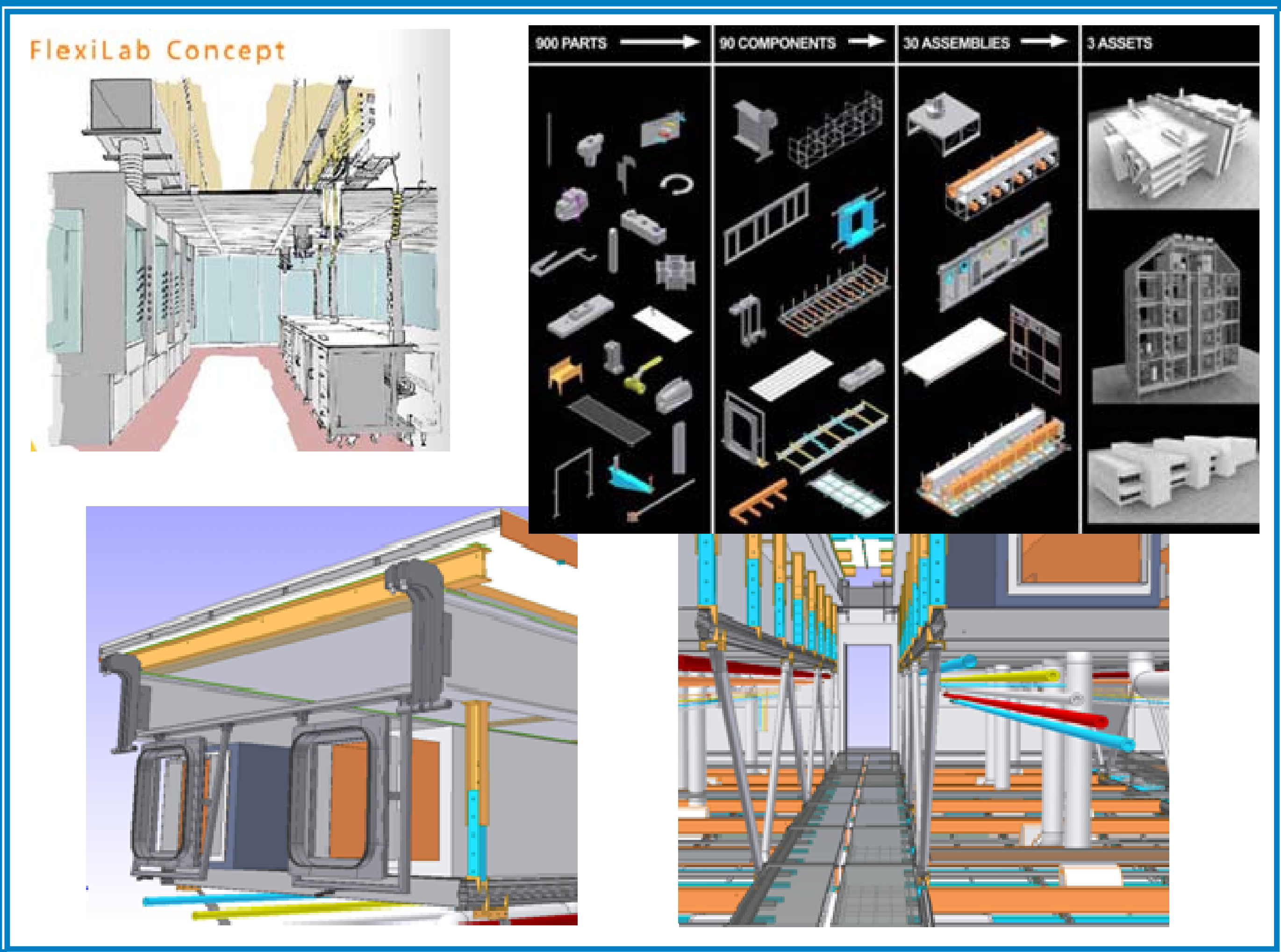
Dr. Abdul Samad (Sami) Kazi, VTT – Technical Research Centre of Finland
Matti Hannus, VTT – Technical Research Centre of Finland
Dr. Samir Boudjabeur, Corus, UK

ManuBuild, March 2009.

1

Newways: An Industrialised Kit of Parts

Almudena Fuster, Alistair Gibb, Katy Beadle, Simon Austin, and Peter Madden



Newways: An Industrialised Kit of Parts

Almudena Fuster, Loughborough University, UK (a.fuster@lboro.ac.uk)

Alistair Gibb, Loughborough University, UK (a.g.gibb@lboro.ac.uk)

Katy Beadle, Loughborough University, UK (k.beadle@lboro.ac.uk)

Simon Austin, Loughborough University, UK (s.a.austin@lboro.ac.uk)

Peter Madden, Loughborough University, UK (p.a.madden@lboro.ac.uk)

Abstract

Loughborough University's Adaptable Futures project is investigating the whole spectrum of adaptability, in the built environment, including 'first-build' adaptable 'kit-of-parts' approaches to produce a variety of solutions, as well as buildings that are adaptable throughout their lifetime. The research focuses on adaptability of complex, framed, non-domestic buildings, through both academic research at Loughborough and practical real-life applications such as GlaxoSmithKline's (GSK) Newways pre-configuration strategy. Newways is the development of an on-demand delivery supply-chain of mass-customised operational facilities, capable of deploying assets into GSK up to eight times faster than existing processes.

This approach allows GSK to delay the building process of the facilities, until they have concluded the more important business decisions regarding their product and its demand. Once they are confident in their needs for a facility, the pre-engineered nature of Newways allows an early understanding of schedule and costs, with a high degree of predictability. Newways brings with it additional benefits including greater reliability in construction and operation, lower capital costs and the ability to quickly reconfigure facilities to meet new business needs.

Achieving this step-change requires totally new technologies, a new approach to every part of the building design and production process and a need to change the business model. At present, technology and environmental issues are forcing a re-evaluation of the construction industry, and aligned to this future, GSK's strategy represents a radical initiative in the built environment.

Keywords: Business risk reduction, Shorter facility delivery, Industrialised kit-of-parts, Pre-engineered product development

Background

Industrial Context

GlaxoSmithKline (GSK[1]) -the global pharmaceutical company- ‘launched’ their Newways initiative in 2007. The main issue addressed was for the company to be able to defer critical investment decisions, through a radical reduction in design and build time for their facilities from years to weeks.

This is driven by a very clear business need to allow the appropriate amount of time for the development of their products without the risk of compromising their procedures through trying to accommodate the construction industry. It asks the construction industry to understand the needs of its customers and to deliver value through a radically different delivery process.

Problem

The construction delivery process of GSK’s facilities needs to align with their operational processes, associated with research, development, business procedures and validation for each new pharmaceutical product. The company needs to release time from the design and construction process to be able to defer critical investment actions. The commitment of capital expenditure should be delayed until the last responsible moment, in order to allow GSK to fully understand their needs and communicate this succinctly to they facilities supply chain, without procuring sub-optimal facilities.

Potential Solution

Key Requirements

The primary target of Newways is to radically shorten facility delivery and implementation times through a rapid facility deployment.

The new product development is directly linked to the delivery of facilities. The aim is to reduce design and construction time of manufacturing and research facilities from 24 months to 13 weeks, allowing a flexible response to production demands. The output is mass customisable, manufactured, on-demand facility process for use globally.

Product development is well established through work by designers Bryden Wood McLeod (BWM) commissioned by GSK. A configurable ‘kit-of-parts’ has been developed to facilitate this step-change, by rationalising assemblies components and parts within their three basic facilities (laboratories, primary plants and secondary manufacturing facilities). The building system is used to maximise the variation in first-build end product. Central to the Newways value proposition is the concept of constructing new facilities quickly using standard components that fit together and work together first time. This would be achieved at no extra cost, rather, the cost would be significantly reduced through the industrialisation of the process, reduction in variation of parts and so forth.

The need of a dramatic shortening of this design and delivery period enables GSK to wait until they really understand the required configuration of the production plants, before they start to build.

[1] GSK international region covers 80% of the world’s population and manages 6.3% of the global pharmaceutical sales.

This approach to the design of the facilities has been influenced by GSK's laboratory system: a completely flexible system of equipment on wheels, with all services fed from above (Figure 1). The FlexiLab has been implemented for some time into GSK's traditional buildings, which has meant that while the fit-out was very quick and all the components able to be moved and reconfigured at anytime in about a day and a half, the buildings took a period of two years to be completed (Fuster and Gibb, 2008).

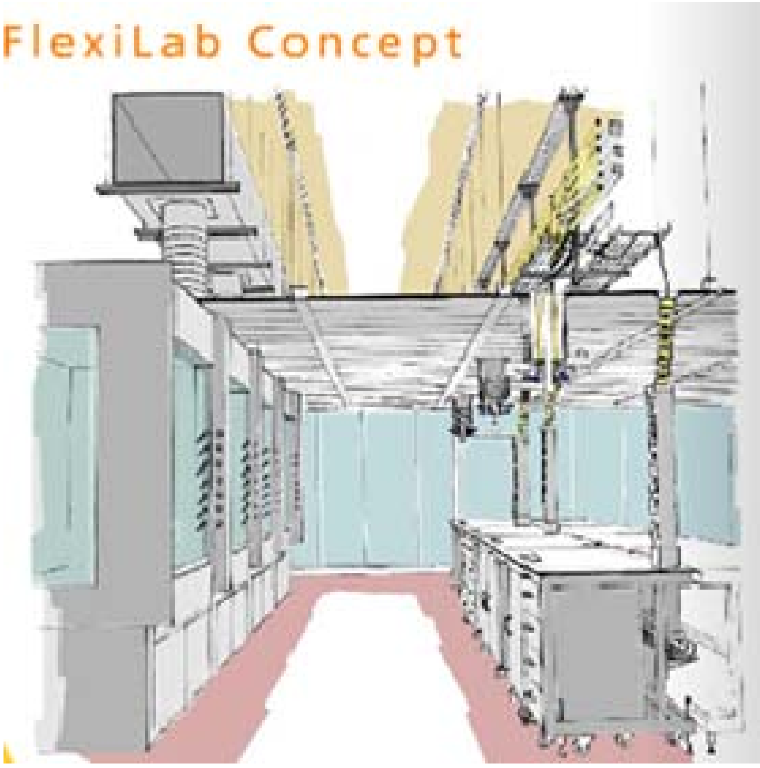


Figure 1: GSK's FlexiLab Concept
(Adapted from Barnes and McLeod, 2008b)

Open Building Manufacturing

Through the development of Newways -an industrialised kit-of-parts system designed for adaptable pre-configuration- GSK is addressing the main principles of Open Building Manufacturing.

Open Building Manufacturing can be seen as a step further towards Open Building principles and Habraken's Housing construction method from the 1960's (Habraken, 2005). As Delft University's Rob Geraedts explained in the *I3Con Conference, Adaptable Futures Workshop* (Beadle et al., 2008a) -while talking about State of the Art Adaptable Housing in the Netherlands- "Open Building is a design method, a consumer orientated building process, that caters for individual user demands, and provides both variety in demand whilst allowing for future changes" (Ibid, p.6), through industrialised construction systems. Habraken (2005) stated that Open Building relates to: a distinct level of intervention, such as 'support' and 'infill', involving multiple participants as well as different kinds of professionals; working with industrialised products and taking into account that the built environment is in constant transformation and change; and the "interface between technical systems" (Ibid), that should allow systems to easily be replaced with others that provide the same function.

From this starting point, Open Building Manufacturing contribution focuses on a "highly efficient industrialised production, combining ultra-efficient manufacturing in factories and on sites with an open system for products and components, offering diversity of supply in the market" (ManuBuild, 2006). New materials, innovative technologies, smart components, ICT systems & intelligent catalogues and platforms will improve a new business process which allows mass customisation and end user participation.

Newways principles are linked to the Open Building Manufacturing philosophy (Figure 2). The strategy and product have been developed from a similar basis (i.e. industrialised production, offsite components, quick on site connections, new business process, ICT tools, etc). However, Newways could also benefit from some of the Open Building Manufacturing principles that are not already being addressed, as a way to identify and assess further research (i.e. moving from a closed system to an open one or focussing on lifecycle flexibility). New approaches in life cycle techniques must be developed and will lead to an improvement of the use, life and sustainability issues of GSK facilities.

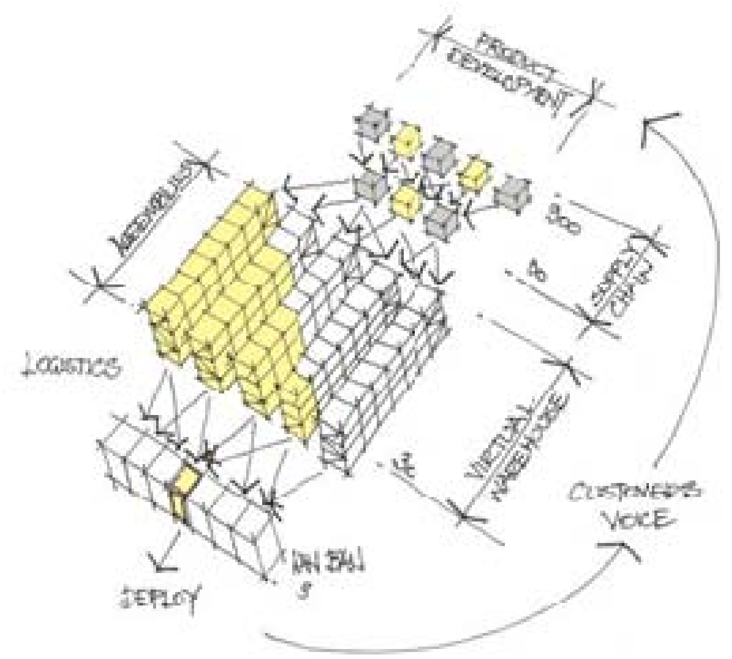


Figure 2: GSK's Newways Concept
(Barnes and McLeod, 2008a)

Approach

Current design, procurement & construction of facilities takes around 24 months. GSK has developed Newways as a rapid facility deployment, providing a radical reduction in building delivery of their facilities to provide flexibility for the business, less risk and a shorter time to market. By standardising elements of the design of their three basic facilities - laboratories, primary plants and secondary manufacturing buildings- design and build time could be shortened from 24 months to 13 weeks.

A set of assemblies have been identified for the delivery of an open floor plan plate building, able to fit any of the three main types of built environment assets, that GSK builds all over the world.

This is a radically different approach to traditional construction and is currently challenging all parts of the organisation to completely change their way of working, specifically the established processes and systems for managing production and logistics.

Analysis

GSK's Facilities

Newways' innovative way of designing, procuring and constructing the basic elements of a building applies to GSK's laboratories and primary or secondary type facilities (excluding equipment). The process has been to identify idealised design studies in which the current best practice thinking within GSK's main types of operating facility models has been brought together into a concept design for each building (Figure 3). The scope of the idealised design element has been limited by time, due to the high level of variance in GSK's current portfolio of buildings and processes. At present, GSK has over 100 facilities of which secondary are the majority, followed by laboratories then primary. These designs have being defined as operational platforms that the Newways products can service and reveal the need for additional elements that will be fed into the product development process (Gibb, 2007).

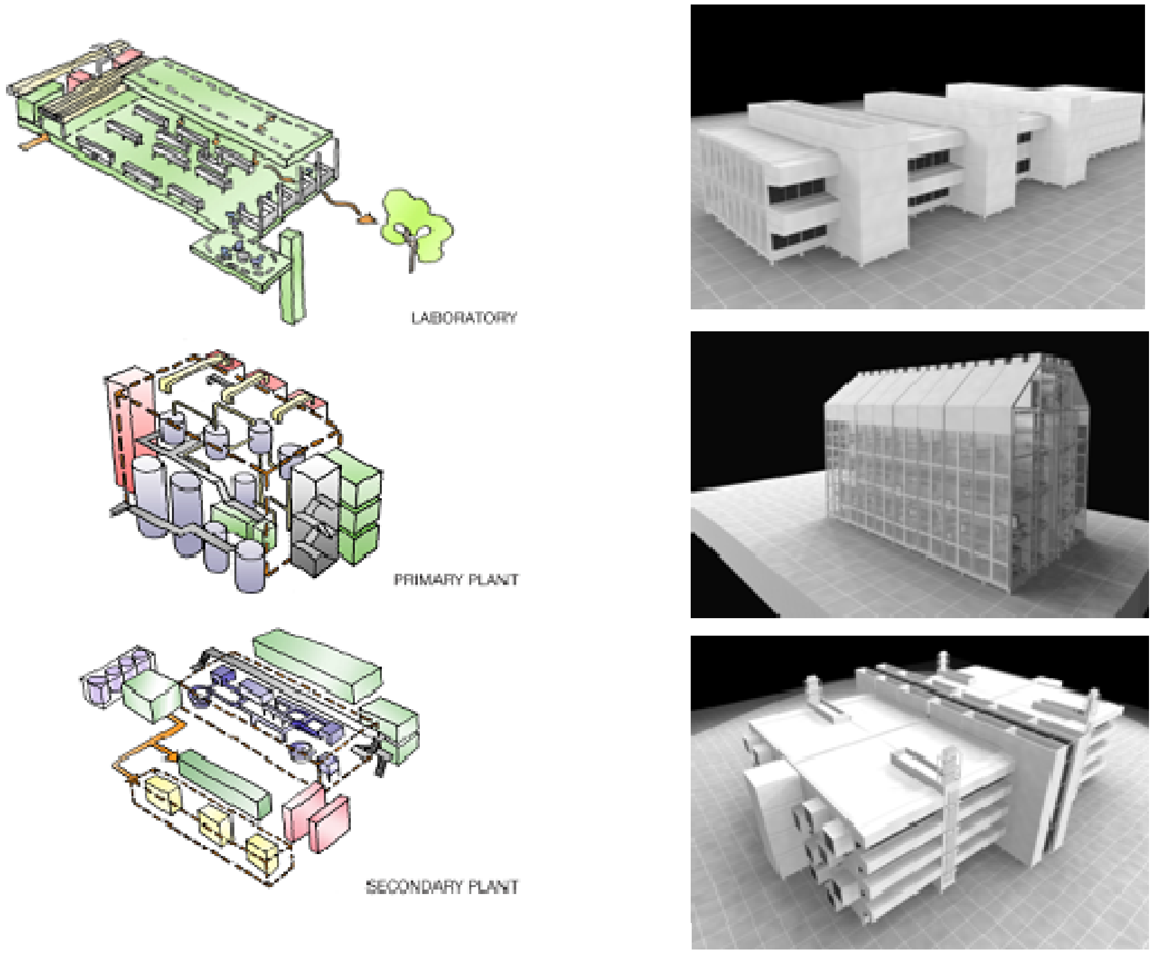


Figure 3: Analysis of GSK's building facilities: laboratory, primary & secondary plant (Adapted from Barnes and McLeod, 2008a)

The research and development stages take place in laboratories -an open floor building fitted out with the FlexiLab system- while primary facilities are used to create the active ingredient of the new drug -a vessel centric facility- and secondary facilities are where the product is made (pills, capsules, etc.)

The product-focussed approach has been driven by Frank McLeod, of BWM consultants, who was chosen and appointed by GSK to lead the engineering/design element of the project. After analysing and breaking down into elements the three GSK main facilities, all the different parts have been identified and reduced to one common platform which relates to the 80% of each of the three idealised designs, leading to just one type of building instead of three (Figure 4). A '10-80-10' rule -context-product-enhancement- has been set up, which refers to different aspects of the idealised platform. The '80' represents the percentage of standard components and assemblies. This has been achieved by taking some parts out -the complex ones- so the rest can be manufactured the same for all the facilities. The first '10' relates to the context where buildings will be placed (site-related elements, regulations, etc) and the last '10' to the enhancement or customisation (finishes & specific features) (Barnes and McLeod, 2008a).

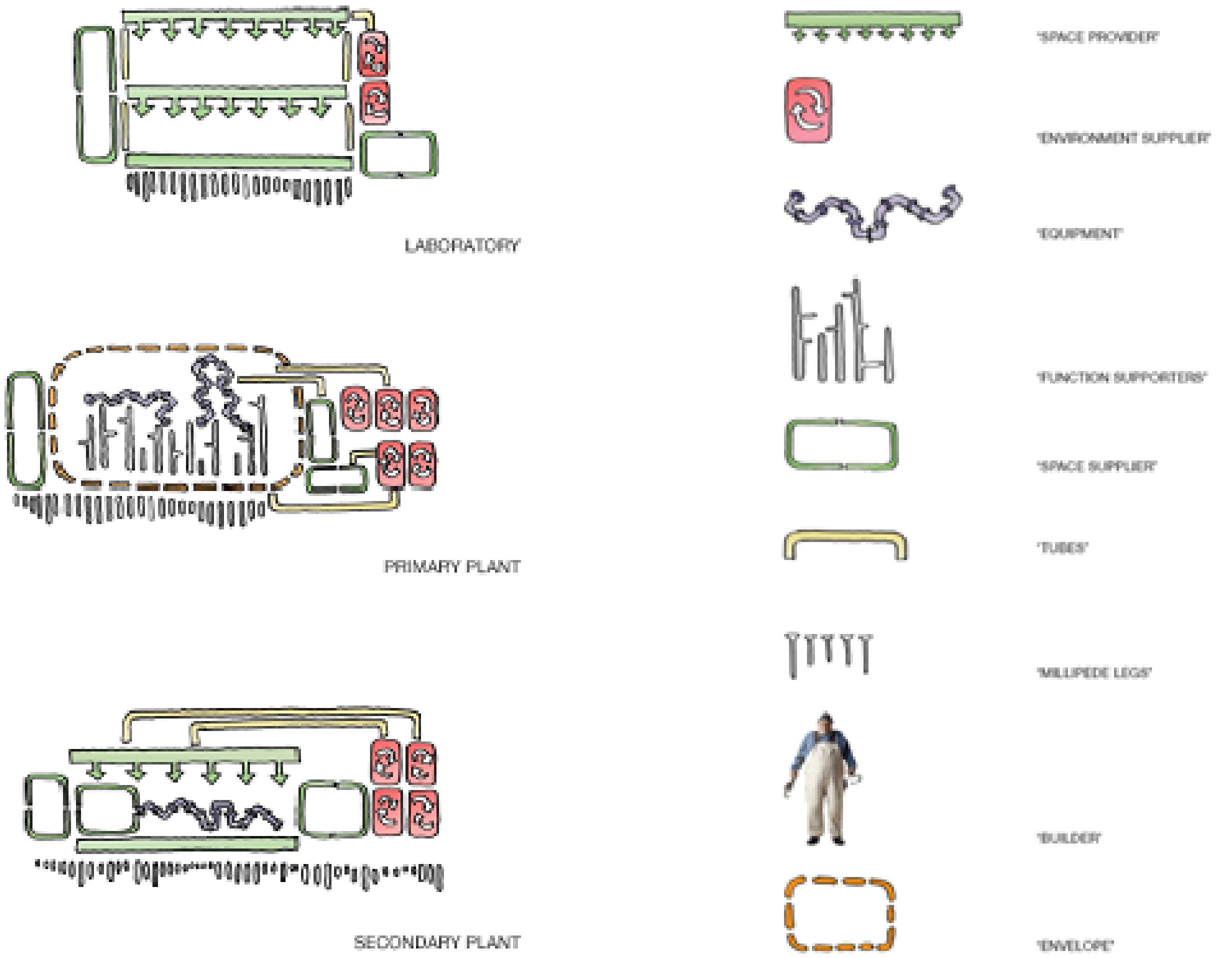


Figure 4: Identification of Common / Different parts of GSK's three building facilities (Adapted from Barnes and McLeod, 2008a)

The facilities are configured from a pallet of 30 pre-engineered products which have been designed to interface with each other, so as to allow the configuration to reflect the particular needs of an individual project (Table 1). Newways rapid deployment facility strategy has been to reduce assemblies to 30 variants, components to 90 and parts to 900 (Figure 5).

Table 1: Extent of standardisation and GSK targets for Newways

	Bespoke	Hybrid	Mass Customised	Mass Produced	Newways' target
Parts					900
Components					90
Assemblies					30
Assets					3

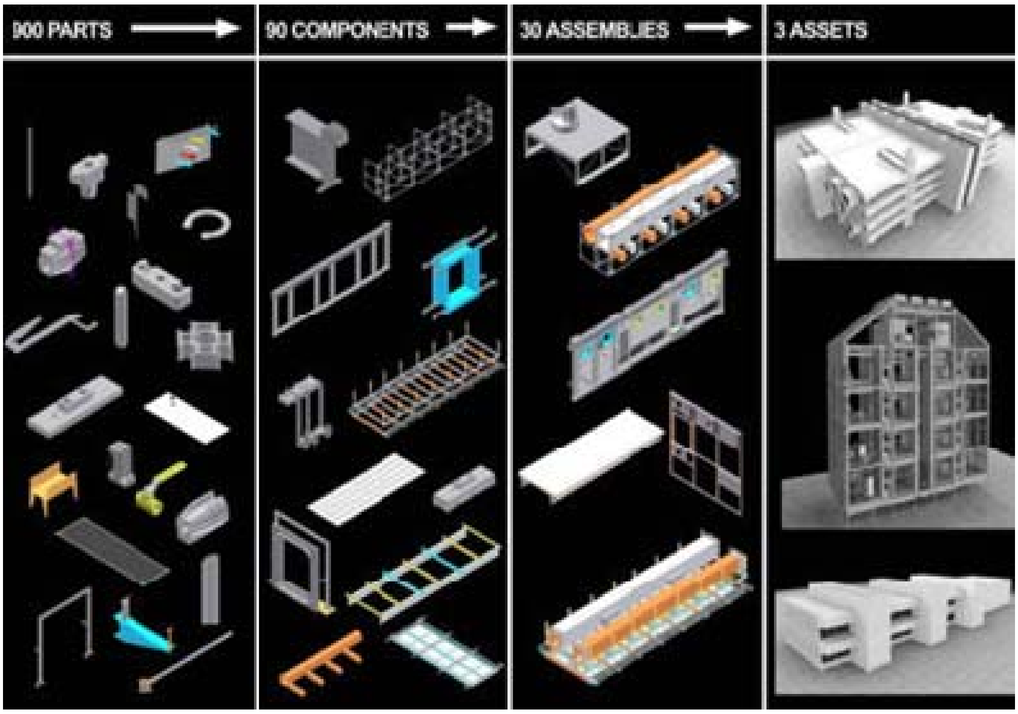


Figure 5: Newways kit of parts (Adapted from Barnes and McLeod, 2008a)

Adaptable Futures research is looking at what are the right sort and best combinations of these parts and components and their aggregation into assemblies. This work aims to identify optimum systems of building components through Dependency Structure Matrix analysis. Matrix analysis techniques potential has been applied mainly in the aerospace and automotive sectors and will help to identify the critical interfaces and highly interdependent elements. From this, optimum sizes of kits will be found to deliver the degree of customisation required.

Product Approach

The set of offsite products contains the same basic parts, components and assemblies and is able to meet the '10-80-10' philosophy for the three main GSK assets. The majority of elements, around 85%, are being performed off-site, with quick on site connections. Newways kit-of-parts includes the structure, M&E services and the fabric. GSK's design consultants have also completed a market search for the best available product for cladding, roofing, partitioning, volumetric modules such as toilets and lifts, able to fit Newways criteria, BWM have employed product designers from a manufacturing background to develop the product approach. The elements will be continually reviewed, as part of a structured product development strategy, to ensure that Newways continues to reflect in future the needs of GSK. The production of components and assemblies will also be optimised through the implementation to specific projects (Beadle, 2007b).

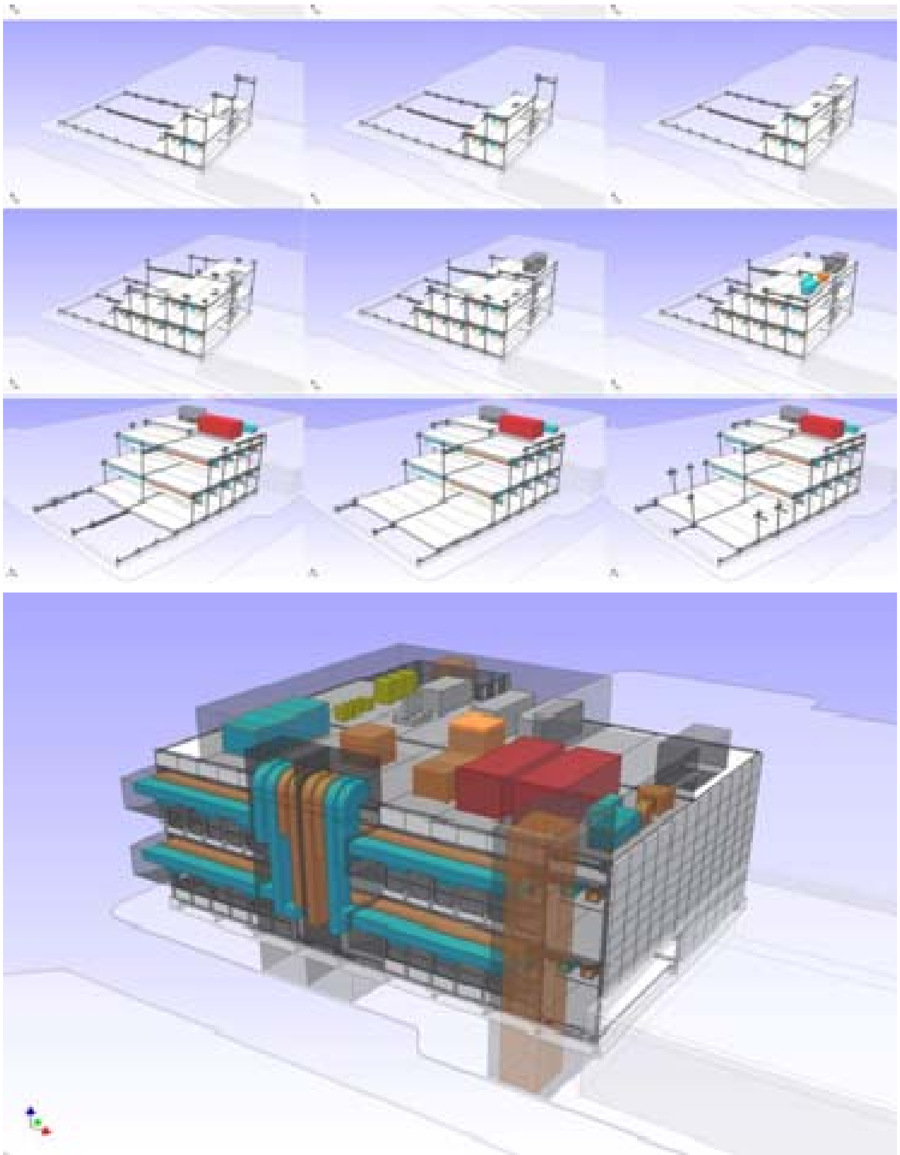


Figure 6: Newways Assembly sequence based on open floor type building (Barnes and McLeod, 2008a)

Structural assembly

The design has been developed in a number of steps. The structural assembly was the first to be completed and tested, using digital prototyping and prototypes (Figure 7). The grid chosen for the open steel framed building -12x12m- came from existing GSK laboratories. A prefabricated floor cassette -4x12m- has been developed to fit the grid and enable transportation on lorries. The aim is to install these on a basis of 16 per day, thanks to the quick connection ‘hook & eye system’ and the spine beam receivers (Beadle, 2007a; Madden, 2007).

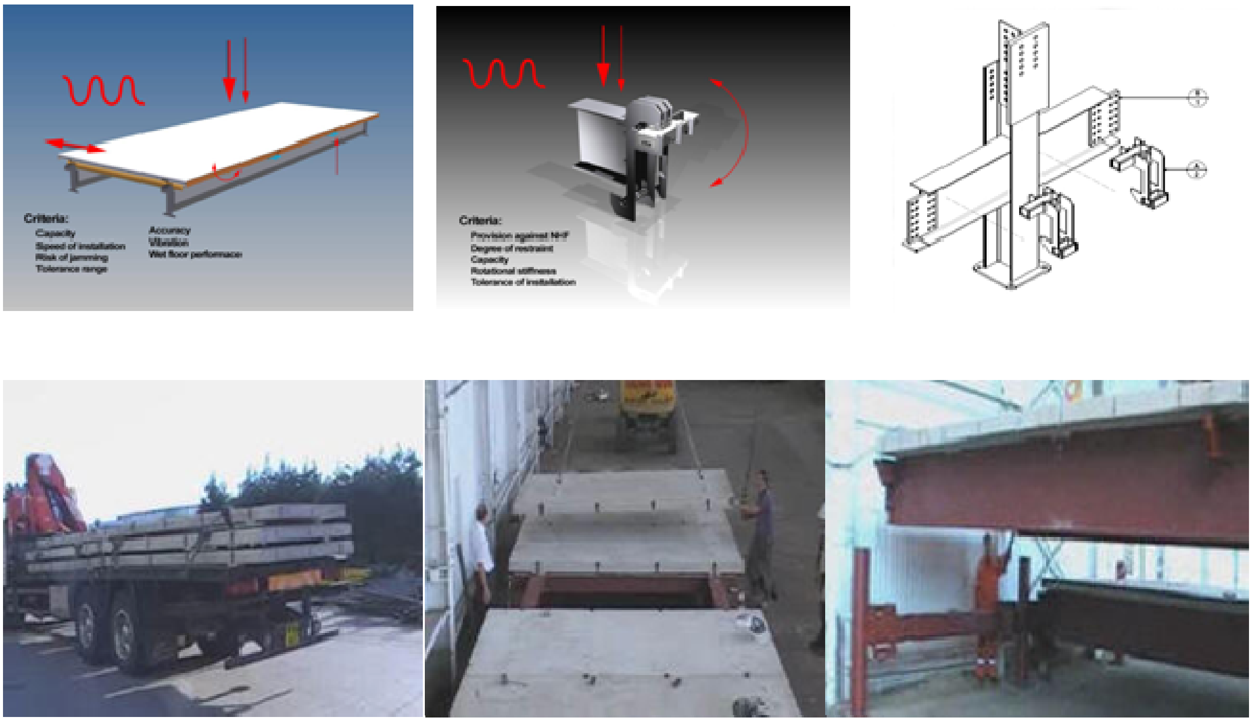


Figure 7: Newways structural system development & assemblies sequences on site (Barnes and McLeod, 2008a)

Mechanical and Electrical (M&E) services

The M&E services have been developed based on the GSK Flexilab concept (Figure 8). FlexiLab is a completely flexible laboratory design solution, with a big scope for change, ranging from services to furniture. This enables the equipment to be fitted very quickly -in about a day and a half- as well as re-fitted easily, by the scientists themselves, during a weekend (Barnes, 2008).

All the services are connected from the ceiling to multiple connections points -electrical power, data, lighting, pipe services, fire circuits- in a plug-in basis, that responds to the changing R&D environment (W.E. Marson & Co. Ltd, 2007).

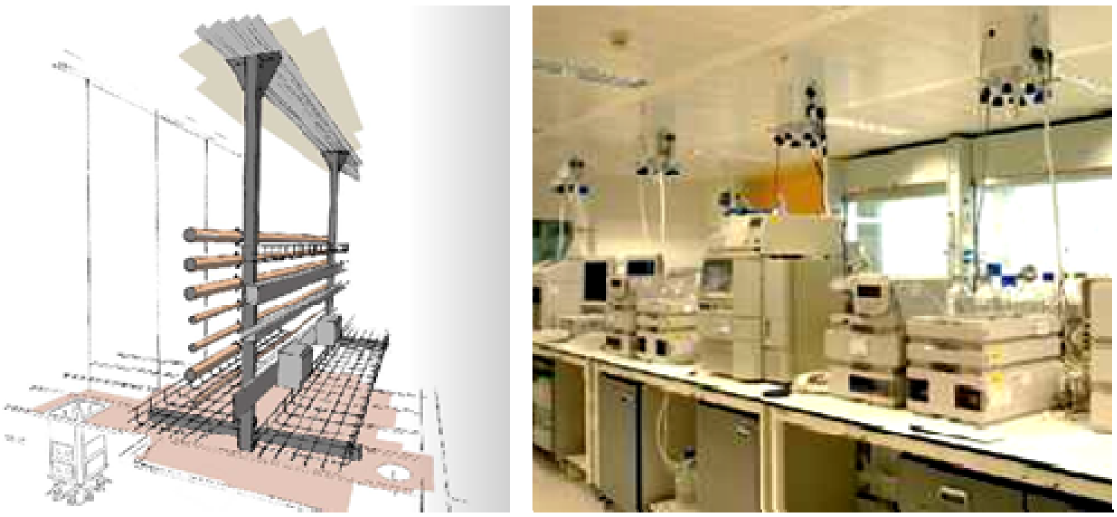


Figure 8: GSK's FlexiLab services infrastructure (Adapted from Barnes, 2008)

The aim has been to develop the Newways M&E systems design with a high level of repeatability, for deployment in future projects. The floor cassette units are provided with services attached. To enable a faster erection, connections are 'quick & easy' for on-site assembly, which includes cable trays and ductwork connections (Figure 9). A walkway through the ceiling is also planned for easy access to all the infrastructure.

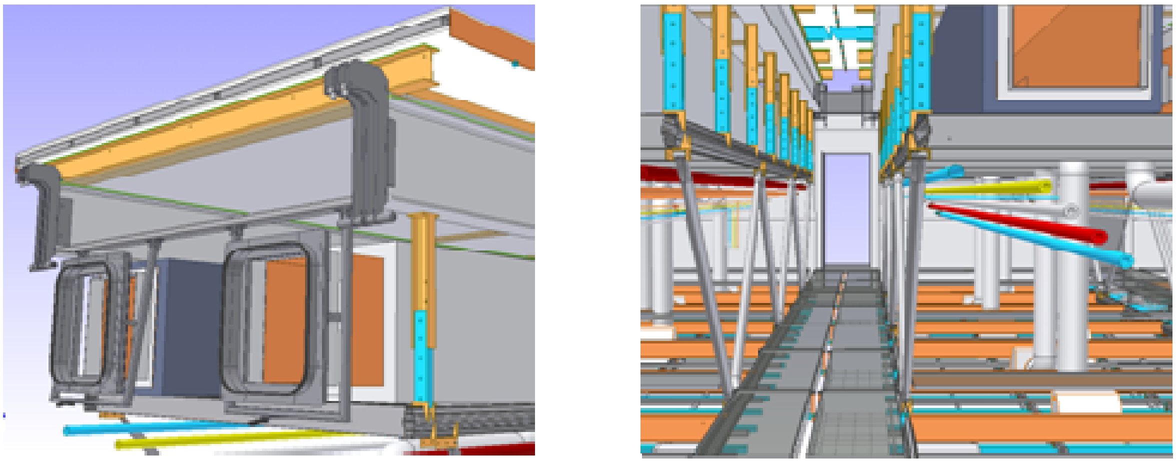


Figure 9: Newways floor cassettes with services attached and walkway (Adapted from Barnes and McLeod, 2008a)

Fabric

Newways kit of parts also includes the fabric of the facilities, which will be completed in parallel to the rest of the Newways components and brought to the site (Figure 10). It will be delivered as a series of mega panels which interface with floor cassettes at each floor plate. The mega panels consist of a pre-engineered carrier frame capable of taking a range of proprietary cladding systems. These panels will be sealed together using a zip-p gasket, developed by BWM with BAA for their segregation corridor product.

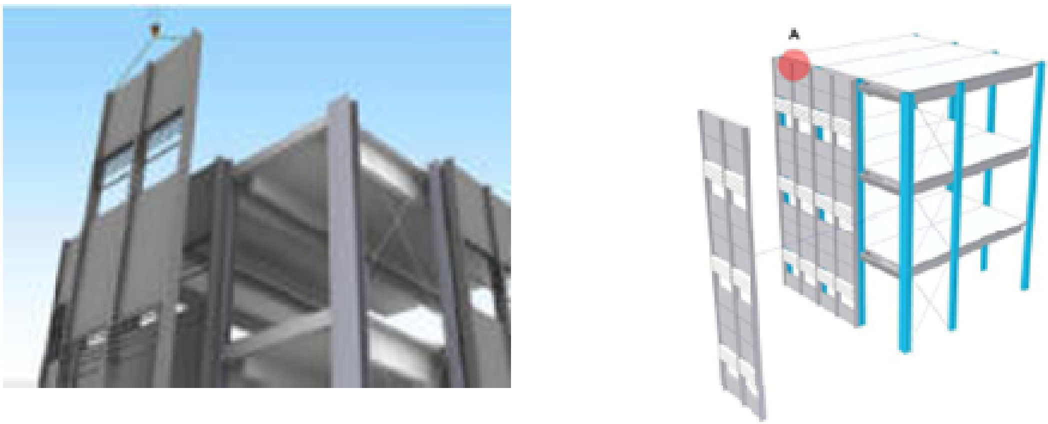


Figure 10: Newways mega panel cladding (Adapted from Barnes and McLeod, 2008a)

ICT tools

There are a number of ICT support systems that provide a set of tools to enable: assembly planning & monitoring; customer-driven design & configuration of manufactured buildings; intelligent components catalogue ICC; and market analysis and production according to demand, which Manubuild (2008) has been developing. GSK have taken a similar approach to software solutions for managing and operating the Newways business model.

Due to the number of external partners involved in the project, an on-line collaborative approach has been also taken to implement the Newways project control strategy, via a shared web portal. During the process, key partners are able to provide progress updates, raise issues or change requests among other essential data for the development of the product.

Newways manufactured buildings are planned to facilitate a high degree of design flexibility and the team is adapting an ‘Ikea’ approach to design deliverables (Figure 11). As the process is improved, the assemblies become more rationalised and repetitive and instructions less complex and more succinct.

Drawings could be diagrams -as the level of dimensional fit is not required- and they could be presented in the hierarchal system of asset-assembly-component-part (e.g. Figure 11).

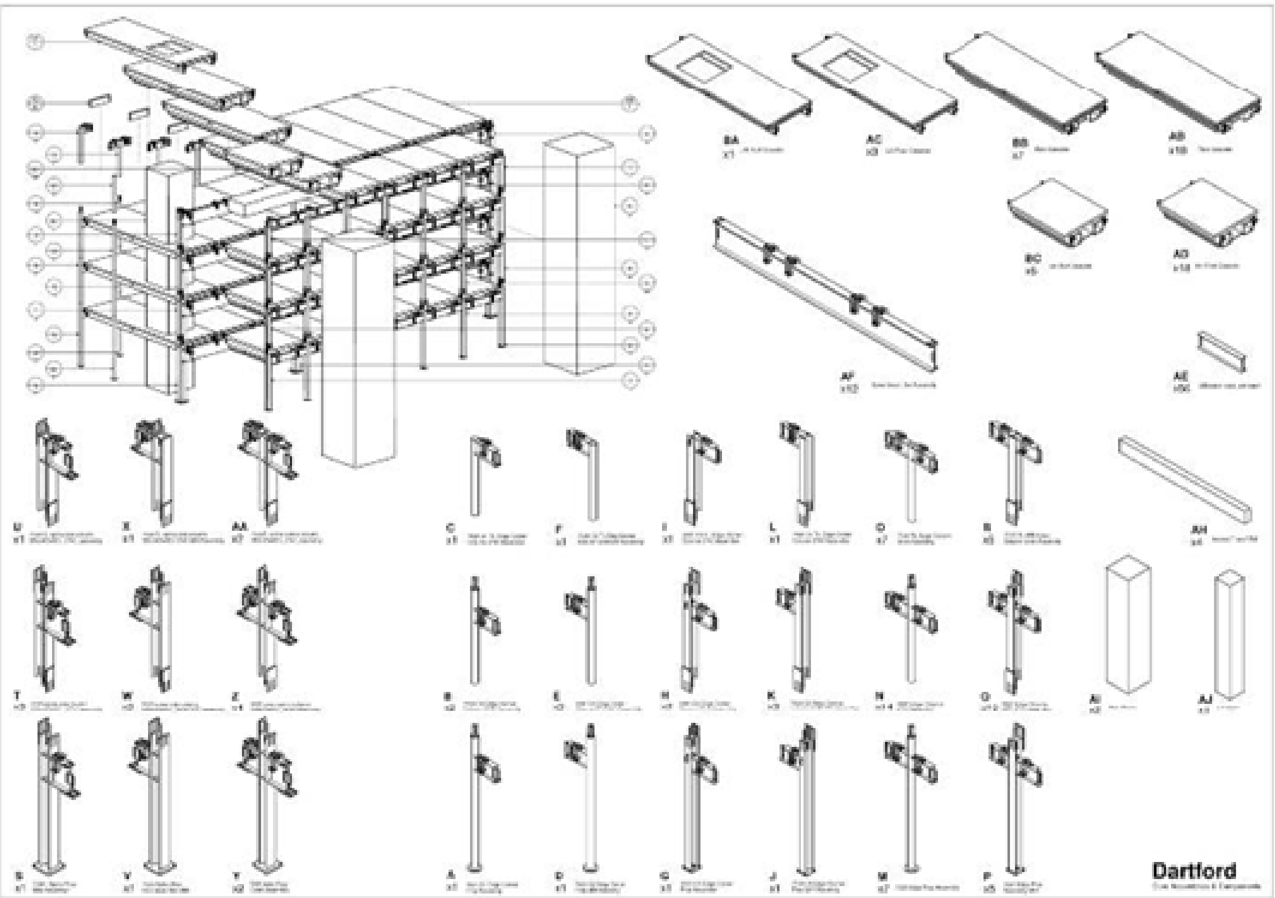


Figure 11: Newways as hierarchal system of asset-assembly-component-part (Adapted from Barnes and McLeod, 2008a)

A possible future of Newways could be a design tool with new object-based design systems. The design of the facilities will be simplified through innovative capabilities which stimulate the communication through the whole process from the client to the manufacturer. The tool will be able to give different information for each of the stakeholders involved and make explicit the set of requirements to be satisfied by any part, as well as the technical information required by project delivery teams when designing, integrating and planning the assembly of projects. An ‘Automated Newways CAD’ (Figure 12 & 13) could also be developed to help designers and engineers reduce the time spent in a project where the assembly diagrams, will drill down into the detailed components and parts. A significant degree of integration will be needed between those systems and the systems used for scheduling and controlling the production and delivery of components and assemblies (Newways, 2007).

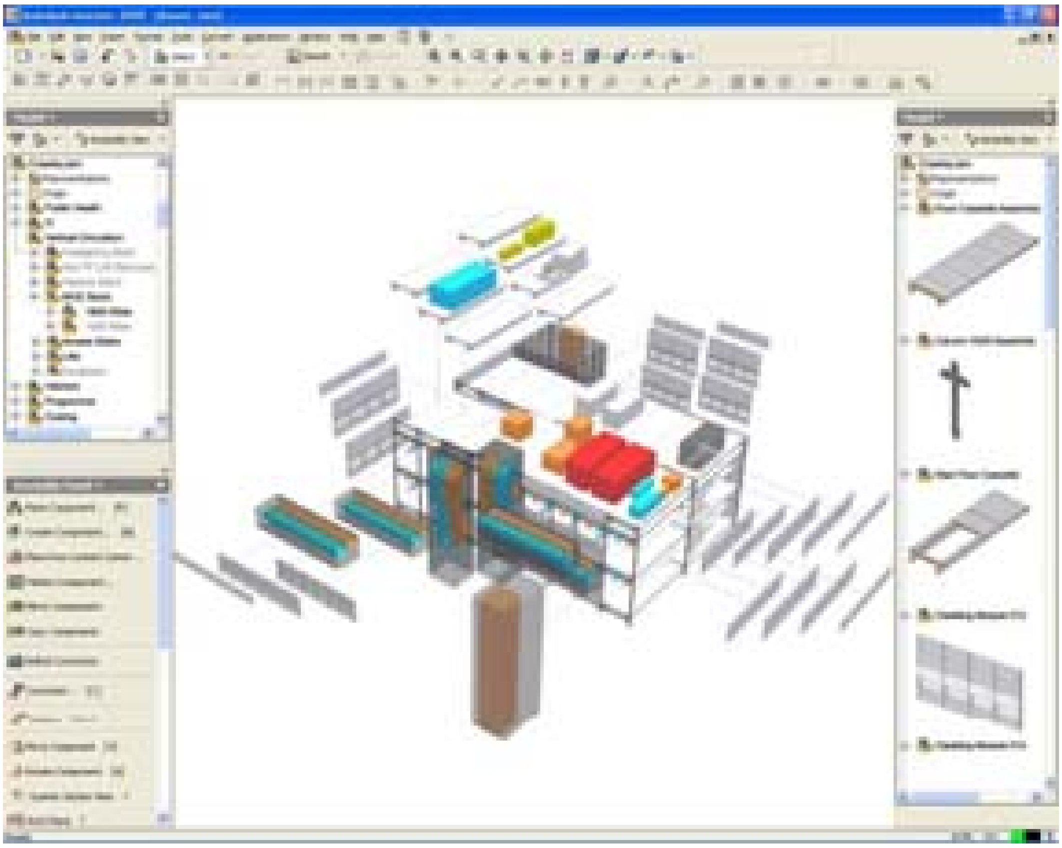


Figure 12: Building in Automated Newways CAD
(Adapted from Barnes and McLeod, 2008a)

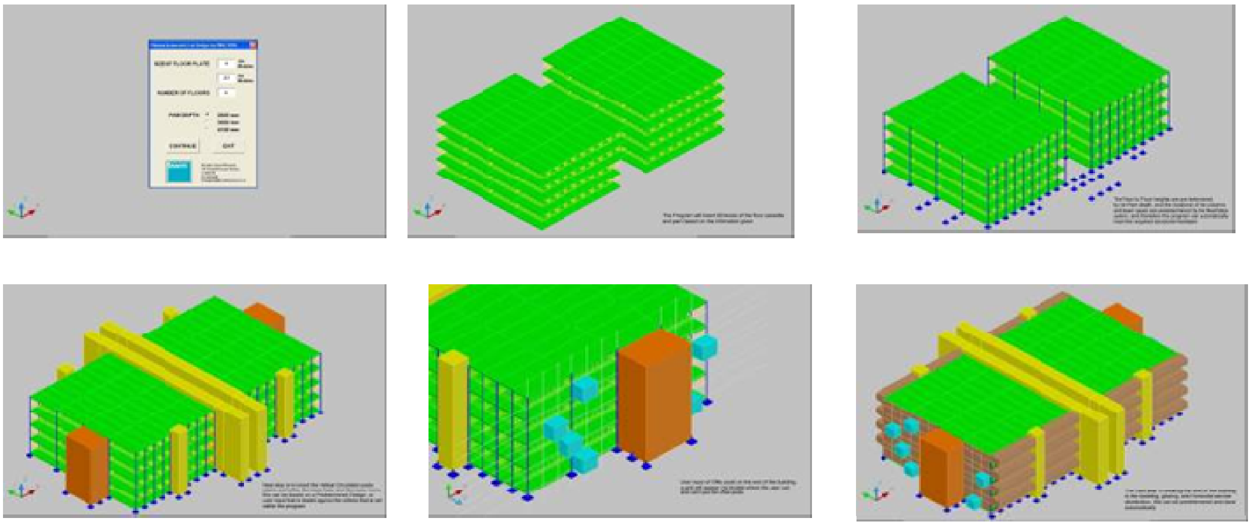


Figure 13: Newways mega panels cladding (Adapted from Barnes and McLeod, 2008a)

Results and Business Impacts

Key Findings

In order to reduce business risk and allow enough time to conclude decisions regarding their product and its demand, GSK have envisaged the development of the Newways strategy -a new way of thinking- leading to a kit-of-parts, capable of deploying assets into GSK up to eight times faster than existing processes. At present construction needs to start in the middle of GSK's pharmaceutical product development, before the product has been fully designed. This produces an unnecessary risk as, even if the investment in the development of drugs is huge, less than 20% of these early developments actually become products.

Newways' kit-of-parts is an on-demand delivery supply-chain of mass-customised operational facilities, where procurement occurs off projects.

Benefits of Newways to GSK will be a reduction of capital expenditure at risk and capital project contingency as well as a lower supply disruption risk, project cost and time scale certainty, a reduction of cost due to bespoke design -repeatability- and improved technology-transfer between sites.

On 16th October 2007, Loughborough's Adaptable Futures team facilitated the first Newways workshop, in which stakeholders from different backgrounds -engineers, consultants, logistics experts, suppliers- were brought together to discuss about the strategy and process. The supply chain and its management were seen as key issues, linked to component production. It was suggested that the supply chain should be owned by GSK or, at least, they would need to be in control to enable a global process. The Newways concept requires direct contracts between GSK and its suppliers of components and assemblies and new relationships that encourage collaboration and efficient production. To achieve this goal, the actual supply chain will need to be reconfigured. Medium to long-term, on-demand performance based relationships will be necessary, formed with specialist suppliers and upon demand forecasts across GSK's capital investment programme. In the automotive market some companies already do this, including Toyota who has a long-term relationship with key suppliers. It will also be necessary to identify suitable partners within the industry who have proven fast build systems or who are willing to develop new systems to suit GSK's requirements.

The Newways supply chain will need to be managed by a new team of delivery specialists, with a high degree of skills in front-end design, logistics and supply-chain management. A cultural change is also needed regarding programme management and should address the shift from managing individual projects to managing GSK's entire programme (Beadle, 2007b).

Business Impacts

The Newways strategy demands a radical change in current business process, and will affect all those involved in it. There is a need to establish the market for the product, moving from a conventional project process to a lean capital programme, and to ensure a monitoring of the results, looking specifically at programme management, product development, supply chain management and production of components and assemblies.

Conventional roles -affecting supplier relationships, design, construction and logistics- need to be broken down. As an example, the project team is formed by a cross functional mix of project managers, end-users, engineers, architects, designers & suppliers. The communication and information transfer is a critical issue and ICT tools need to be developed to facilitate it. Business and the supply chain need to be reformed to see cultural change, a new way of working, as getting things delivered on time and when expected on site. At the Newways workshop in October 2007, it was proposed that, during the transition from the existing projects organisation to Newways, a team with expertise in change management and communication could be useful.

GSK is engaged with a range of projects which could benefit from Newways implementation. They will gain experience on the first ones and a review of each project will capture benefits and compare traditional and expected results to the real new ones. Newways strategy will be constantly improving as it's developed (Beadle, 2007b). Business aspects also form part of the Adaptable Futures research project.

Conclusions

Newways strategy should address sustainability in all its three aspects -economical, environmental and social- and specifically, lifecycle issues need to be analysed to ensure future-proofed assets. The Newways' kit-of-parts should not only be able to configure different types of facilities from the same set, but be able to reconfigure and adapt during its life.

To guarantee longer life and better performance, buildings should be adaptable to changing parameters and evolving environments. The flexibility in the short and long term, the possibility of rearranging internal spaces, upgrading of materials and technology or disassembling components is crucial. The lifespan of GSK primary and secondary facilities is linked to the patent life of the pharmaceutical products developed, this should be reinforced by the possibility of facilities being refitted, dismantled and reused. At the moment, the majority of buildings are designed and constructed to suit a particular use at a certain time, with little thought for the future. The Newways concept is applying the concept of FlexiLab to the whole building. The Newways' lifecycle cost has been calculated by GSK as being lower than conventional laboratories and the reconfiguration cost was seen as being negligible (Beadle, 2007a). This should set a precedent and facilitate adaptability of Newways facilities.

Practical Tips

- GSK Newways system is an on-demand delivery supply-chain of mass-customised operational facilities, capable of deploying assets up to eight times faster than existing processes
- To achieve a configurable kit-of-parts requires totally new technologies
- The parts will be continually reviewed, as part of a structured product development strategy, to ensure that Newways continues to reflect in future the needs of GSK
- The Newways strategy means a radical change in the current business process, and will affect all those involved in it
- ICT tools will be of great help to enable the development and implementation of the Newways strategy
- The Newways process will gain experience and improvement through implementation and review of results
- Future-proofed facilities will be enabled through adaptability during their lifecycle

Acknowledgements

The authors would like to thank the Newways team for contributions to this chapter, including GSK's, John F. Dyson, Al O'Dornan and Nigel Barnes (now CEL), and BWM's Frank McLeod.

References

Barnes, N. (2008) Newways, Presentation at 2nd Adaptable Futures Partners Meeting, 7th February 2008, unpublished.

Barnes, N., and McLeod, F. (2008a) Building GSK Model, Presentation at 2nd Adaptable Futures Partners Meeting, 7th February 2008, unpublished.

Barnes, N., and McLeod, F. (2008b), Presentation at the Leading European Architects Forum – Offsite, London, January, 2008, unpublished.

Beadle, K. (2007a) Report on BWM Newways Meetings – 30/10/2007, unpublished.

Beadle, K. (2007b) Report on GSK Newways Workshop – 16/10/2007, unpublished.

Beadle, K., Fuster, A., Madden, P., Gibb, A., and Austin, S. (2008a) Critical Parameters for Adaptable Buildings: from small houses to big buildings – Workshop Report, unpublished.

Beadle, K., Gibb, A., Austin, S., Fuster, A., and Madden, P. (2008b) Adaptable Futures: Sustainable Aspects of Adaptable Buildings. In: Dainty, A. (Ed.), ARCOM (Association of Researchers in Construction Management) Twenty-Fourth Annual Conference 2008, 1-3 September, Cardiff. ARCOM, Vol. 2, p.1125-34.

Bryden Wood McLeod (BWM). (2007) Newways Drawings, unpublished.

Fuster, A., and Gibb, A.G. (2008) Adaptable Futures – 2nd Partners Meeting, 7th February 2008, unpublished.

Gibb, A. G. (2007) Adaptable Futures – 1st Partners Meeting, 21st September 2007, unpublished.

Gibb, A, Austin, S, Dainty, A, Davidson, N and Pasquire, C (2007) Towards Adaptable Buildings: pre-configuration and re-configuration – two case studies. In: Sharp, M (Ed.), ManuBuild 1st International Conference - The Transformation of the Industry: Open Building Manufacturing, 25-26 April, Doelen Congress Centre, Rotterdam. Manubuild, Vol. 1, 147-58.

Habraken, J. (2005) Open Building; brief introduction, http://www.habraken.com/html/introduction.htm (date accessed: 27 March, 2008).

Newways (2007) Newways: The Product Pipeline, Newways USB Drive Presentation, unpublished.

Madden, P. (2007) Notes from BWM Newways Meetings – 30/10/2007, unpublished.

ManuBuild. (2006) Open Building Manufacturing, http://www.manubuild.org (date accessed: 21 April, 2008).

Murray, S. (2007) GSK Newways: Organisation and processes for delivering Newways, unpublished.

W.E. Marson & Co. Ltd (2007) FlexiLab, http://www.wemarson.co.uk//index.php?view=flexilab (date accessed: 22 January 2008).

Author Biographies

Almudena Fuster is senior researcher at Loughborough University Adaptable Futures project. Her background as an architect is from private practice on residential, commercial, cultural/educational and health building projects. She has been involved in a number of high profile European Commission research projects in building and environment from FP5 & FP6, while working for the Innovation department of Madrid City Council Housing Company, in Spain.

Alistair Gibb is Professor of Construction Engineering & Management at Loughborough University. He is a Chartered Engineer and Chartered Builder with an industrial background and strong research track record in construction innovation, offsite production and health & safety.

Katy Beadle is a Research Associate on the Adaptable Futures project in the Civil and Engineering Department at Loughborough University, which she has been working on for the past year. She has a background in Architecture and gained a PhD in the Institute of Energy and Sustainable development, De Montfort University, which investigated the design process for low-energy housing. She also has an MSc in Renewable Energy and Architecture from the University of Nottingham.

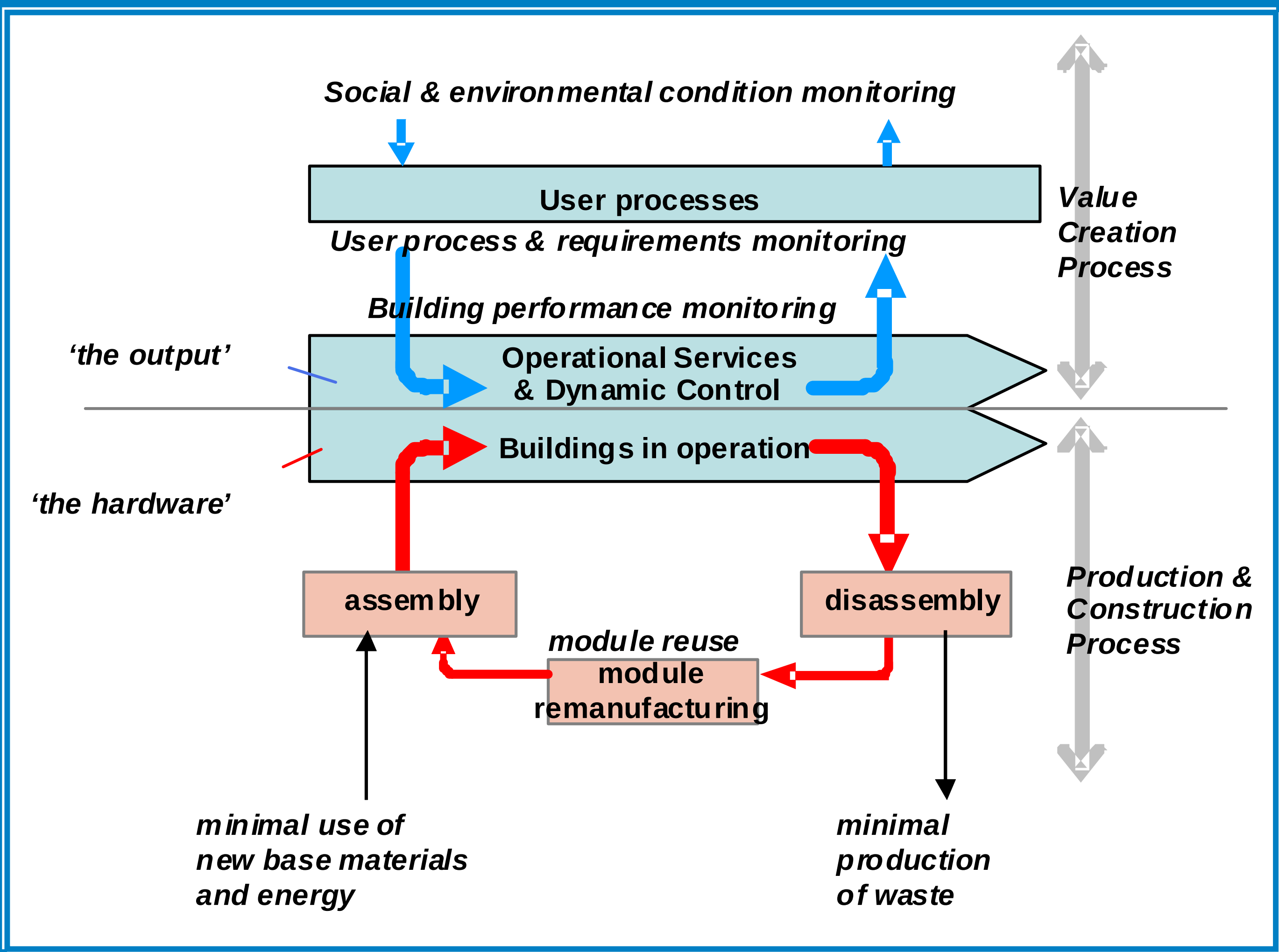
Simon Austin is Professor of Structural Engineering at Loughborough University. He is a Chartered Engineer with industrial and research expertise in design management, information and value management, process re-engineering and associated technologies.

Peter Madden is a Senior Research Associate on the Adaptable Futures project at Loughborough University. He has an architectural background, practicing as an Architect as well as being a former Head of Birmingham Universities' Architecture department.

2

Value-Oriented Industrial Building for a Sustainable Future

Sander van Nederveen, Wim Gielingh, and Hennes de Ridder,



Value-Oriented Industrial Building for a Sustainable Future

Sander van Nederveen, Delft University of Technology, the Netherlands (g.a.vannederveen@tudelft.nl)

Wim Gielingh, Delft University of Technology, the Netherlands (wgielingh@tiscali.nl)

Hennes de Ridder, Delft University of Technology, the Netherlands (h.a.j.deridder@tudelft.nl)

Abstract

In this chapter three themes are discussed and innovative concepts for these themes have been presented.

The first theme is value orientation. The building industry can create more client satisfaction and appreciation from users and society when a value-driven approach is used instead of a cost-driven approach. A value-price-cost model is presented that can be used for value-driven building projects. The concept of Product Service Systems, that is already known in other domains, can be very useful for flexibility in value-driven building projects.

The second theme is industrialisation and open building manufacturing. The advantages of industrial building are obvious, yet industrial building has not become a mainstream development. In this chapter we argue that integration of available technologies is needed, but it is more important that an innovative business model is developed and introduced that is based on the concept of "supplier-driven demand".

The third theme is life cycle orientation and open building remanufacturing. Recent global issues such as climate change and expected shortage of fossil energy have lead to an urgent need of more insight in energy use and waste production of the entire building industry, including the production and transport of building materials. The next step is of course the development of methods and approaches to decrease energy use and waste production. For this development cradle-to-cradle thinking and remanufacturing can be the leading principles.

Keywords: value-driven business models, industrialised construction projects, living building concept, cradle-to-cradle, remanufacturing

Background

Industrial Context

Construction projects can be great examples of craftsmanship and collaboration, leading to wonderful new or renovated buildings. But often construction projects come with disappointments: delays, cost overruns, quality issues, or just results that are significantly different from what the client expected.

Typical problems in construction projects that have been subject of research in the last decade are failure costs, lawsuits between clients and contractors and the unpredictability of construction projects. Failure costs are extra costs related to construction failures or design failures. Lawsuits are almost always caused by inadequate construction contracts, put on paper in the design stage and rendered out of date by changed circumstances. Unpredictability of construction projects can be regarded as the result of the process-related problems described above, combined with technical unpredictability. For example, the position and structural behavior of construction elements are usually known in advance, but only approximately, never exactly. And the deviations from expected values are considerably higher than in common manufacturing industries.

In the near future, the construction industry will face additional challenges that are related to the issues of global warming and shortage of fossil energy. Society will ask for a zero waste, zero impact construction industry. Until recently, the construction industry contributed to a sustainable society by for example building energy-efficient buildings and using sustainable materials. This will no longer be sufficient. The construction industry will need to justify material and energy use and waste production during construction as well as during use of buildings, and at the time of demolition, including re-use of materials and re-manufactirung of building parts.

Problem

As discussed above, a range of common process-related issues can be identified in construction projects. In this chapter we will focus on three general problems in construction.

The first one is the problem of developing construction contracts that support successful projects instead of forming an obstacle. In our view many problems in construction projects are related to inadequate contracts. Many construction contracts are still based on lowest price only; value orientation is still uncommon in construction. In this chapter we will discuss methods, tools and experiences for flexible, value-oriented construction contracts.

The second problem is the lack of industrialisation of the construction industry. Industrialisation in construction has been a research themes for several decades (e.g. in research on Open Building), but for some reason this research has not really led to big changes in practice. Instead, industrialisation in construction could potentially lead to a much higher predictability of projects and lower failure cost. In this chapter we will focus on the identification of success factors for industrialisation in construction.

The third problem to be addressed is the need for low impact, low waste construction in all life cycle stages. The full extend of this problem has only recently become apparent, with the acknowledgement of the global warming problem and the renewed interest for energy shortage, partially caused by the rapid economic developments in China and India resulting in increasing energy demands from these countries.

Potential Solution

Key Requirements

The three general problems in the construction industry described above have lead to the following key questions:

- How can we make the transition from the traditional tendering practice based on lowest cost towards an innovative value-based tendering practice?
- How can we achieve successful industrialisation in construction?
- How can we achieve low-impact and low-waste construction?

These questions lead to the following requirements:

- A business model for value-based construction that supports most economically advantageous tendering (MEAT) and dynamic, flexible contracts that can handle changed requirements, changed stakeholders and other changes caused by external influences.

- Identification and resolution of factors that hinder industrialisation for construction.
- Insight in energy usage and waste production during the entire life cycle of both built facilities and built components.
- An approach or configuration system for remanufacturing of building facilities with components that have been used elsewhere but that are well suited for reuse.

Open Building Manufacturing

Open Building Manufacturing methods can play an important role in the solution for the problems described above. This is most apparent for the industrialisation issue. In particular, an important concept for successful industrialisation is, in our belief, the concept of “supply-driven demand” as opposed to “demand-driven supply” (De Ridder and Vrijhoef, 2007). In common construction projects clients have the initiative and suppliers react on clients. But in a more industrial set-up suppliers have the initiative and clients make a selection out of the options provided by the supplier. This implies that suppliers no longer offer everything, but only offer products that fit in their configuration system.

In the context of the zero-impact and zero-waste objectives, an important concept is open building re-manufacturing. Remanufacturing (Steinhilper, 1998) is an innovative concept for re-use of used parts in other products. Remanufacturing is successfully applied in products such as cars or copiers, but can also be applied in building facilities. Successful remanufacturing in construction could lead to significant reduction of waste of building materials.

Approach

The work presented in this paper is not the result of one specific project, but it is the result of a continuous effort that has been ongoing for a number of years. As can be read above, it is also an effort in which many related themes are dealt with.

As an overall concept for our work, we use the term “Living Building Concept” (LBC). This concept can be seen as a placeholder for a number of innovative concepts and principles such as value-oriented construction processes, parametric design and industrial building, and life-cycle-orientation aiming at low waste and low impact construction. The word “Living” points at the view that building facilities should not be seen as static, “dead” artefacts, but as things that change over time. Such a view is needed in order to cope with the dynamics of the built environment. For example hospital facilities are typically completely reorganised every ten years. Also in the design and construction phases change is very common; many of the common problems in construction processes occur in our view because current collaboration forms are based on a static view on construction processes and cannot cope with changes in requirements, stakeholders or other external factors.

The research approach we use is a combination of theory development and case studies in practice. The theory development has been an ongoing effort for a number of years. Over the years many existing concepts have been incorporated or integrated in the “Living Building Concept”. Value orientation and the dynamic character have been key themes for a number of years, while industrialisation and life-cycle orientation, including concepts such as cradle-to-cradle thinking and remanufacturing, are of more recent date.

Analysis

In this section the themes that have been addressed in the Key Requirements section will be elaborated. This will be done in three subsections, which focus on the three general themes: value orientation, industrialisation and life-cycle orientation.

Value Orientation

As stated above, a shift is needed from traditional contracts based on lowest cost towards innovative contracts based on best economic value for money. This idea can be illustrated by the so-called Value-Price-Cost model, see Figure 1. This model can also be used to illustrate a number of other basic concepts for building project management.

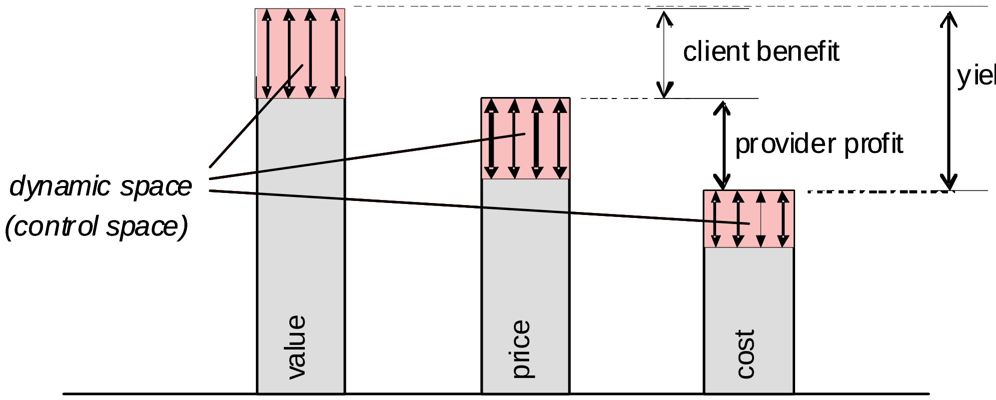


Figure 1. The Value-Price-Cost model

First of all, for a building project the value created by the project must be greater than the price. Otherwise there is no reason for the client to participate and invest in the project. Similarly, the price of a project must be greater than the cost, otherwise the provider would not participate in the project.

But the figure can also be used to compare value-based contracts against cost-based contracts. In traditional contracts based on lowest price and lowest cost there will be a tendency to make the price and cost columns as small as possible – and to pay little attention to value. But sometimes a slightly higher price can result in a much higher value (left column). In such cases it can be worthwhile to invest a little bit more and create a lot more value. This would result in a much higher yield, that can be divided in client benefit and provider profit.

The Value-Price-Cost model takes an economical viewpoint to building projects. But the idea can also be translated into a model with a more technical/engineering viewpoint, see Figure 2.

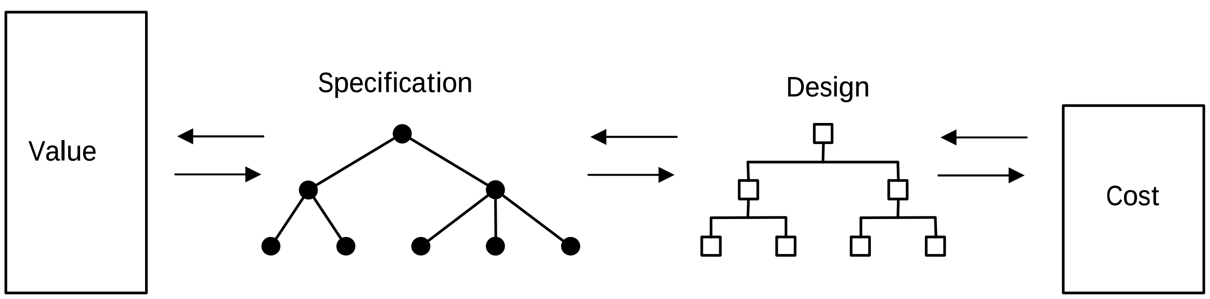


Figure 2 Design as a process to optimize the trade-off between value and cost

Figure 2 shows that Value is translated into (requirements) Specifications. This translation is similar to the systems engineering notion of the translation from User Requirements to Systems Requirements. Next, the Specifications (or System Requirements) are translated into a Design.

This translation is a very complex process (namely the design process, for which the term “translation” is actually not a very appropriate name). It is often modelled as an iterative process, in which top level requirements are translated into a top level proposed concept, which in turn is translated in “level two” requirements, etc. Finally, the design information is used for cost calculation.
The ideas and models described here formed the starting point for the case studies mentioned above. Experiences with the case studies will be discussed in the Results section.
Another important requirement for innovative building project management is the ability to deal with project dynamics such as changed requirements, changed stakeholders and other changes caused by external influences. A relevant and useful business concept in this context that is not yet often used in building is the concept of Product Service Systems (PSS). Goedkoop et. al. (1999) define a Product Service system as "a marketable set of products and services capable of jointly fulfilling a user’s need". A key point of Product Service Systems is that companies in essence do not sell technical artefacts such as buildings, but *functions*. As a consequence, PSS agreements can be made for various periods of time. In case of long-term agreements it is well possible that many parts of the technical artefact are replaced, etc. The use of Product Service Systems in building is further discussed in Gielingh et al (2008).

Industrialisation and Open Building Manufacturing

Industrialisation in building has been going on for decades. Many building parts are now industrially manufactured, in a completely different way than 50 or 100 years ago (many building parts did not even exist at that time, for example HVAC-system components). But the building process has hardly become an industrial process.

Characteristics of industrial production are mass production, repetition & standardisation, off-site production (in a conditioned environment, often in a factory) and machine-made production. In building, some of these characteristics apply, others are hardly applicable. Mass production of buildings obviously exists in many places, for example in post-war housing. Also repetition and standardisation are quite common in building.

But off-site, machine-made production usually applies only to building parts or elements, such as doors, windows, wall elements, or HVAC components. Houses and other building facilities are normally still manufactured or assembled on site. This is done with a lot of hand work, with a relatively low degree of precision and a with high degree of building failures. Furthermore, there are building projects that look industrial, where a lot of work is done off-site in the factory, but still involving a lot of hand work which is only moved to the factory.

The highest degree of industrialisation is probably reached in semi-permanent building solutions as offered by companies such as De Meeuw in the Netherlands. Only in this kind of companies the full potential of industrial building can be recognized, including fast construction processes with high accuracy and a low degree of failures.

As we all know, there is also a lot of opposition and resistance against industrial building. Part of this opposition is related to aesthetics, or taste: some people do not like built facilities with an industrial appearance. They just do not want to live in an industrial looking building.

Also more rational arguments are used: industrial building would create uniformity and boredom, and industrial methods would not work in building because building is a one-of-a-kind industry, with site characteristics that are different every time, and often also a line up of project participants and stakeholders that are different every time.

However, the Open Building movement has convincingly proven that industrial building and standardisation do not necessarily result in uniformity and boredom. Instead they have shown that standardisation creates flexibility. The Open Building movement has also shown that industrial methods can indeed work in building projects.

The potential benefits of industrial building are even larger when advanced ICT is used. “Pure” industrial building implies a building system with standard elements. Building design is in fact the configuration of selected standard elements. This can be supported very well by parametric design systems, in which standard elements are represented as parametric CAD objects. The resulting design system can become very powerful when the parametric CAD objects also contain meaningful information (or “semantics”, or “intelligence”) about material properties, physical behaviour, function, etc. In addition, configuration or composition rules can be implemented in the parametric design system. Furthermore, knowledge such as information can be added to the system, and cost forecasting functions could be implemented. The result would be a system that a building facilities supplier such as a project developer could bring his (or her) laptop with his building system to the client, develop a design during their talk and show the financial consequences on the fly – including different financing alternatives.

For manufacturing industries such as automotive, design systems as described above are quite common. As a result, these industries can perform better, with lower failure rates. Then why is it that the building industry does not adopt such technologies? What is needed for building to become really industrial?

In our view, two things are needed for industrialisation of building. First of all, the available technologies such as parametric design, building information modelling, cost calculation and industrial production need to be fully integrated. Technologically spoken, this is not extremely complex. It is only a lot of work, but it can be done.

Secondly however, we think that a change in the common building process is needed. In a common traditional building project, a client develops a specification and a provider develops an offer for the realisation of the proposal. In this setup the client has the initiative and starts the specification from scratch; the provider has (and must have) a “we build everything” attitude, reacts on and follows the client. This can be called “client-driven supply”. This way of working has several drawbacks: because the provider must be able to build “everything”, he cannot develop a building system with a limited (but still big) set of elements and possible configurations, and deep knowledge of the possibilities and expected performance of these elements and configurations.

The alternative way of working is what we call “supply-driven demand”. In this way of working the initiative is with the provider, who has a building system with a lot of building knowledge and intelligence implemented in advanced ICT. It is the provider who develops a proposal and maybe some alternatives, and the role of the client is to select out of these alternatives. This way of working is highly similar to the way the car industry is currently working.

Probably this alternative “supply-driven demand” way of working is an essential condition for industrial building. It might also explain why Open Building has never become a mainstream approach in construction.

Life Cycle Orientation and Open Building Remanufacturing

A building is not only a fulfiller of e.g. a sheltering function, it is also a *materialized* solution for user needs that existed before it was made. Once the building is declared to be useless, it may be demolished. This attitude causes construction to be a large producer of waste. Not only the waste may be a problem, it causes also an exhaustion of natural resources.

Systems and components that are not any longer useful for one building may be re-installed in another building. And if systems or components cannot be re-used as such, the materials from which they are made can be disassembled and remanufactured for the production of new components or systems. The latter principle complies with the cradle-to-cradle concept such as described by McDonough & Braungart (2002). Furthermore, it forms an extension of the concept op open building manufacturing – to open building re-manufacturing.

The cradle-to-cradle principle implies that a design takes aspects such as reusability and disassembly into consideration. It has also implications for the use of materials and the way in which components are joined. An analysis of 20 Australian schools done by Ding (2007) revealed that the amount of energy needed to produce, maintain and demolish a school equals about 37 years of operational energy (heating, cooling, electricity). The selection of materials has therefore a major impact on the overall energy-consumption of a building. Materials such as cement and brick require very high temperatures in production; temperatures that may only be reached through the burning of hydrocarbons. Hence, the use of these materials contributes significantly to the global CO2 problem.

An LBC provider will be rewarded for the creation of value. Various kinds of value can be distinguished, such as user value, client value, social value and environmental value. User processes and the environment have to be monitored and measured. The provider, in consultation with the user(s), may take the initiative to modify the building so that more value can be created. During the modification of a building, user activities should continue, preferably undisturbed.

Where current, static buildings require high investments that have to be written off and are risky if user needs change considerably over time, the components and materials that constitute a living building have an extended lifetime that may be substantially longer than any individual building. Hence, the risks for investors decrease.

The other side of the medal is that the number of actions or operations per unit of material increases. In current construction practice, only the production, manufacturing and construction costs contribute to material costs. In living buildings, materials and components are manufactured, assembled, disassembled, remanufactured, and so on, perhaps many times during their (extended) lifetime. Manual work will therefore be costly. It may be more economical to automate these processes for Living Buildings than for traditional buildings.

The envisioned process of a Living Building product/service provider is sketched in Figure 3.

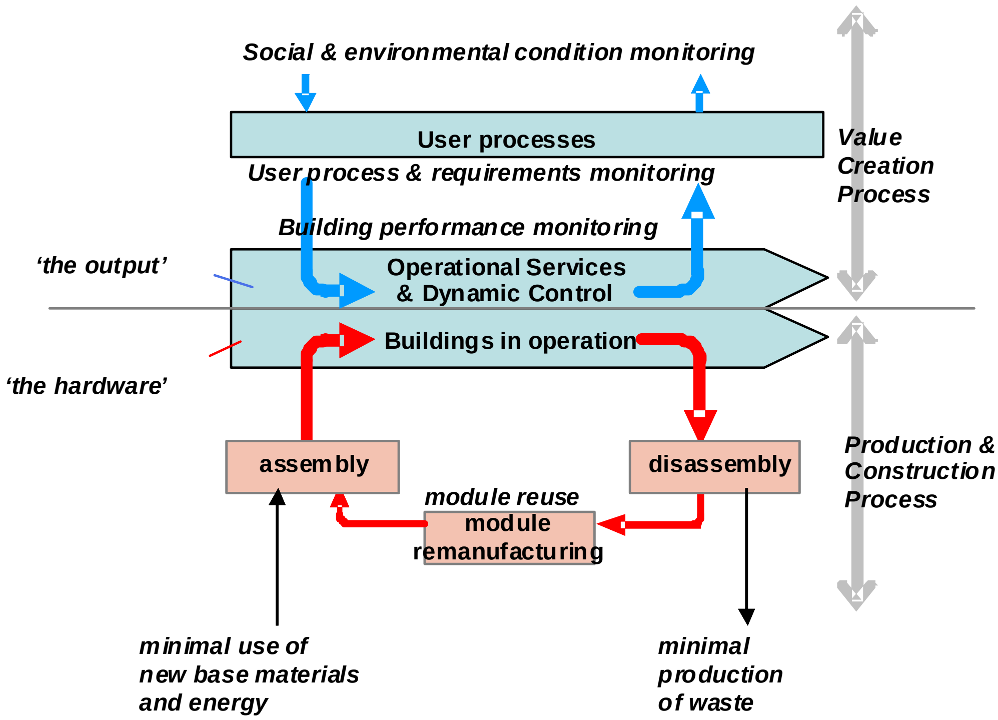


Figure 3. The process of a Living Building provider aiming at reducing costs in the construction process and the increase of client value

The left side of this diagram shows, from bottom to top, the construction process. The shown process starts with the production of assemblies out of raw materials, base materials and components.

In case changes of the building are needed during its operational life, the building will be partially disassembled and re-assembled. Removed modules may be re-used for assembly in the same or another building. If modules cannot be re-used as a whole, they will disassembled into components. Disassembly can be drastically simplified if fixtures of components and modules are designed for that purpose. Further, given the fact that vitalization may take place in a fully operational building, main disassembly and re-assembly should be designed such that ongoing activities in the building can continue with little or no disturbance.

Results and Business Impacts

Key Findings

The work presented in this paper has been applied and tested in a few real projects: a school construction project, a canal project and a hospital redevelopment project. These projects mainly focused on the first theme discussed in this paper: value orientation. Basically, in these projects used the concepts illustrated in Figure 1 for the management and decision making of the project.

The findings and conclusions of these case studies are not very clear. One of the projects ran into trouble, but that was not because of the application of value-driven project management. The other projects are still running and conclusions cannot be drawn as yet.

For the other two themes discussed in this paper, industrialisation and life-cycle orientation, no findings from practice can be reported as yet. We are looking for opportunities to apply and test the concepts presented in the near future.

Business Impacts

As discussed above, the findings from practice are still very preliminary and incomplete. Therefore we can only discuss potential business impacts of the concepts presented in this paper. Potential impacts of these concepts are listed below:

- Value-driven building projects can lead to more client satisfaction and more appreciation of building facilities by users and society.
- Industrial building and open building manufacturing based on “supplier-driven demand” can have a number of positive impacts; the key point however is that the predictability of the result can become much better, when it is based on intelligent building design/configuration systems with embedded knowledge on physical characteristics of building components but also economic characteristics etc.
- Life cycle orientation and open building remanufacturing can lead to lower energy usage and lower waste production of the building industry as a whole, including production of building materials.

Conclusions

In this chapter three themes have been discussed and innovative concepts for these themes have been presented.

The first theme is value orientation. The building industry can create more client satisfaction and appreciation from users and society when a value-driven approach is used instead of a cost-driven approach. A value-price-cost model is presented that can be used for value-driven building projects. The concept of Product Service Systems, that is already known in other domains, can be very useful for flexibility in value-driven building projects.

The second theme is industrialisation and open building manufacturing. The advantages of industrial building are obvious, yet industrial building has not become a mainstream development. In this chapter we argue that integration of available technologies is needed, but it is more important that an innovative business model is developend and introduced that is based on the concept of “supplier-driven demand”.

The third theme is life cycle orientation and open building remanufacturing. Recent global issues such as climate change and expected shortage of fossile energy have lead to an urgent need of more insight in energy use and waste production of the entire building industry, including the production and transport of building materials. The next step is of course the development of methods and approaches to decrease energy use and waste production. Leading principles for this could be cradle-to-cradle thinking and the concept of remanufacturing.

A lot of work remains to be done. First of all, much more business cases are needed in order to test whether the concepts presented work in practice. Moreover, the concepts presented here require more theoretical development. For both industrialisation and life-cycle orientation work must be done on the development of new business models that support the principles presented. But especially in the area of life-cycle orientation also more fundamental work is needed, such as a profound study of all energy usage and waste production that is produced by the building industry, including the production and transport of building materials.

Practical tips

- Use most economic value as driving force in building projects, instead of lowest price.
- Provide flexibility in the use of building contracts; provide for possibilities to make changes. Consider the use of the concept of Product Service Systems for this purpose.
- Aim for a “supplier-driven demand” building process with suppliers that can offer high-quality building solutions, based on an intelligent building design/ configuration system.
- Be aware of the total energy use of a building facility over its life-cycle, including energy used for the production of building materials.
- Be aware of the total waste production of a building facility over its life-cycle, including waste produced during the production of building materials.
- Look for opportunities for remanufacturing of building components in other building facilities or elsewhere when a building facility is no longer used; take remanufacturing opportunities already into account in the design process.
- Extend the concept of open building manufacturing to open building re-manufacturing.

References

McDonough, W., Braungart, M. (2002), *Cradle To Cradle, Remaking the Way We Make Things*, North Point Press, 2002.

Ding, G.K.C. (2007) *Lifecycle energy assessment of Australian secondary schools;* Building Research and Information, 35(5) 487-500.

Gielingh et al (2008), Business Innovation in Construction through Value Oriented Product/Service Offerings for Living Buildings, *Proceedings I3CON Conference*, Loughborough University, May 2008.

Goedkoop, M., et al (1999), *Product Service Systems, Ecological and Economic Basics*. Report for the Dutch ministries of Environment (VROM) and Economic Affairs (EZ), 1999.

Ridder, H. de (2006), *Het Living Building Concept*, PSIBouw, Gouda, ISBN-10: 90.78572-01-9 (in Dutch).

Ridder, H. de and Vrijhoef, R. (2007a), "From demand-driven supply towards supply-driven demand in construction". In Hughes, W. (ed.) *Proceedings CME25 Conference*. 16-18 July 2007, University of Reading, UK. Proceedings on CD-ROM.

Ridder, H. de and Vrijhoef, R. (2007b), "Living Building Concept applied to healthcare facilities". In Abbott, C., Aouad, G., Kagioglou, M. and Ruddock, L. (eds.) *Proceedings 4th International SCRI Symposium*. March 2007, University of Salford.

Steinhilper (1998), *Remanufacturing, the Ultimate Form of Recycling*, Fraunhofer IRB Verlag, 1998, ISBN 3-8167-5216-0.

Author Biographies

Dr **Sander van Nederveen** is Assistant Professor at Delft University of Technology, Faculty of Civil Engineering and Geosciences. He teaches and conducts research in the area of design and information technology for building and civil engineering. Before joining Delft University in 2005, he has worked as a researcher at TNO in the field of information technology for construction and as a systems engineer/configuration manager at the Dutch High Speed Link (HSL) project organisation.

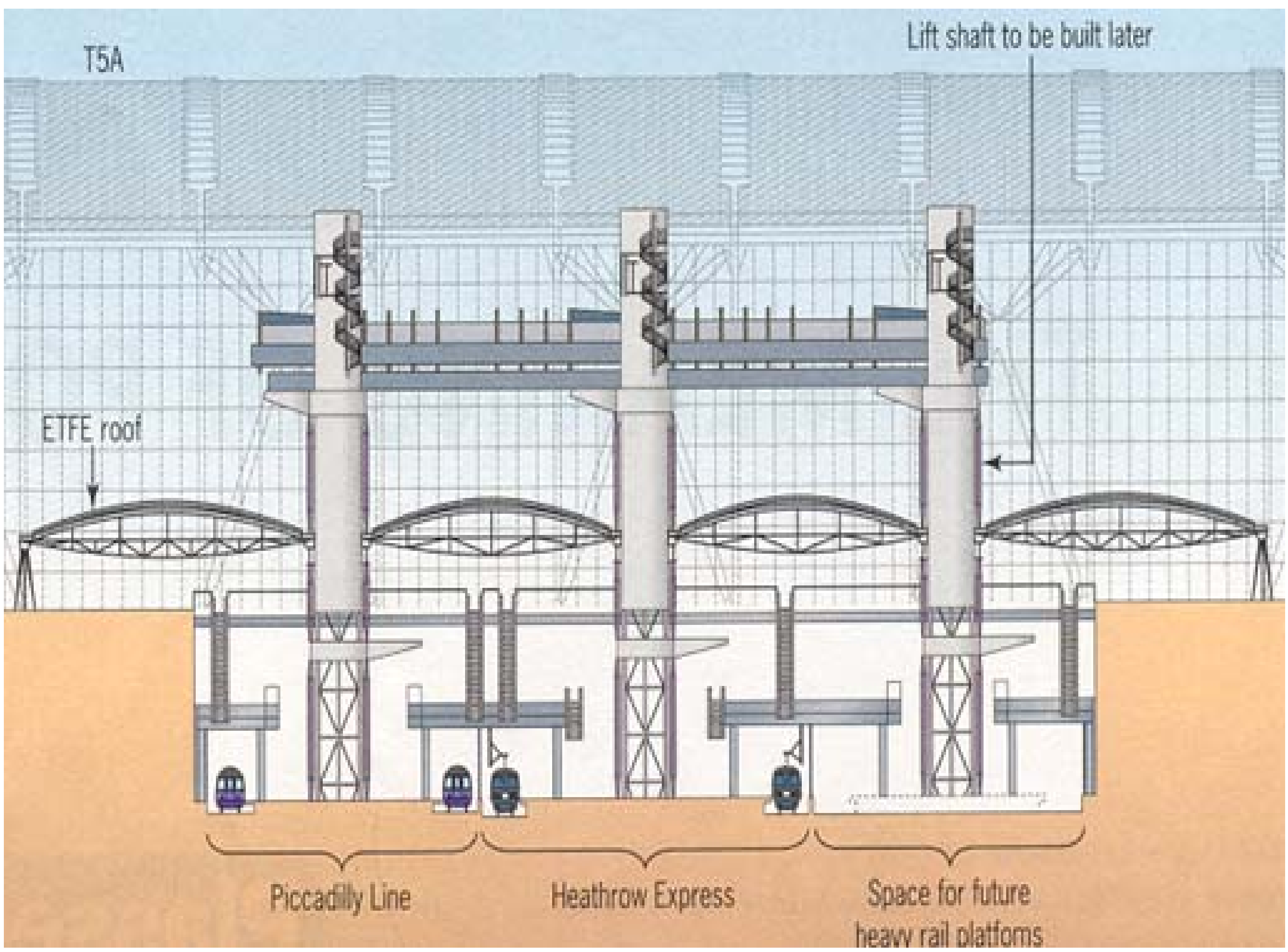
Dr **Wim Gielingh** is Senior Researcher at Delft University of Technology, Faculty of Civil Engineering and Geosciences. He conducts research and advises in the area of design and construction processes and information technology for building and civil engineering. Before joining Delft University in 2006, he has worked as a business consultant at CAP Gemini, and before that, as a (senior) researcher at TNO, where he was involved in several EU-project, for example as project manager of PISA.

Prof dr **Hennes de Ridder** is Professor at Delft University of Technology, Faculty of Civil Engineering and Geosciences. He teaches, conducts research and advises in the area of design and construction management, with emphasis on value-orientation in design and construction processes. Before joining TU Delft in 1995, he has been employed for 25 years at HBG construction company, where he was involved in the engineering, project and risk management of various large civil engineering projects in The Netherlands and abroad, including the extensive sea defense works in the estuary of the river Rhine near Rotterdam.

3

Evolvable or 'Future-Proof' Infrastructure Design: Integrating Modularity and Safeguards

Nuno Gil



Evolvable or 'Future-Proof' Infrastructure Design: Integrating Modularity and Safeguards

Nuno Gil, The University of Manchester, UK (nuno.gil@mbs.ac.uk)

Abstract

In the infrastructure co-development process, the project promoter or developer allows the customer organizations which will later operate the facility to participate in the design and development process. Co-development aims to align the design definition of the new facility with the customer needs. But in the years it takes to deliver a new infrastructure project, as well as throughout the operational life of the new facility, the customer needs are likely to evolve. This evolution stems from external changes in the way the customers strategically position their businesses, as well as from relevant changes in fit-out technologies, regulation, and end-user requirements. The evolvability of infrastructure is the problem at the heart of this chapter: How to best design new infrastructure so it can economically adapt to changes in the external environment over time while limiting the capital investment upfront, i.e., how to develop affordable 'future-proof' designs? Here, I build upon empirical findings on the co-development of a new airport terminal to examine how the characteristics of the design architectures affect the extent to which the infrastructure can accommodate change in customer requirements. The findings stem from observing the airport developer's strategic effort in delaying design decisions during project delivery, as well as in leaving selected options open in the design definition. The strategies aimed to make both the infrastructure design definition and the development process cope efficiently with the foreseeable evolution in the needs of the two main customer groups: the airport operator and the airline occupying the new terminal. The analysis sheds light on the value of two design approaches that complement one another in building flexibility to accommodate external change: First, modularity, i.e., the mapping of functionalities to physically decoupled elements with tested, standard interfaces. And second, safeguarding, i.e., the delivery of provisions built in the design that 1) leave open options to accommodate foreseeable change when the architectures are integral; and 2) reduce the costs of integrating functional modules when the architectures are modular. Infrastructure developers and suppliers who learn how to make good use of the two approaches will be well positioned to respond to evolution in the external world, and to improve the performance of their business.

Keywords: Flexibility, Design, Modularity, Safeguards, Evolvability

Background

Industrial Context: The Infrastructure Gap

The needs for new physical infrastructure have grown dramatically around the world in the last decades. Broadly, infrastructure encompasses transportation systems (e.g., airports, roads, railways, ports), utility networks (e.g., water, gas, electricity), and social assets (e.g., hospitals, prisons, and schools). These facilities contribute to deliver services that are central to the continuance and growth of every community and state. The massive pressure for new infrastructure stems from a conflation of factors: population increase, migration flows towards cities, deterioration and obsolescence of existing assets, and the globalization of the supply chains. A report from the OECD has recently stated that infrastructure spending needs to be $53 trillion worldwide between 2007 and 2030, if governments in developed countries are to perform the needed upgrades to utility and transport systems and emerging markets industrialize. OECD has also exhorted developed nations to invest 2.5% of their GDP a year in infrastructure (OECD 2007). For the case of the European transportation sector alone, The Van Miert Group report (2003) estimates that the investments for realizing the trans-European transport network (approved by the European Council and the Parliament in 2004) come to more than €600 billion up to 2020 for the totality of the projects of common interest, of which €235 billion for the priority projects (0.16% of GDP in annual investments). The private sector is expected to contribute up to 20% of the total cost of the transport network (ibid.). And for the case of energy, the International Energy Agency estimates in its 2006 World Energy Outlook report that $20.7 trillion would be required today if all governments simultaneously decided to enact over 1,400 policies to secure energy supplies due to decades of underinvestment in basic energy infrastructure (IEA 2006).

To bridge this infrastructure gap, states around the world have recourse to privatization or the divestment of government-owned enterprises, as well as to private finance for developing and/or operating assets for a limited period (aka Concessions or Private Finance Initiatives/PFIs). Privatization, the first scheme, transfers the ownership rights of the assets from the public to the private sector. Concessions or PFIs involve long-term management contracts through which the government only allocates to the private enterprise the responsibility for providing infrastructure services for a limited period at an agreed level of performance. This *de facto* transformation of infrastructure into a business gained popularity in the modern age after the United Kingdom initiated a sweeping programme to privatize the utilities, airports, railways, and highways in 1979. Many countries followed suit. Two major forces triggered the trend. On one hand, the ideology that the private firm – motivated by profit-seeking – is more efficient, cost-conscious, customer-focused, and can deliver quickly than bureaucracies do. On the other hand, the pragmatic necessity to supplement constrained state budgets burdened with growing expenditures on health care and on the retired population. As a result, infrastructure has become relevant for businesses, both as the suppliers of engineering, manufacturing, and construction work, and the developers and operators of new assets.

More recently, infrastructure has become highly attractive to investment firms, pension funds, and family houses. Other investors include export-import banks of the BRIC economies and the Government of China (Orr and Kennedy 2007). Infrastructure assets supposedly can provide secure, steady inflation-proof income and market-beating returns due to their monopoly-like position. These assets are a useful source of diversification as they provide low correlation to equity markets and the economy. From 2000 to 2006, infrastructure transactions have risen from $52 billion to about $145 billion, and demand for new deals rose faster than supply (Saigol 2006). In 2006, there were over 70 infrastructure funds, with targets to raise more than $122 billion; their activities were focused primarily on US and European brownfield infrastructure, with 8 to 15 planned investments (Stodder and Orr 2006).

Problem

The problem at the heart of this chapter looks at how to balance the profit-seeking and public interests in the design of new infrastructure. Unlike most commercial products, infrastructures are built to last many decades. Bridges and airports are expected to operate 40-50 years or more, for instance, whereas parts of the water distribution and sewerage systems may be designed to last almost 100 years. During the operational lifetime of these facilities, the external environment will change: new technologies will be developed, the needs of the customers and end-users will evolve, and the government will put together new legislation and regulation. The core building systems of the new Terminal 5 (T5) at Heathrow airport, for example, are expected to operate for at least 40 years. But between the conceptualization of T5 in the mid nineties and its opening in

2008, the airline and airport activities changed dramatically in Europe, with the surge of low cost carriers, self-service and on-line check-in, stringent security procedures, and the introduction of jumbo aircrafts. Many more external changes will occur in the future, presumably. Designing affordable infrastructures that can cope with external changes over time is at the crux of the private development of new public infrastructure.

When capital was readily available, an approach to ensure that infrastructures could flex to external change over time consisted of designing in upfront provisions for foreseeable needs in the future. The London Victorian brick-built sewer network launched in 1865, for example, comprised 264 km of underground brick main sewers to intercept sewage outflows, and 1769 km of street sewers. The network still remains largely operational today due to the generous allowance which was built into its original design (Downey 2006).[1] Likewise, a major toll suspension bridge in Lisbon, Portugal, was engineered and built in the sixties with a structural allowance that left two options open for the future: first, add two more lanes to increase capacity from four to six lanes for car traffic; and second, add two railway tracks. Both options were exercised almost thirty years after the bridge opened to the public in 1964 once demand for additional car traffic and passenger railway finally materialized. A key element of the structural reinforcement was placing a second set of main cables above the original set (Figure 1).

Figure 1- Bridger over the River Tagus, Lisbon (built in the sixties, upgraded in the nineties) (photos downloaded from Wikipedia)

But when scarcity of capital jointly with profit-seeking interests are at the base of design decision-making, designers have to judiciously balance provisions to make infrastructures adaptable to foreseeable evolution in the future with the capital that the infrastructure promoter can afford to spend at the present. In particular, promoters are wary of making upfront capital investments that will fail to pay off over time (or lead to unsatisfactory rates of return on investment) because the foreseeable scenarios about the future made at the project onset got it wrong. This means that designers need to find out original ways to efficiently 'future-proof' infrastructures, i.e., design new infrastructures that can economically adapt to change over time while requiring limited capital investment upfront. The British National Health Service (NHS) pioneered the request for future-proof designs when it commissioned new hospitals through PFI schemes. The contractualization of this notion was, however, contested by designers who felt they could not be made liable for future proofing new hospital designs (Kitching 2004).

[1] An unforeseen use for the sewer network emerged in the modern age: a quick and cost-effective location to run the London-wide optical fibre network with minimal street-work disturbance. The adaptability of infrastructure to unforeseen external changes is, however, not discussed in this chapter.

Learning Objectives:

- Become aware for the tension between profit seeking and public interests in the design of new infrastructure
- Become aware of the importance of evolvable or future-proof infrastructure design, i.e., affordable infrastructure that can economically accommodate external change over time
- Be able to characterize the architectures of large-scale functional elements relative to the surrounding built environment as modular or integral.
- Identify the value of modularity as a strategic approach to build flexibility in infrastructure design
- Differentiate situations where modular functional elements are available ex-ante from situations where modules can be developed
- Identify the value of safeguarding as a design approach to build flexibility in infrastructure design, especially in infrastructures with integral architectures

. Option-like Thinking applied to New Infrastructure Development

Key Requirements

The involvement of the profit-seeker in the development of new infrastructure creates a challenge about how to efficiently reconcile and integrate in design the concerns about affordability and evolvability. The core question is: how to design affordable infrastructure that can evolve in response to evolution in customer requirements, in technology, and in regulation over time? Stated differently, how to design and develop 'future-proof' infrastructure, i.e., infrastructure that can meet the constraints on capital spending upfront without undermining the capability to economically adapt to changes in the design requirements over the project delivery and the operating lifecycle?

Potential Solution: Design modularity and safeguards

The application of option-like thinking to the design of new infrastructure, or paraphrasing Wang and de Neufville (2005) the effort to build real options ''in' projects, offers a promising avenue for operationalizing design for future proofing. An option is "the right but not the obligation" to choose a course of action (such as expanding, acquiring, deferring, or abandoning) and obtain an associated payoff (Dixit and Pindyck 1994). The real options approach extends the financial option theory to 'real' assets. The aim is to incorporate the effects of private risk and foreseeable externalities into the valuation of capital investments, thereby moving beyond static methods to valuate capital investments based on the net present value (Trigeorgis 1996).

But unlike the advances that have been made using real options theory for valuating infrastructure investments and managing financial risk, i.e., building options 'on' projects, research on formally applying option-like thinking to the design of new infrastructure is still in its infancy. Gil's (2007) seminal study of practices in airport design suggests that designers intuitively apply option-like thinking, particularly as they search for modular designs warranting that the airport can flex to foreseeable change in requirements. Modular designs involve a one-to-one mapping between functionalities and the physical elements (Ulrich 1995). More specifically, design modularity requires decoupling functional elements, agreeing the rules about how the elements should interface, and establishing tests that can validate how the interfaces work (Baldwin and Clark 2000). Because the modules are relatively easy to substitute, remove, or add, they represent options that are built into the design of a new product or system (op. cit.).

Modular principles underpin the development of trenchless technologies to lay down pipes inside conduits already buried in the ground. These technologies have allowed modern urban societies to avoid the disruption of major open-cut construction (Downey 2006). The same principles help to make sense of the award-wining design of the new Upton-upon-Severn viaduct in the UK. Flood waters inundate the Severn floodplain and rise above the road typically once in five years, rendering the route to the east of Upton upon Severn impassable for several days. The urgency to replace the deteriorated 1939 reinforced-concrete viaduct meant that there was insufficient time for a wholesale elevation of the roadway. The 170m long deck was designed both for inundation conditions, as well as to be jacked up in the future (Sreeves 2007). And the same principles also inform recent efforts to engineer ‘adaptive’ infrastructures that can move in response to outside forces, such as bridges in which the load-bearing capability might literally follow a large truck driving across.

Approaches to develop modular infrastructure echo in some ways the effort incurred by manufacturers to search for new product architectures that can ‘evolve’ in response to external change (Baldwin and Woodard 2008) Or stated differently, to search for product architectures that allow for ‘generational variety’, i.e., architectures that minimize the design effort for future products and make selected design structures common across generations (Martin and Ishii 2002). But a caveat is in order. Evolvability in commercial product design primarily involves searching for modular platform architectures that can support the efficient generation of a large number of product derivates in response to external evolution. In contrast, evolvability in public infrastructure design demands, first, flexibility to economically change the design during project delivery to accommodate customer-driven change. And second, evolvable infrastructures also need to economically accommodate physical modifications so as to cope with change in requirements during their operating life.

Notwithstanding the advances in the modularization of the architectures of new infrastructure, some of the large-scale functional elements of a new infrastructure can be very difficult or very costly to modularize. In these cases, the design architecture of these elements needs to remain integral to the surrounding building systems. The same happens in product design where modularity seldom comes for free (Ethiraj and Levinthal 2004). Further, modularity can occasion penalties in product performance (Fixson and Park 2008). In effect, modularity is easier to accomplish for products based on electricity than for those based on mechanical and structural systems because of the one-dimensional flow of electrons vis-à-vis the multidimensional surfaces of the physical systems (Baldwin and Clark 2006).

Integral design architectures do not exhibit neatly decomposable systems (Simon 1962) or built-in options (Baldwin and Clark 2000) and, as a result, have low flexibility to accommodate external change. In these circumstances, infrastructure designers can future-proof by incorporating safeguards, i.e., structural provisions or allowances designed in the infrastructure that purposely leave open the capability to accommodate a foreseeable functional option in the future (Gil 2007). Safeguards manifest Simon’s principle (1962) that designers should avoid designs that create irreversible commitments for future generations. Going back to the Terminal 5 illustration, the construction of an underground train tunnel and two extra platforms (unneeded at the present) has safeguarded the extension of an additional train line to the Heathrow airport in the future (Figure 2). This costly upfront investment was deemed crucial to leave open the option to increase the capacity of the airport in the future. It would be difficult otherwise for the airport owner to overcome the growing concerns of the public with the detrimental impacts of the growth of airport-related traffic to the local environment and to the welfare of the local communities.

Safeguarding can also be used to reduce the costs of integrating a new functional module in the future, or in other words, to reduce the costs of exercising a modular option. For example, investments can be made upfront in digging pits and placing temporary covers on the ground floor for a new infrastructure if the developer foresees increasing the number of lifts or escalators in the future. The pits are not a necessary condition to ensure that the option stays open. Their absence also does not prohibit the developer from installing the modules at a later time. But while the spending in executing the pits is marginal relative to the overall capital investment, these safeguards can significantly reduce the costs of integrating the modular lifts in the future. If the pits are ready, the installation will be cleaner, quicker, and will impact less the performance of the facility. This, in turn, can increase substantially the value of the option.

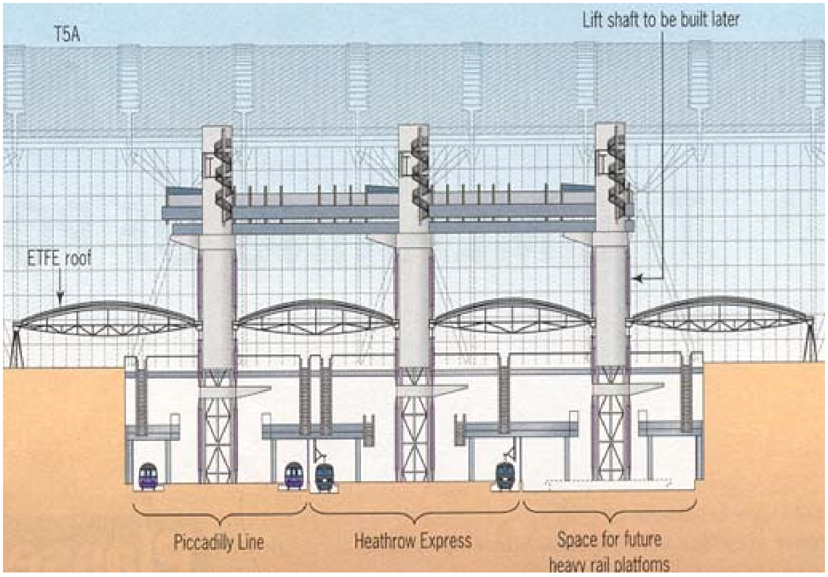


Figure 2 – Design of the Train Station for Terminal 5 showing the two unused platforms

Investments in safeguards can be passive or active. A passive safeguard consists of an instruction built in the design documents that does not need to be physically executed to ensure that the option stays open in the future. For example, an infrastructure promoter can acquire land adjacent to a new facility so as to leave open the option to further expand the facility in the future. Detailed plans about how the land will be occupied in the future can be designed into the master plan. But the infrastructure promoter can delay the physical construction of the expansion until the uncertainties resolve favourably. In contrast, active safeguards involve design instructions that need to be physically executed at a cost in the present so as to leave open the option to take an action in the future. For example, in the case of the suspended bridge that was designed in the sixties mentioned in the previous section, some of its main structural elements (foundations, towers) had to be engineered and physically built upfront to stand the design loads corresponding to the ultimate scenario.

The next section introduces the case of a new airport terminal development. It aims to illustrate how infrastructure developers can resort to modularity and safeguards to leave options open; or stated differently, to design for 'future-proofing' or evolvability.

Leaving Options Open in Infrastructure Design: The Case of a New Airport Terminal

This case study examines design practices that were empirically observed throughout the co-development of a new airport terminal. The findings draw predominantly from two empirical studies: First, Gil et al. (2008)'s research on the implementation of design postponement. This strategy – long practiced in the world of commercial new product development (Iansiti 1995) –

enables some parts of the design definition to remain unresolved while other interrelated parts progress into design detailing and physical execution during project delivery. Gil et al.'s (2007) chapter "Operationalizing the Open Building Approach in the Management of Large-scale Engineering Projects" in the first book of this series reveals the value of postponement when the infrastructure project unfolds under conditions of uncertainty and ambiguity. Specifically, postponement is useful to leave unresolved downstream design parts (fit-out systems and tooling) while moving the upstream design parts (civil engineering) into physical execution. Design modularity is a key enabler for implementing a postponement strategy. And second, Gil (2007)'s research on the value of safeguarding. This strategy aims to leave open the option to economically make adaptations after project completion provided that foreseeable uncertainties resolve favourably throughout the operational life of the facility. Strategic safeguarding is a key enabler for leaving options open when the design architectures are integral. Safeguarding can also be used to reduce the costs of integrating selected options in modular design architectures

Research Base

This research was inductive since few studies are available that theorize on how the concepts of design modularity and safeguarding can apply to the design of new large-scale infrastructure. The units of analysis were instances of design choices through which the developer and designers for the new airport terminal sought to implement the postponement or safeguarding strategies. A set of constructs from literature on modularity and option thinking applied to design were organized in empty table shells (Miles and Huberman 1994). I then induced the conceptual ideas by cycling between collecting raw data and playing theory against data through tabular and graphical cross-comparisons (Miles and Huberman 1994). The choice of the units of analysis was based on theoretical sampling (Eisenhardt 1989), i.e., the need to build a sample representative of cases along a range of 'polar types'. Thus, I examined instances of strategic implementation associated both to modular and integral design architectures. Some of the design choices aimed to meet the needs of the major occupier airline for leaving options open throughout the delivery of the new airport terminal project. Other design choices aimed to build flexibility in the design of the new terminal so as to accommodate the resolution of foreseeable uncertainties in the businesses of the airport owner and occupier airline during the operating lifetime of the airport. The data collection process took place from May 2004 to July 2007. It involved almost 100 face-to-face, one-on-one interviews, analysis of archival documents, site observations, and numerous informal conversations.

The Use of Modularity in the Airport Terminal Design

The analysis of the characteristics of the large-scale functional elements of the airport terminal differentiates three situations from the perspective of design architecture: First, some of the functional elements that exhibited a modular interaction relative to the surrounding building systems were available from the onset of the development process; second, the physical interaction of some functional elements relative to the surrounding building systems was modularized during the development process; and third, some functional elements remained integral to the surrounding building systems because breaking apart the interdependences was technically too complex or too costly.

Functional Modules Available Ex-ante

The availability of functional elements with modular architectures at the onset of the terminal development process occurred with technologies that have little stand-alone value, yet they are valuable once integrated in the infrastructures that need them. The addition of single-function physical modules, for example, was part and parcel of installing a trolley ramp, a passenger lift, or a baggage-reclaim belt. These elements involve technologies that are associated to stable design rules. These rules specify the interfaces between the module and the surrounding building systems, as the director of the project supplier for the lifts and escalators explained:

> “Our design process is different from other people. We have a product for more than 25 years. Our machines generally sit on the edge of the structure on a rubber pad. We just need to tell people the size and depth of the pit, the electrical power, and how the control panel interfaces with fire alarms.”

The limited group of firms that supply these technologies — over 80% of the world market share for lifts and escalators belongs to 7 companies (Mikkola and Gassman 2003) — may be said to form a modular cluster in the same way that clusters play host to the evolution of modular computer designs (Baldwin and Clark 2000). The modular design of these functional elements makes it relatively easy to postpone the decision about exactly how many modules should be incorporated in the design during project delivery. Design modularity also facilitates leaving open the option to incorporate more functional elements during the operational life of the facility: add more lifts to the cark park, more trolley ramps to the train station; and more baggage-reclaim belts to the baggage reclaim area (Figure 3).

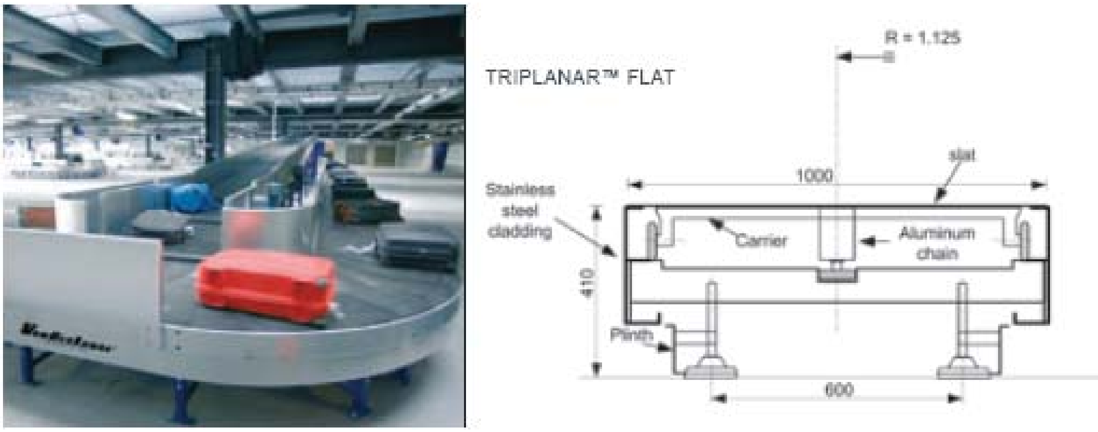


Figure 3 – Standard Baggage Carrousels
(image reproduced from Baggage Carrousels, VanDerLande Industries)

Still, exercising these built-in options in an economic fashion – whether during project delivery or afterwards – will invariably require making functional space available for installing the modules. This space can be safeguarded in the design definition for the terminal at the project onset as discussed in the section about design safeguards.

Development of Functional Modules

In a second group of cases, the designers modularized the architecture of selected functional elements. The structure of the car park, for example, was designed to accommodate the addition of a modular steel mezzanine for parking 500 cars between the ground and the first floors. A key principle of the modular design was guaranteeing that the integration of the mezzanine will not negatively affect the aesthetic qualities of the car park in the future. Likewise, designers physically decoupled the floor plate superstructure of the main terminal building from its exterior roof and façade (Figure 4). This design solution allowed leaving an open void between the top floor and the ceiling. This void makes space available to fit a modular steel mezzanine that will expand the floor plate area. This additional area was foreseen to be needed in the future for two reasons: first, to expand the retail area of the terminal if a compelling business opportunity comes across to increase retail revenues; and second, to expand the main lounge that the airline runs for Commercially Important Passengers (CIP lounge).

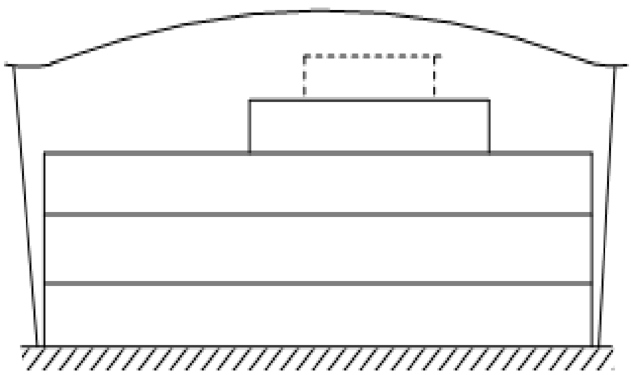


Figure 4 – Cross-section of the terminal building with room for the steel mezzanines

The Use of Safeguards in the Airport Terminal Design

In a number of cases, the designers of the new airport terminal were unable to modularize the interaction of the large-scale functional elements with the surrounding building systems. The design interdependences that were hard to break apart could be between the functional element and the building systems of the same facility, or between the functional element and the building systems belonging to other adjacent facilities. The concrete layer of the pavement of the aircraft stands (a set of layers of granular materials topped with a thick concrete layer), for example, had to remain integral with the tunnels carrying the mechanical, electrical, fuel, and baggage systems under the aircraft stands. The service ends of the tunnels penetrate the concrete layer of the pavement in various locations on both sides of the central lane where the aircraft wheels park. The integral architecture of the aircraft stands makes it hard to economically accommodate requests to accommodate changes in the configuration of the aircraft fleet of the occupier airline in the future. This situation was particularly concerning since the airline was considering purchasing a number of jumbo aircrafts (Airbus A380), but could not state a date when a commitment would be made. This problem was resolved by safeguarding the option to park A380 aircrafts on four stands that could also be used to park two small aircrafts each (Figure 5)[2]. The investment on the four Multi-Access Ramp Stand (MARS) to service one code-F aircraft with wingspan up to 80m (e.g., A380) or two small aircrafts was estimated around €1.5 million. It involved tripling a number of utility services running underground, providing three reinforced concrete lanes for receiving the loads transmitted through the wheels, as well as providing additional pier services and loading bridges.

[2] Real options literature would call this decision a switch option in the sense it allows for operating an aircraft stand with different sets of inputs

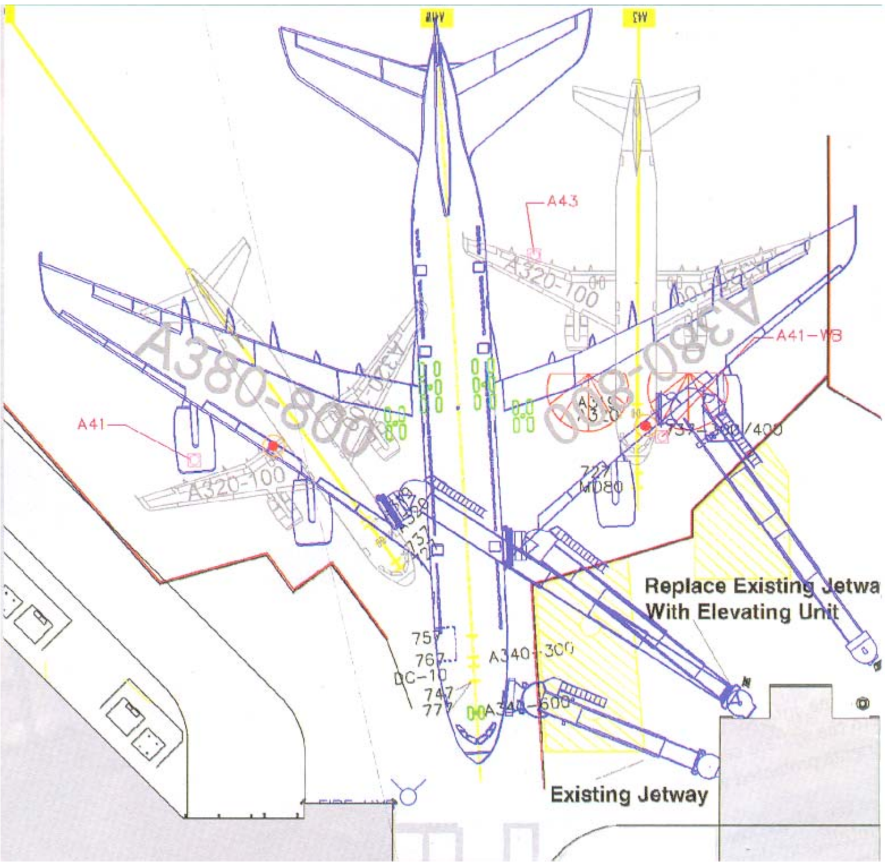


Figure 5 - Generic Representation of an Aircraft Stand with Multi-Access Ramps

In a second example, designers were interested in staging the delivery of the new airport terminal into two phases (so-called 'stage-option'). The first phase would include two terminal buildings and a car park, whereas the second phase would include a third terminal building (Figure 6). While the airport developer publicly committed to open the first phase in 2008 from the project onset in 2001, the exact timing for moving ahead with the development of the second phase remained contingent on the growth of air traffic demand. Growth projections suggested that the second phase could open sometime between 2012 and 2015. The airport developer was nonetheless cognisant that a number of investments on safeguards were needed for leaving open the option to efficiently execute the second phase in the future. Hence, the developer decided to design and build the foundations for the third terminal building concurrently with the design and physical execution of the other two terminal buildings and ancillary facilities. The developer also decided to physically execute the design extension of the inter-terminal train and baggage handling systems to the third terminal building in the first phase.

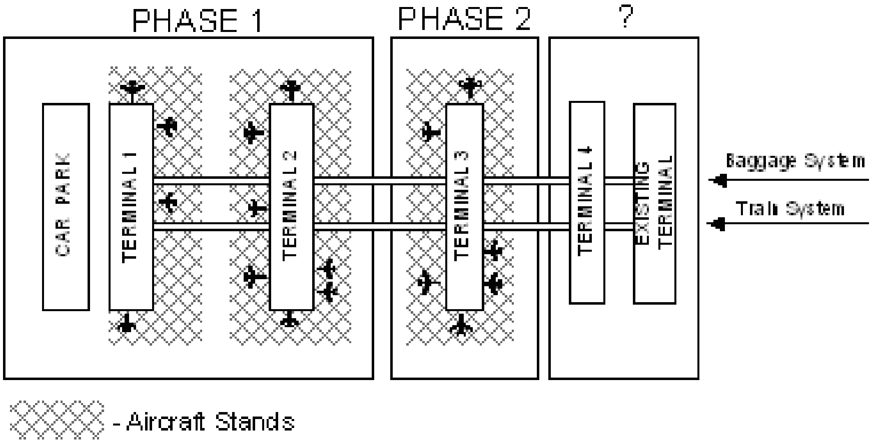


Figure 6 - Schematic Layout for the New Airport Terminal

This set of safeguards added at least €150 million to the capital investment for the first phase. But the developer reckoned that this spending was needed to efficiently leave the option open as three factors made at least six times more costly executing the extension of the two systems after the opening of the first phase. First, the construction costs in airfield conditions would be much higher due to the additional security requirements; second, the tunnels would need to be bored as the more economic cut and cover process would be too disruptive to the airfield operations; and third, the construction works would likely require putting temporarily out of service a number of aircraft stands, which would be extremely costly for airport operations.

Results and Business Impacts

Key Findings

This empirical study sheds light on the value of applying option-like strategic thinking to the new infrastructure development process. Specifically, it shows how developers and customers can use the modularity and safeguarding approaches when searching for design solutions that will be flexible to accommodate external change over time. This flexibility translates on the extent to which developers will be capable to, first, postpone design decision-making during project delivery; and second, economically accommodate external change throughout the operating life of a new facility. This capability matters to enable developers respond to the difficulties that infrastructure customers face in freezing the design requirements at the project onset, years ahead of the date when the infrastructure opens to the public. This capability also matters to enable developers to respond efficiently to changes in customer requirements stemming from evolution in fit-out technologies, business environment, and user-needs. Of course, the findings of this research are grounded in the world of airport development. Future research should investigate how the insights induced through this study play out in other major infrastructure developments.

There can be two major hurdles in the implementation of option-like strategic thinking in infrastructure design, though. First, developers should be aware that developing reliable scenarios about how the design requirements for a new infrastructure will evolve over time is not a trivial task. It can actually be quite challenging. The application of option-like thinking calls for embedding a portfolio of options into a new infrastructure design. But even developers that undertake a meticulous application of option-like thinking in design must be prepared to incur risks that some of the options may never be exercised over time. The point of option-like strategic thinking applied to design is not about limiting investments only to the safe options, i.e., those options for which developers are one hundred percent sure of the need to exercise them in the future. Rather, option-like thinking aims to ensure that a sensible range of strategic options remain open. As one developer put it, “there will always some winners and some losers in this game.” Notwithstanding this, a judicious application of option-like thinking can ensure that the value produced when exercising some built-in options far outweighs the cost of the other options which turned out unneeded in the long term.

A second issue in the application of option-like thinking to infrastructure design concerns the extent to which customers are ready to disclose their business thinking years ahead. Infrastructure customers may be reluctant to do so afraid that their plans can leak to competitors and/or suppliers, which would undermine their competitive advantage. But infrastructure developers and designers cannot search for solutions that can efficiently flex to external change unless the customers share how they anticipate their plans to impact the design requirements for the new infrastructure in the future. For example, in the case reported above, the airline was reluctant to share the plans for procuring new aircrafts. The airline was concerned that a design of the aircraft stands that revealed too much about its plans could undermine its bargaining position with the aircraft manufacturers. This stance, in turn, made the developer – understandably - reluctant to make capital investments to build options in the design of the aircraft field. In effect, the developer only decided to invest on the flexible MARS stands after communicating to the airline that it would reserve the right to park aircrafts from other airlines on the MARS stands if the airline failed to use them efficiently. It merits further research how developers and customers can share strategic plans needed to make sound design decisions without undermining the commercial interests of both of them.

Business Impacts

The findings reported here shed light on two fundamental approaches – modularity and safeguarding – that are highly relevant for infrastructure developers and suppliers interested in applying option-like strategic thinking. The use of option-like thinking can become a requirement in the case of concessions or PFI projects in the long term. Recent studies have started to develop procurement and contractual mechanisms that a government can employ to explicitly request the private enterprise to price the value of design adaptability (Lee 2007). In the case of new hospitals, for example, the hospital trust can include in the tender documents selected options that the bidders need to price in the bidding documents that they have to submit. It will be then up to the hospital trust to decide whether to buy the flexibility to exercise the selected options in the future by paying for the option fees upfront. Governments appear interested in this approach due to the high costs that they often experience when they request the private enterprise to make changes in the infrastructure throughout the concession period (op. cit.).

Empirical findings also suggest that option-like strategic thinking, and its implementation in infrastructure design, can help the private owner of infrastructure assets to become more efficient. Of course some infrastructure owners face limited commercial competition because they operate natural monopolies that are difficult to contest by competitors. But other infrastructure owners face commercial competition. For instance, major European airports are facing increasing competition from airports in Dubai. Publicly listed infrastructure owners are also under pressure to increase commercial revenues year after year. Because they often have regulatory caps on the maximum fees that they can charge users, these owners need to improve the efficiency of their capital investments. This study suggests that the private enterprise will benefit commercially if it learns about how to develop evolvable or future-proof infrastructure. Finally, there is a clear role here for suppliers interested in engaging in open building manufacturing. Innovative large-scale functional modules are one way to efficiently meet the needs for combining affordability and evolvability in new infrastructure development. The more functional modules exist ex-ante of the design and development process, the easier will be for infrastructure developers to, first, build options into the new infrastructure; and second, exercise those options as uncertainties resolve favourably over time. Manufacturers want to seize the business opportunities that arise from the growing urgency to develop affordable future-proof designs. This promises increasing revenues for their business.

Conclusions

The tension between the public interest and the commercial interests of the profit-seeker is an important outcome of institutional decisions to involve the private sector in the provision of public infrastructure. This tension has direct implications to infrastructure design as it calls for reconciling affordability constraints for capital cost with evolvability guarantees for operational longevity. Affordability is a function of how much capital the promoter wants/can borrow to build anew at specified rates of return on investment. Evolvability is a function of how efficient the infrastructure can accommodate external change. Option-like strategic thinking applied to design and development stands out as a way to resolve this tension. Design modularity and safeguarding are two approaches that allow building flexibility in new infrastructure development to accommodate external change over time. Their application can help infrastructure developers and suppliers efficiently build options in new infrastructure designs. These options can be exercised if uncertainties resolve favourably in the future. This in turn will prevent the premature obsolescence of new infrastructure.

Key Lessons Learned

- Large-scale functional elements with modular architectures can be available ex-ante of the development process or be developed
- Some large-scale functional elements are very difficult, or extremely costly, to modularize
- Design safeguards are particularly useful to build options in infrastructures with integral architectures
- Design safeguards can also help to reduce the costs of exercising options in infrastructures with modular architectures
- Building options in new infrastructure development calls for the application of both modular and safeguarding approaches
- Design options are valuable to help postpone design decisions during project delivery
- Design options are valuable to leave open options to adapt the infrastructure if foreseeable uncertainties resolve favourably in the operating life of the infrastructure
- Modularity and safeguarding are at the heart of efforts to design future-proof infrastructures, i.e., design affordable infrastructures that can economically adapt to change over time
- Future-proof infrastructures are needed to prevent the premature obsolescence of capital investments

References

Baldwin, C.Y. and Clark, K.B. (2000). *Design Rules: The Power of Modularity*. Vol. I, MIT Press, Cambridge, MA.

Baldwin, CY. and Clark, K.B.. (2006). "Modularity in the Design of Complex Engineering Systems." In *Complex Engineered Systems: Science Meets Technology*, edited by A. Minai, D. Braha and Y. B. Yam. New England Complex Systems Institute Series on Complexity. N.Y.: Springer-Verlag.

Baldwin, C.Y. and Woodard, C.J. (2008). "The Architecture of Platforms: A Unified View." *Harvard Business School Working Paper*, No. 09-034, September 2008.

Dixit, A.K. and Pindyck, R.S. (1994). *Investment under Uncertainty*. Princeton University Press, Princeton, NJ.

Downey, D. (2006). "Trenchless Technology: a Modern Solution for Clean—Flowing Cities," *Proceedings of ICE Civil Engineering*, 159, 26-30.

Eisenhardt, K.M. (1989). "Building Theories from Case Study Research," *Academy of Management Review,* 14: 488-511.

Ethiraj, S.K. and Levinthal, D. (2004). "Modularity and Innovation in Complex Systems," *Management Science*, 50 (2) 159-173.

Fixson, S. K. and Park, J.-K. (2008). "The Power of Integrality: Linkages between Product Architecture, Innovation, and Industry Structure." *Research Policy,* 37, 1296-1316.

Gil, N. (2007). "On the Value of Project Safeguards: Embedding Real Options in Complex Products and Systems," *Research Policy,* 36 (7) 980-999.

Gil, N., Beckman, S., and Tommelein, I. (2007). "Operationalizing the Open Building Approach in the Management of Large-scale Engineering Projects." Chapter in *Open Building Manufacturing: Core Concepts and Industrial Requirements*, ManuBuild. Kazi, A.S., Hannus, M., Boudjabeur, S., and Malone, A. (Eds.).

Gil, N., Beckman, S., and Tommelein, I. (2008). "Upstream Problem-Solving under Uncertainty and Ambiguity: Evidence from Airport Expansion Projects," *IEEE Transactions on Engineering Management*, 55 (3) 508-522.

Iansiti, M. (1995). "Shooting the Rapids: Managing Product Development in Turbulent Environments." *California Management Review*, 38 (1) Fall, 37-58.

IEA (2006). *World Energy Outlook*. International Energy Agency.

Kitching, R. (2004). ""Future proof" Hospital Design Impossible, say Consultants," *New Civil Engineer*, December 2.

Lee, Y.S. (2007). "Flexible Design in Public Private Partnerships: A PFI case study in the National Health Service." MSc. Dissertation, Judge Business School, University of Cambridge.

Martin, M.V. and Ishii, K. (2002). "Design for Variety: Developing Standardized and Modularized Product Platform Architectures," *Research in Engineering Design*, 13, 213-235.

Miles, M.B. and Huberman, A.M. (1994). *Qualitative Data Analysis. An Expanded Sourcebook.* Sage Publications, 2nd Ed.

Mikkola, J.H. and Gassman, O. (2003). "Managing Modularity of Product Architectures: Toward an Integrated Theory," *IEEE Transactions on Engineering Management*, 50 (2): 204-218.

OECD (2007). Infrastructure to 2030. Mapping Policy for Electricity, Water and Transport. Vol. 2, *Organization for Economic Co-operation and Development*.

Orr, R. and Kennedy, J.R. (2007). "Highlights of Recent Trends in Global Infrastructure; New Players and Revised Game Rules." *Transnational Corporations*, 17 (1) 95-130.

Saigol, L. (2006). "Infrastructure Deals Soar to $145 bn," *Financial Times*, October 13.

Simon, H.A. (1962). "The Architecture of Complexity," *Proc. of the American Philosophical Society,* 106 (6): 467-482.

Stodder, S.M. and Orr, R. (2006). "Understanding Renegotiation and Dispute Resolution Experience in International Infrastructure Investment." *Proc. 2nd General Counsel's Roundtable*, Stanford University, CA, 1-3 Feb.

Sreeves, J. (2007). "Future-proof: Upon upon Severn viaduct, UK" *Proceedings of ICE*, Civil Engineering 160, 33-38.

Trigeorgis, L. (1996). *Real Options: Managerial Flexibility and Strategy in Resource Allocation*, Cambridge, MA, MIT Press.

Ulrich, K.T. (1995). "The Role of Product Architecture in the Manufacturing Firm," *Research Policy*, 24, 419-440.

Wang,T., de Neufville, R.(2005). "Real Options "in" Projects," *9th Annual International Conference Real Options*, Paris, France.

Van Miert Group (2003). *Trans-European Transport Network: The Enlarged EU must Find Adequate Resources.* European Commission. Directorate-General for Energy and Transport. Ref. IP/03/914.

Author's Biography

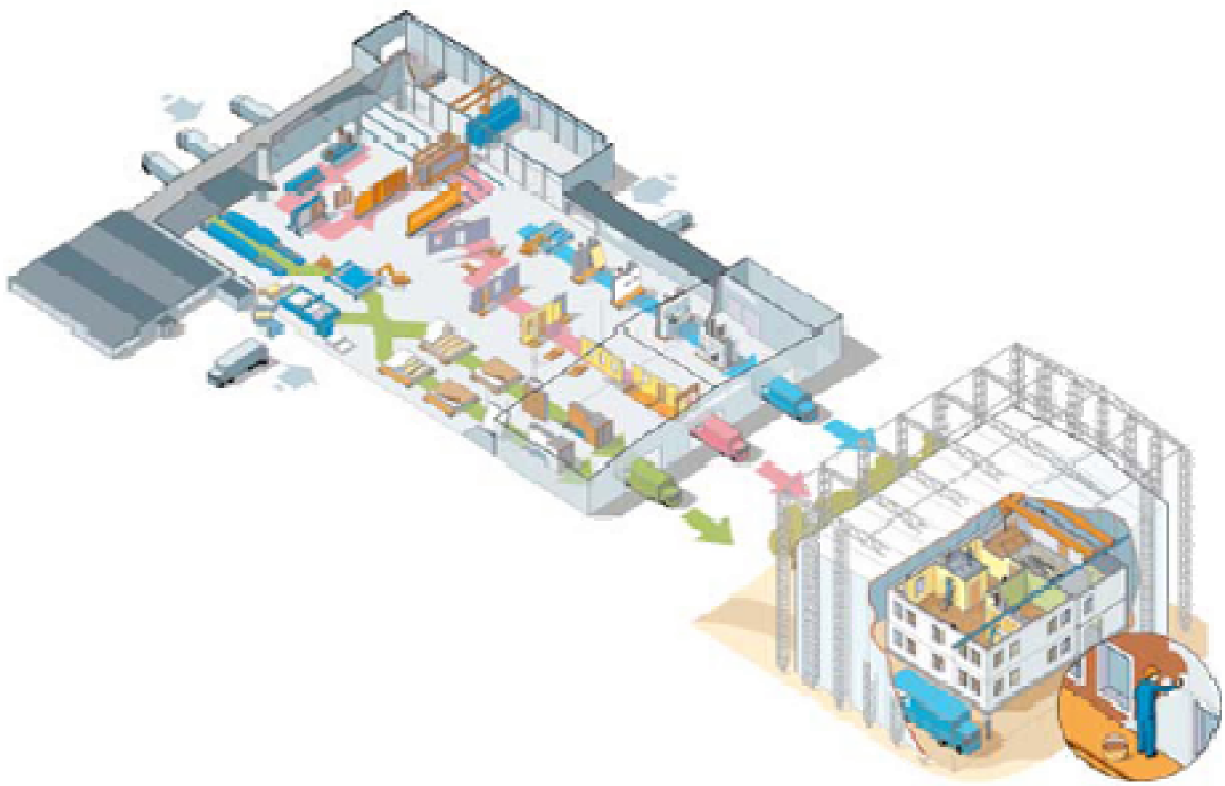
Nuno Gil is a senior lecturer (associate professor) at the Manchester Business School, The University of Manchester, UK. His research focuses on the processes and design decisions in the development of new infrastructure, including production facilities, transportation systems, hospitals, schools, and high-rises. His research develops frameworks for communicating novel approaches and instruments that project stakeholders can adopt to efficiently and effectively structure new infrastructure development. Nuno is the deputy director of the MBS Centre for Research in the Management of Projects (CRMP), and coordinator of the case study strategy for the British Petroleum (BP) Project Management College. Dr. Gil is a corporate member of the British Institution of Civil Engineers (ICE).

4

The Long Tail and Innovation of New Construction Practices - Learning Points from Two Case Studies

Christian Thuesen, and

Christina Claeson Jonsson



The Long Tail and Innovation of New Construction Practices - Learning Points from Two Case Studies

Christian Thuesen (Ph.D.), Consultant in Thuesen Consulting and External Lecturer at Management DTU (christian@thuesen.com)

Christina Claeson Jonsson (Ph.D.), NCC Engineering R&D (christina.claeson@ncc.se)

Abstract

This chapter juxtaposes two initiatives that tried to rethink the construction business within NCC – the NCC Komplett™ and the German platform for house building. It is found that both initiatives, more or less articulated, have applied a mass customization strategy – in line with the fundamental ideas of ManuBuild. However, their point of departure has been different. While the NCC Komplett™ worked with a high degree of manufacturing off-site (90%), the German platform is all in-situ based. The official results of the initiatives have been completely different. The German platform has created a unique competitive position for NCC in Germany – resulting in dramatically improved revenues and an offset for organic growth. In contrast, the NCC Komplett™ was discontinued due to uncontrollable costs. The paper concludes that "manufacturing" not by default is the only solution to the improvement of the construction industry. The German case shows how a very committed implementation of a platform – which optimises customer value and production cost – can give substantial benefits. Furthermore, it is found that radical innovation initiatives poses a high risk of failure.

Keywords: The long tail, building manufacturing technologies, flexible and configurable buildings, Mass Customization, Innovation

Background

Historically, numerous studies have shown the construction industry's lack of productivity compared to others industries (Egan 1998, Byggepolitisk taskforce 2000). In order to understand this it is important to keep in mind that the construction industry are characterized by being a project based industry that delivers one of a kind products (Kazi and Hannus, 2003).

Research shows how the lack of productivity is related to inefficiency by repeating the same mistakes across projects (Josephson & Hammarlund 1999, Apelgren et al. 2005). Thuesen (2006) argues that this phenomenon emerge from the lack of practices and technologies for accumulation of knowledge. There simply does not exist organizational learning processes, where companies systematically learn from the experiences they gain from their projects. This implies that there does not exist a platform for a continuous innovation.

One of the strategies to overcome this situation has been a strong focus on reapplying industrialized ways of working in the building industry – combined with an emphasis on radical innovation as a tool for implementing the required change.

This has resulted in an extensive focus on new industrialization efforts in the building industry the last couple of years. Different initiatives have been initiated – but what experiences can be gained from these projects?

Objectives

This paper evaluates two development initiatives by the construction company NCC, which both seek to deliver customized buildings (housing) in a standardized way: the NCC Komplett™ initiative in Sweden and the technical platform for house building in NCC Germany. Although the initiatives origin from the same company, they are fundamentally different in their production approach. The NCC Komplett™ concept was based on an extremely high manufacturing degree (90%). Compared to this, the production in the German platform can be considered in-situ based.

Approach

The two cases are analyzed with a framework developed from the concept "The long tail". "The long tail" was termed by Anderson (2004) and further develop in the book *"The Long Tail: Why the Future of Business Is Selling Less of More"* (Anderson 2006). It gives an overview of the market by juxtaposing the popularity of products with the number of product variants. The normal distribution in the market place or a company's product portfolio is that a small amount of products represents the majority of the production. In this way "The long tail" is heavily related the "Pareto principle".

The figure below relates the long tail to different production philosophies exemplified by the car industry: from mass production –> mass customization -> individual customization.

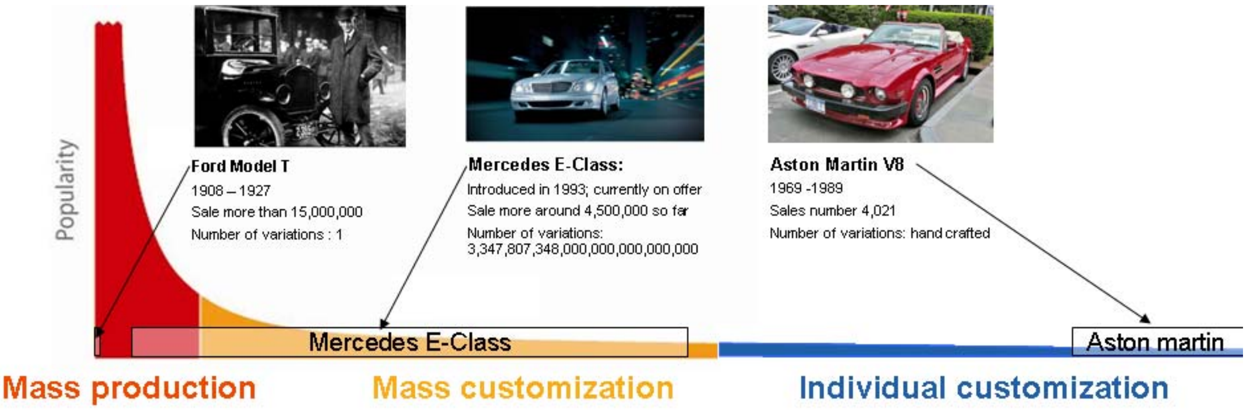


Figure 1 The long tail related to different production philosophies exemplified by the car industry

Traditionally, industrial companies have focussed on the small amount of products which are most the popular, as these products can be delivered based on the mass production paradigm leveraging economy scale. The most well know example is Ford Model T which in the beginning only was produced in one variant – an extremely standardized product. As Ford stated *"you can have all the colors you want as long as it is black"*

But the development of car manufacturing has evolved dramatically over the years. By the use of platforms, customers can today design their own cars. This capability of delivering customer tailored cars increases the customers' perceived value of the car, while the company still can leverage the economy of scale of mass production. In this way car manufactures have addressed the long tail by applying mass customization strategies.

The last production paradigm of the long tail is the "individual customization" strategy, where every product is produced uniquely for one customer. Within the car industry this paradigm is only adapted for certain extreme luxury cars such as the Aston Martin.

But what does the long tail of construction industry look like? Thuesen (2008) argues that the long tail is extraordinary long in the construction industry as every project starts from scratch trying to satisfy the customer's individual needs. Thus, the construction industry follows an individual customization strategy – just like the luxury car producers.

But this has not always been the case. Thuesen (2008) argues further that the building industry in Denmark, and throughout Europe, in the 60' & 70' was driven by a *"mass production"* paradigm – driven by a myth of buildings as being standardized. This development was e.g. initiated by the ideas of Corbusier. By his work and blessing, it was legitimate for architects to think industrialised and the implementation of mass production principles in the construction began.

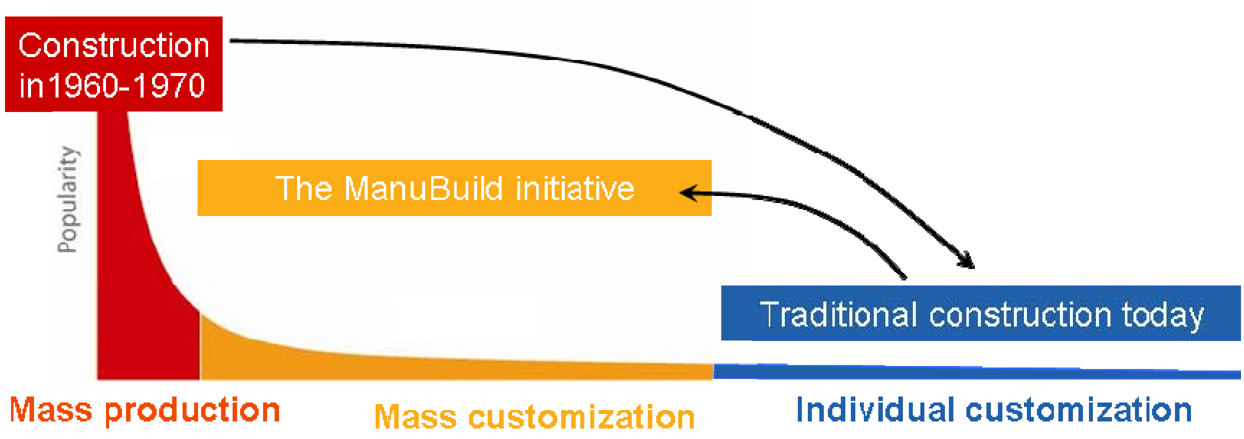


Figure 2 The long tail of construction

However, in the beginning of the 80s, a revolution evolved against the results of this paradigm and construction became, once again, a matter of tailoring unique buildings to each customer. Today we are predominately and tacitly following this *"individual customization"* strategy. Compared to this, the aim of the ManuBuild initiative is to move to a higher degree of standardization without loosing the ability to deliver customized products (Eichert & Kazi 2007) – in this way the ManuBuild initiative is working within the mass customization paradigm.

Analysis

We will now take a closer look at the NCC Komplett™ initiative and the German platform for housing to see how these managed to rethink the business of construction.

NCC Komplett™

Why would you even consider producing apartment buildings in any other way than is traditionally done today? Well, there are mainly four good reasons for this:

- There is a big debate regarding housing shortage and housing cost in Sweden (market driver)
- Upcoming labour shortage. It is estimated that 40 000 skilled workers will have retired until year 2015. Only half of that number will be replaced through the traditional method, i.e., recruiting from universities or vocational schools.
- Construction errors and maintenance problems
- Inefficient regarding cost and production time compared to other manufacturing industry.

To summarize, there is a great need to

- Deliver with a higher quality
- Construct at a lower cost
- Increase profitability
- Break patterns!

NCC Sweden had since 2002 worked intensively on developing an industrialized concept for residential buildings and in mid 2006 assembled the first manufactured building: the multi-storey apartment building in Hallstahammar. The NCC Komplett™ system was a radically new building manufacturing system to construct high quality multi-storey apartments in a factory based on the customer's requests. This system aimed to allow NCC to build houses in half the time and to a lower cost compared to ordinary construction methods. NCC Komplett™ aimed to take a radical step – the step into the factory.

The core market

One of the great challenges of manufactured buildings is surprisingly not technical, even though one must admit plenty of those exist, but society acceptance. Due to the mass housing of the 1960s and 70s, and its social effects, industrial construction has a bad reputation among people. Thus, it was felt necessary to not limit the architectural freedom but to present a concept that was as flexible as possible.

NCC aimed to serially produce multi-family dwellings on a larger scale, in order to reduce construction costs. The demands in the medium price segment were, at that time, healthy, particularly in Sweden.

Construction time

NCC Komplett™ aimed to cut construction time by half compared to traditional construction, see Figure 3 below. The elements were 90% completed when leaving the factory, thus, only 10% of the work needed to be carried out on site.

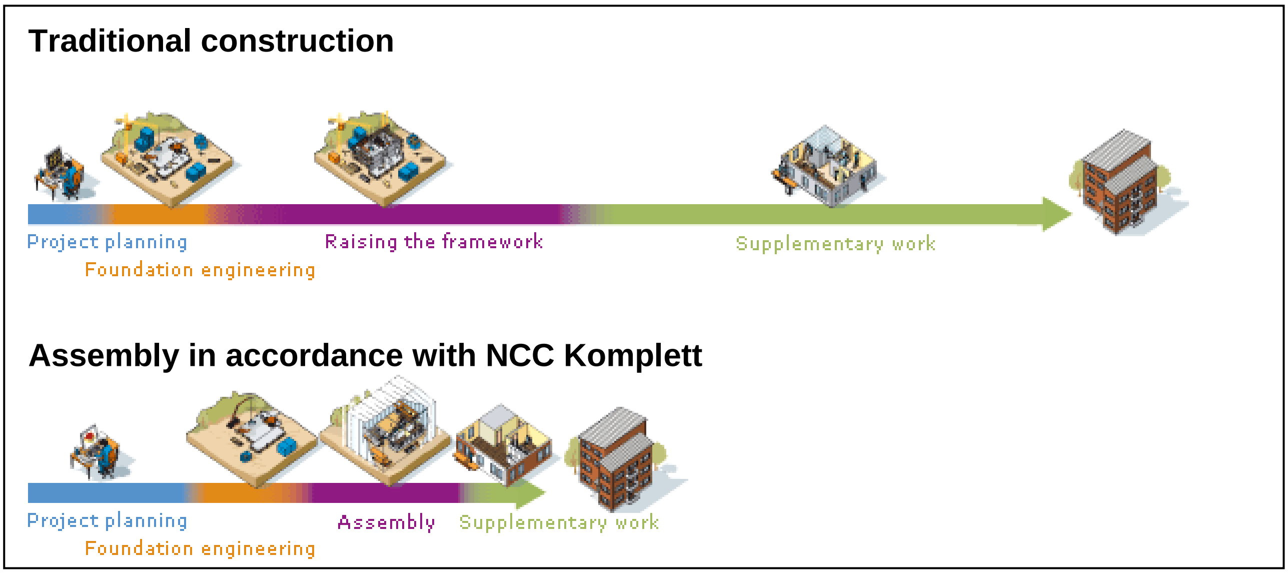


Figure 3 The NCC Komplett™ process intends to cut construction time by half (from www.ncc.se).

Working environment

With NCC Komplett™, construction could proceed in all types of weather without the risk of damp-related damage. Compared with a conventional construction site, it also offered a much better work environment. All production was performed indoor, either on the factory premises or in a heated assembly hall at the construction site. The factory was completely clean, and components were assembled by workers wearing gloves to protect the finished surfaces. By establishing an industrial process, it was also possible to introduce more ergonomically correct solutions, requiring fewer heavy lifts and increasing safety.

Figure 4 Principle sketch of the NCC Komplett™ factory (from www.ncc.se)

The factory

The factory was the heart and hub of the concept. This is where the walls were cast, the floor structures and ceilings were joined and all surface finishes are applied – from parquet flooring to wallpaper. The technical installations (electrical, water and sewage, ventilation) were also assembled in the factory.

In the factory, each wall was customized in accordance with the architect's blueprints. Following reinforcement and the placement of, for example, electrical installations, the walls were cast using high-performance concrete. After curing, the windows, doors and radiators were assembled. Subsequently, the wall was sent for wallpapering and was equipped with electricity switches and power sockets. The ceilings were surface treated and, like the floors, were delivered in a fully complete state. When the modules left the factory as completely finished flat packages, they were sequentially loaded onto the trucks and ready for assembly. Flat packages gave better options for flexible products (houses) but also better possibilities for efficient flow and standardized processes.

The assembly

Assembly took place on finished foundations slabs in mobile assembly halls that were totally protected from the weather. The different modules were lifted into place with overhead cranes and were joined together with the help of smart coupling devices. The maximum house height was 8 floors and maximum length 60 m. Only four assembly workers plus an assembly foreman were needed per building. The goal was for these five persons to assemble 3-5 apartments per week. Key concepts in assembly were logistics and orderliness. It is no question that this required radical innovation and an industrialised approach.

Result

Before the Board of Directors decided to halt the initiative in late 2007, approximately 5 projects had been delivered. While there were still problems associated with the design and the manufacturing processes, it is interesting to note that the architectural and end-users reviews were unanimously positive. Thus, it is clear that the ambition to achieve the society's embrace had been realised. This was in itself a huge step forward for the manufacturing construction industry. Furthermore, it illustrates a successful learning process. Much effort had been put in integrating the different phases (design, manufacturing, assembly etc) in order to achieve an understanding of the whole process and the consequences certain choices had on the following processes. One can only speculate on the outcome if this type of understanding had truly spread also to the traditional construction processes.

The German platform

The German platform for house building has been developed since 1994. Back then, and up until now, the organisation has faced an extreme pressure on the margins – due to a market in recession. They early realised that the existing construction practice was not able to produce low cost houses. They needed to rethink their business – and they started to develop their platform for housing. The platform was developed based on the following requirements. It should

- be applicable in 90% of the markets that NCC Germany addressed.
- be designed in respect to German culture and tradition for industrial production, focusing on incremental improvement rather than drastically changes.
- be flexible for producing many different houses like: one family houses, row houses, double houses and apartment buildings up to 6 stories
- use a decentralised serial production, enabling very small projects.

The core market

The development of the platform has been driven by targeting a specific selected market. The platform should be able to produce homes for families which traditional had not been able to afford their own homes but had been stuck in the renting market.

Cost value optimization

Over time the platform has been carefully designed to suit this segment – optimizing the cost/value ratio as illustrated in the following figure:

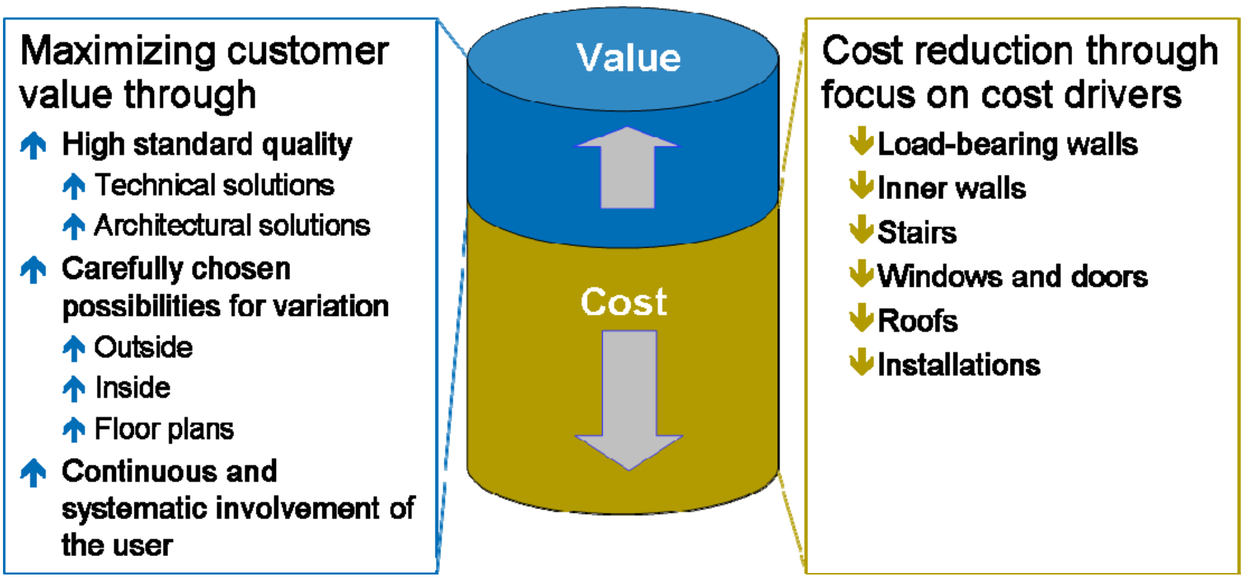


Figure 5 Optimizing the cost/value relation – a fundamental principle of the German platform

The cost has been reduced dramatically by focusing on the cost drives of the process. The technical solutions for reducing cost have carefully been chosen so it would not reduce the quality level but would optimise the long term economy. This is exemplified in the construction principal of the load bearing walls.

The core component of the outer walls is 60x60 cm modules of aerated concrete. The 60 cm module has been selected as it is easy to work with – it does not require heavy machinery but only a small lift for helping the blue-collar workers put them in place.

Based on these modules the design dimensions of the house are defined – as a multiple of 60 cm. Furthermore, the windows and doors are designed in compliance with this modularity. In this way only a very small percentage of the modules need to be altered – resulting in a low complexity, the use of well know solutions and effective use of work resources. In the few cases where the modules need to be altered – as the inclined fittings between the gables and the roof - there is a strong focus to keep the cost down. The chosen solution in this situation has been to produce these modules offsite instead of letting the blue-collar workers do it locally.

But while the modularity is enabling an effective construction process it is also putting constraints on the design. This can potentially decrease the value for the customer. An example of this dilemma is the room height. Due to the size of the building blocks they have chosen to work with a greater room height than normal. From a theoretical perspective you could decrease the room height and thereby save material – and cost. However, they have identified that the cost would increase due to a need for an extra dimension of the building blocks increasing the complexity due to new operations in the production phase. Instead the greater room height is sold as an increase in quality and customer value. This dilemma between cost and value is illustrated in the following two pictures.

Figure 6 The German platform: achieving value creation and cost reduction by using 60x60 cm modules

By consequently using the 60x60 module as the basic construction principal, they have been able to concentrate their volume, leveraging their bargaining power towards the suppliers of the modules. In this way they have managed to reduce the cost even further and at the same time ensure a fixed price for a 2 year period– reducing their risk for increases in material prises.

In order to reduce the risk even further, the construction of the outer walls are carried out by NCC own blue-collar workers – ensuring the initial phase in the “projects” are realised effectively. In some of the other areas like the pluming the work is outsourced to subcontractors. Unlike the traditional construction practices these subcontractors have agreements for multiple NCC projects enabling them to optimize the production flow and utilization of resources across projects.

Development and implementation of the platform

Based on the platform, each building is configured to suite the specific site and specific customer. In this way the flexibility is carefully designed to match the specific market and not just to create a huge flexibility from a theoretical perspective.

A central driver in the development of the platform has been NCC's own activities as developers – in the acquisition of land – the general design of houses – the production – and the concluding sale to local customers. In this process the developer usually spot and buy unattractive pieces of land as the one below – located near a railroad and having an odd shape.

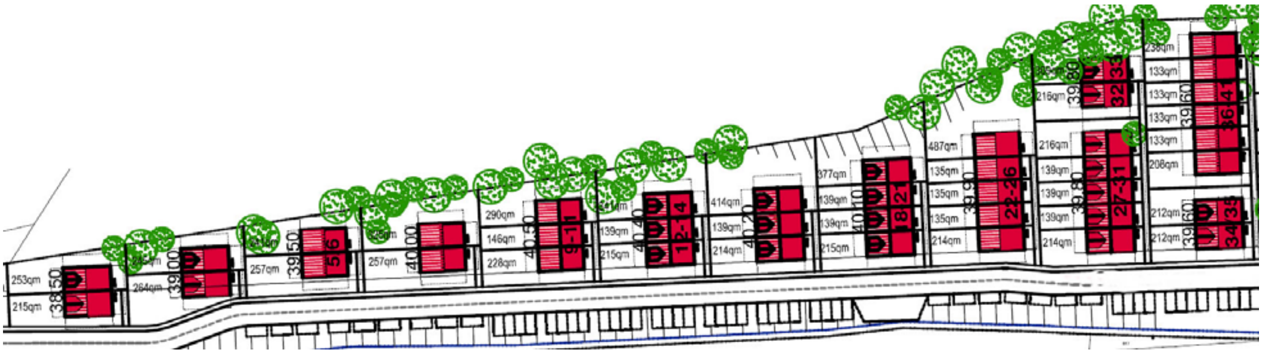


Figure 7 The German platform: optimizing the use of land

Usually plots like this are cheap as it is very difficult to effectively use the land. However, as the platform enables a floor plan with an optimised width of 5,5 meter – many houses can be arranged on the plot – effectively using every m2. In this way the cost can be kept down – fulfilling the need of the target market.

Outlook

The cost/value optimization has been carefully formalized in the platform, enabling NCC Germany to expand their business into other segments. On the basis of the platform for single family row houses – they have expanded their use of the platform to other segments: Apartments in buildings up to 8 stories, high-end single family houses and holiday immobiles. This expansion is illustrated in the following figure, based on Meyer & Lerhnerd´s (1997) typology for platform development:

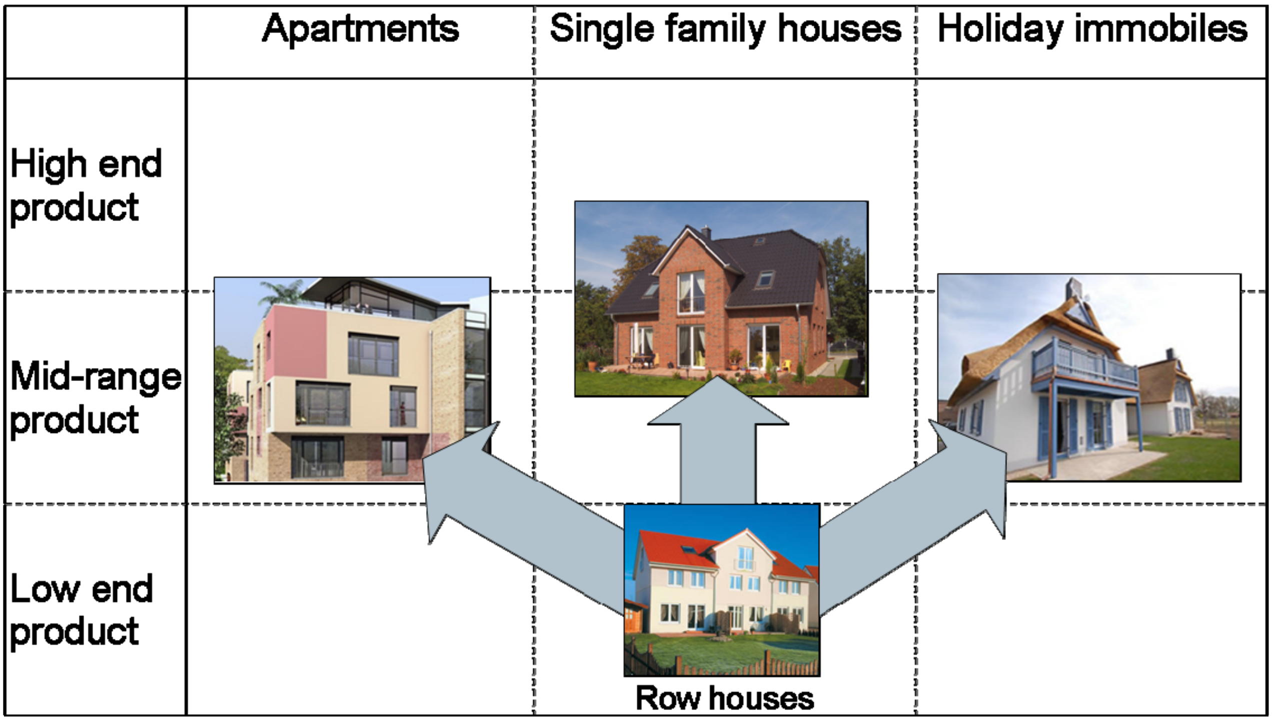


Figure 8 The development of the German platform

Conclusions

Based on the platform, NCC Germany has managed to create a high quality product at low cost, by systematically finding the optimal solutions between cost drivers and value propositions.

This optimization of the cost/value ratio has targeted a specific market – a new market for homeowners that normally have not been able to afford a home of their own. In this way, NCC Germany has realised a blue ocean strategy - just like Ryanair.

Results and Business Impacts

Key Findings

On a generic level the result of the two cases is completely different. The NCC Komplett™ failed as it was abolished by the NCC's Board of Directors and the German platform is today a huge success. How come?

The interesting case about NCC Komplett™ is that they seemed to do all the right things and they really developed a total new approach for building – a well celebrated case on radical innovation throughout the industry. However, they lost control of the costs. They developed a manufacturing technology, which from a technical stand point where superior, but from a manufacturing point of view not fully mature. Furthermore, because of the competitors' development of manufactured standardized (in relation to flexibility) houses, and to calm the architects and community administration who feared that the mass production of the 60s and 70s industrialization would repeat itself, NCC wanted to market the concept associated with a very high flexibility. In fact, it may very well be this striving for full flexibility that caused the unexpected increase of cost in the first assembled projects and in the end made the directors decide to abolish the concept. Perhaps it would have been wiser to focus on a smaller market, limit the number of variants and instead remain in full control of the logistics and take advantage of the repetition effects, and thereby providing a product which had optimized the relationship between cost and value.

Compared to this, the German platform has managed to reduce the production cost with more than 30% over the past 10 years while still offering a high quality product and with a flexibility carefully targeted a specific market.

In the following figure the two cases are related to the long tail.

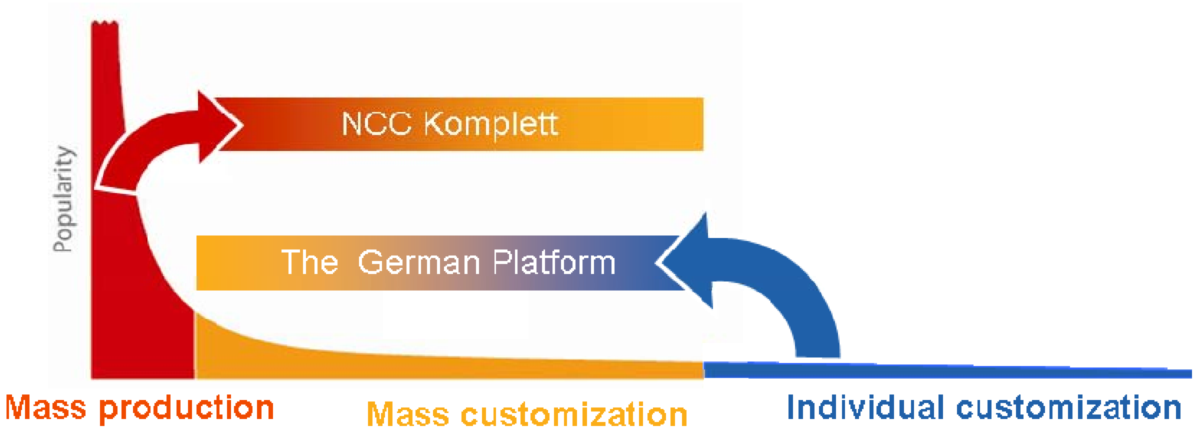


Figure 9 Addressing the long tail from different perspectives

If we look at the ambitions behind NCC Komplett™ and the German platform we will discover that they are quite similar. They both worked towards implementing the mass customisation paradigm. However, the key difference between the two is their point of departure. While NCC Komplett™ was trying to implement a huge flexibility through industrialised manufacturing processes, the effort of the German platform was to constrain the flexibility in traditional construction - focusing on delivering value to the customers and to reduce costs.

The German case is interesting as it contradicts the predominant understanding that a high degree of manufacturing is the way forward for the construction industry. Compared to NCC Komplett™ the German platform is extremely practical and low-tech.

Thus, a high degree of manufacturing is not by default the sole solution to the problems the industry faces. However, the examples show the benefits of an integrated approach where an industrialized train of thought is governing the overall system.

Furthermore, the cases show that radical innovation is extremely difficult – as an internal NCC employer formulated *"If you want to learn to jump four meters in pole vaulting you don't put the bar at four meters in the first jump. You need to start at small heights and then gradually heighten the bar."* Basically, this proves that the most difficult step in transforming the sector is related to the business model, the understanding and acceptance by the individual persons.

The learning point is that radical innovation is not necessarily the best strategy for implementing new ways of working in the construction industry. Radical innovation can be too risky. In contrast the German platform has shown that incremental innovation can be a success if it is managed with a deep understanding of the market as well as strong commitment for implementing the platform.

Business Impacts

The collected experiences from the two NCC cases, give input to the future development of a more effective building industry. The learning point is that it is not the technology in itself which gives a competitive advantage, but how the whole value chain is organized around a specific market (and the stakeholders requirements).

Furthermore, it is illustrated how the concept of the long tail is a fruitful way to analyse the market orientation of a concept keeping the focus on having the right flexibility. This is increasingly important as the market gets more and more individualized (Pine & Gilmore 2007). Anderson (2006) argues that the number of unique product offerings expands as the market shifts from the popular hits (the head of the distribution) to niche products (the long tail). That is why the future of business is selling less of more. This change in the market is important to be aware of in the development of new ways of working in the construction industry.

Conclusions

The two initiatives discussed in this chapter both originate from the fact that the construction sector today is associated with too high costs, too low productivity and a transfer of knowledge that has high potential of improvement. While the ways to solve these problems were somewhat different, both of the described cases understand the value of understanding the customer's needs and requirements.

The cases show that "manufacturing" not by default is the solution to improve the construction industry. In fact the termination of NCC Komplett™ could give the impression that manufacturing is not at all the way forward for the construction industry. This is, however, a poorly substantiated conclusion. The German case shows how a very committed implementation of a platform - which optimises customer value and production cost – can give substantial benefits for both customers and the company.

Clearly, the main difficulties with transforming the construction sector are basically not technical but instead organisational. To succeed, each individual must understand, accept, act and commit to this new way of thinking. In this process, it important to realize that radical innovation initiatives can be associated with a high risk of failure.

Practical Tips

- The way to open manufacturing building can be numerous, however, a deep commitment from all are required
- An understanding of the market and the customers´ needs are essential
- Only by systematic learning from previous experience can lasting improvements be made.

Acknowledgements

We would thank our colleagues at NCC. Without their input and special insight we wouldn't have been able to write this paper. Especially we want to thank Ingvar Lundström for his valuable information about the German platform.

References

Anderson, Chris (2004) *"The Long Tail"* in Wired Oct. 2004

Anderson, Chris (2006). *The Long Tail: Why the Future of Business Is Selling Less of More*. New York: Hyperion.

Apelgren, S., Richter, A., Koch, C. (2005) Snublesten i byggeriet, Byg.DTU, ISBN 87-7877-173-0

Byggepolitisk taskforce (2000) *Byggeriets fremtid – fra tradition til innovation*, EBST (http://www.ebst.dk/publikationer/rapporter/byg_frem/index.html)

Egan, Sir J. (1998) Rethinking Construction, Department of the Environment, Transport and the Regions, London

Eichert, J. & Kazi, A. (2007) *Vision and Strategy of ManuBuild – Open Building Manufacturing* in Open Building Manufacturing – Core Concepts and Industrial Requirements (editors. Kazi et al.), pp. 3-14 ManuBuild VTT, ISBN 978-951-38-6353-1

Josephson, P.-E & Hammarlund, Y. (1999), *The causes and costs of defects in construction – A study of seven building projects*, Automation in construction Vol. 8. P. 681-687

Kazi, A.S., Hannus, M (2003) *Interaction Mechanisms and Functional Needs for One-of-a-kind Production in Inter-enterprise Settings*, Global Engineering and Manufacturing in Enterprise Networks (editors: Karvonen, Ii, et al.), pp. 301-312, VTT, ISBN: 951-38-5739-5.

Meyer, H. Marc & Lerhnerd, Alvin P. (1997) The Power of Product Platforms - Building Value and Cost Leadership, The Free Press, ISBN 0-684-82580-5

Pine, J. & Gilmore, J. (2007) Authenticity: What Consumers Really Want, Harvard Business School Press, ISBN 978-1591391456

Thuesen, C. (2006) “anvendelsen ad den rette viden – et studie af byggeriets kulturelle organisering” Ph.D. dissertation, Byg.DTU. ISBN 978-87-7877-237-2

Thuesen, C. (2008, forthcomming) Constructing the long tail, Proceedings of the Conference Managing the Construction of Buildings, CBS, Copenhagen, Denmark, 13-14 November , 2008.

Author Biographies

Christian Thuesen holds a Ph.D. from DTU (Technical University of Denmark), were he currently are engaged as external lecture. His PhD project (2002-2006) was the first project in Denmark funded by a contractor (NCC). After ending his PhD he has been working for NCC Denmark as an R&D consultant on various development projects like, development of a purchasing system, redesigning the quality management system etc. Lately he has been working on the development and implementation of platform strategies within NCC. In September 2008, he started his own company and is know working as an external consultant for NCC.

Christina Claeson-Jonsson works for NCC Engineering since 1998. She is currently the manager of the R&D unit, where her main research 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 concepts. She has a M.Sc. in Structural Engineering and holds a Ph.D. in design of concrete structures.

5

Flexible and Innovative Manufacturing – Two Case Studies

Jian Zuo, George Zillante, and Mark Smeaton

Flexible and Innovative Manufacturing – Two Case Studies

Dr Jian Zuo, University of South Australia, (Jian.Zuo@unisa.edu.au)

Dr George Zillante, University of South Australia (george.zillante@unisa.edu.au)

Mr Mark Smeaton, Ahrens Group (msmeaton@ahrens.com.au)

Abstract

This chapter reports on the application of the principles of open building manufacturing to small scale projects. Two relatively small projects that were designed, in part and constructed by the Ahrens Group were studied in this research, viz the Stadium Australia re-configuration and the Riparian Plaza Spire. Despite their relatively small size the projects encountered a number of challenges. For instance, in the Stadium Australia re-configuration project, the client had a requirement that the construction process not disrupt the operation of the stadium facilities. Similarly, the complicated construction environment and the requirement to lift heavy construction sections to a great height posed significant challenges for the project team in the Riparian Plaza Spire project. This chapter focuses on the innovative design and production techniques adopted for these two projects. In particular, it focuses on the systems used for prefabrication, transportation and on-site assembly. These innovative design and construction techniques have contributed to Ahrens achieving significant successes in both projects. For example, the Ahrens approach enabled the client to save significant cost for the Stadium Australia re-configuration project i.e. some two thirds of the original project budget. Similarly, the implementation of a fully bolted construction procedure for the Riparian Plaza Spire led to significant cost savings and minimized the considerable safety risks involved with constructing at height.

The innovative approaches used by Ahrens have benefited both Ahrens and the community as a whole. Ahrens have gained a reputation for being able to solve construction problems and deliver complicated construction projects whilst the broader community has gained by being able to apply these innovative approaches to other construction projects.

Keywords: Stadium Australia, Riparian Plaza Spire, flexibility, innovation, case study

Background

Industrial Context

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. This chapter reports how these principles have been successfully applied in two small-scale construction projects.

The first project involved Stadium Australia, which served as the major venue for the 2000 Sydney Olympic Games. Three years after the Olympics, the client engaged a project team to reconfigure the roof of the stadium. This involved:

- Removal of the temporary seating in the northern and southern terraces and;
- Construction of two new 3500m^2 roof areas to cover those terraces and provide for all-weather accommodation.

The initial design for the new roof sections comprised a traditional “heavy” design with little flexibility and required the stadium to close whilst the new roof sections were constructed. In addition, it exceeded the project budget and was eventually rejected by the client.

There were significant risks associated with this project, the biggest of which was the client’s requirement that the construction was not to disrupt any of the scheduled events proposed for the stadium e.g. the 2003 Rugby World Cup amongst others.

The head contractor, Multiplex engaged Ahrens Construction as the builder and truss fabricator to deal with the above issues on a design/construct basis. Ahrens drew on its experience with complicated construction projects and worked very closely with the roof structural designer to achieve some interesting innovations for this project.

The second project involved the design and construction of the tubular steel spire on top of the Riparian Plaza in Brisbane. The 50 tonne communication spire was placed on top of the Riparian Plaza at level 50 making the structure the tallest in Brisbane at that time. The Spire was erected by pre-fixing the individual mast section off site before erection and installation on site. Wind and height posed a concern as the structure measured over 70m in height on top of the 194m high building giving a total height of 264m to the top of the spire. The scope of works included:

- A cylindrical structural steel tower:
    - more than 70 meters in height
    - 1.5 meters in diameter
    - with 2 supporting struts, each 18 meters in length
    - with 5 satellite rings, and
    - 7 main tower sections plus 2 struts.

Problem

There are studies that report on the application of open building manufacturing approaches for large-scale infrastructure projects (e.g. Gil, et al. 2006). However, there are limited studies on how these principles can be transposed and applied to small scale projects.

Given the complex nature and risks associated with the two projects listed above, this study serve as a demonstration of the benefits of applying open building manufacturing practices to small scale projects.

Potential Solution

Key Requirements

This Chapter has three objectives:

- To investigate how the principles of Open Building Manufacturing were applied in the reconfiguration of Stadium Australia;
- To investigate how the principles of Open Building Manufacturing were applied in the Construction of the of Riparian Plaza spire.
- To discuss the business impacts of these applications on Ahrens Constructions and the broader community

Open Building Manufacturing

By introducing features of efficient manufacturing to the construction sector, open building manufacturing allows for significant benefits such as: cost savings and higher levels of customer satisfaction (Eichert & Kazi 2006).

In their research involving a major health sector project, Zuo & Zillante (2006) discovered that the adoption of relevant open building manufacturing methods, e.g. innovative procurement approach, ICT support and value-driven performance evaluation, contribute towards better project outcomes and improved satisfaction of user requirements. Similarly, Tam & Tam (2006) identified that the use of prefabrication to reduce waste generation and to lower cost was one of the best methods used to achieve open building manufacturing.

A people-focused open building manufacturing approach can be used to develop sustainable communities (Thompson 2007). The development of an open building manufacturing system can also contribute positively to the developmental agenda of a developing country (van Wyk 2007).

The Open Building Manufacturing system consists of building concepts, building processes, improved production technologies, ICT support and training education (Figure 1).

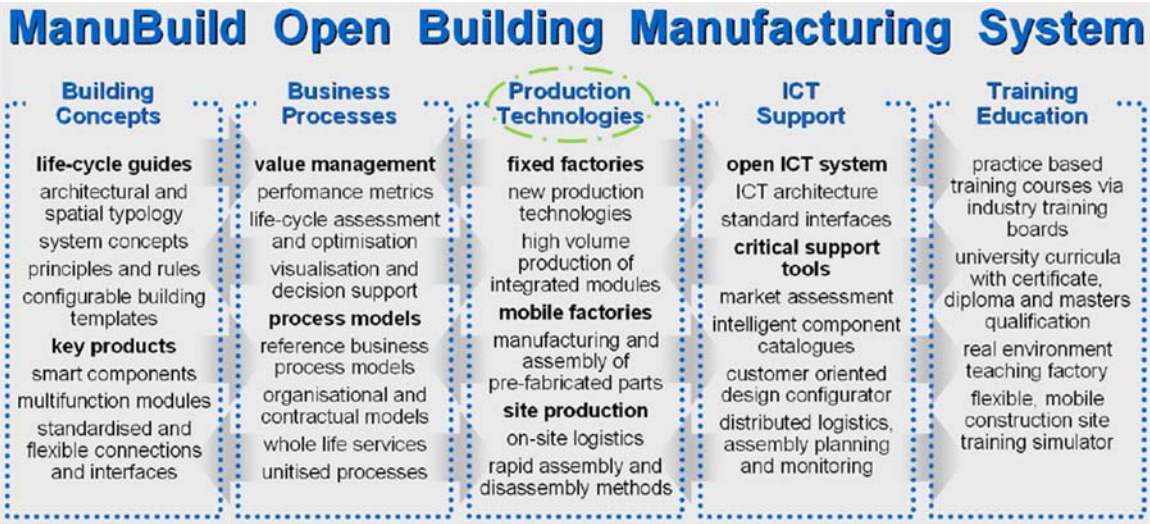


Figure 1 Manubuild Open Building Manufacturing system, source: Eichert & Kazi 2006, p.11

This study focuses on the production technologies part of this system with special focus on flexible design, prefabrication and on-site assembly.

Approach

A case study methodology was adopted for this study. This approach lends itself well to the investigation of how the principles of Open Building Manufacturing were applied in the two projects; especially with regard to:

- meeting societal needs;
- flexible design
- prefabrication
- transportation
- on-site assembly

All relevant documentations for the projects (e.g. drawings, specifications etc) were made available by Ahrens Construction and were reviewed by the project team. Similarly, the project manager responsible for the design and construction of both projects made himself available and was interviewed.

Analysis

Case 1: Stadium Australia

International builder, Multiplex engaged Ahrens to undertake the fabrication, supply and erection of the steelwork for the new northern and southern roof structures.

After the conclusion of the 2000 Sydney Olympic Games the temporary northern and southern grandstands were removed.

Approximately 1000 tonnes of structural steel, along with polycarbonate roof sheeting and stainless steel guttering, was used in the reconfiguration of the stadium.

All the steelwork was fabricated at the Ahrens workshop at Sheaoak Log in South Australia and transported for final assembly at Homebush in Sydney, New South Wales. The roof trusses were designed as a clear single span so as to ensure a continuous and completely column free viewing arena.

Ahrens's reputation in meeting deadlines was one of the main reasons why they were chosen to carry out this contract. This was demonstrated by them completing the project on time for the opening of the 2003 Rugby World Cup.

Meeting societal needs

The client and the community had the following requirements with respect to this criteria:

- completion on time to accommodate the pre-scheduled events
- continuous operation of the facilities during construction
- completion within a limited budget;
- increasing of the stadium capacity, especially for under cover seating (see Figure 2)

Ahrens worked very closely with the other parties involved with the project and realised a number of innovations that met the above requirements. Those parties included, Multiplex as the head contractor, Bigspace as the roof structural engineer, Sinclair Knight Merz as the consulting engineer, HOK Sport+Venue+ Event joint venture with Bligh Lobb Sports Architecture as the architect, and SW Healey and Associates as the detailing engineer.

The original cost for this project if the client had continued with the original design was cut by two thirds by using the Ahrens approach. In terms of structural design, a post-tensioning technique was adopted to fabricate the steel trusses for the long span roofs. The post-tensioning technique helped to reduce the weight of the structure, the cost and the erection and production time when compared to the more conventional approach (Manley 2006).

Figure 2 Newly built undercover seating in Stadium Australia

These innovations are illustrated as follows.

Peripheral truss and outer cords

As shown in Figure 3, the peripheral truss was made in transportable sections with bolted connections for both ease and speed of erection onsite. In addition, the outer chords required precision rolling and complex fabrication to ensure the radial curve was maintained (see plan view A-A in figure 3).

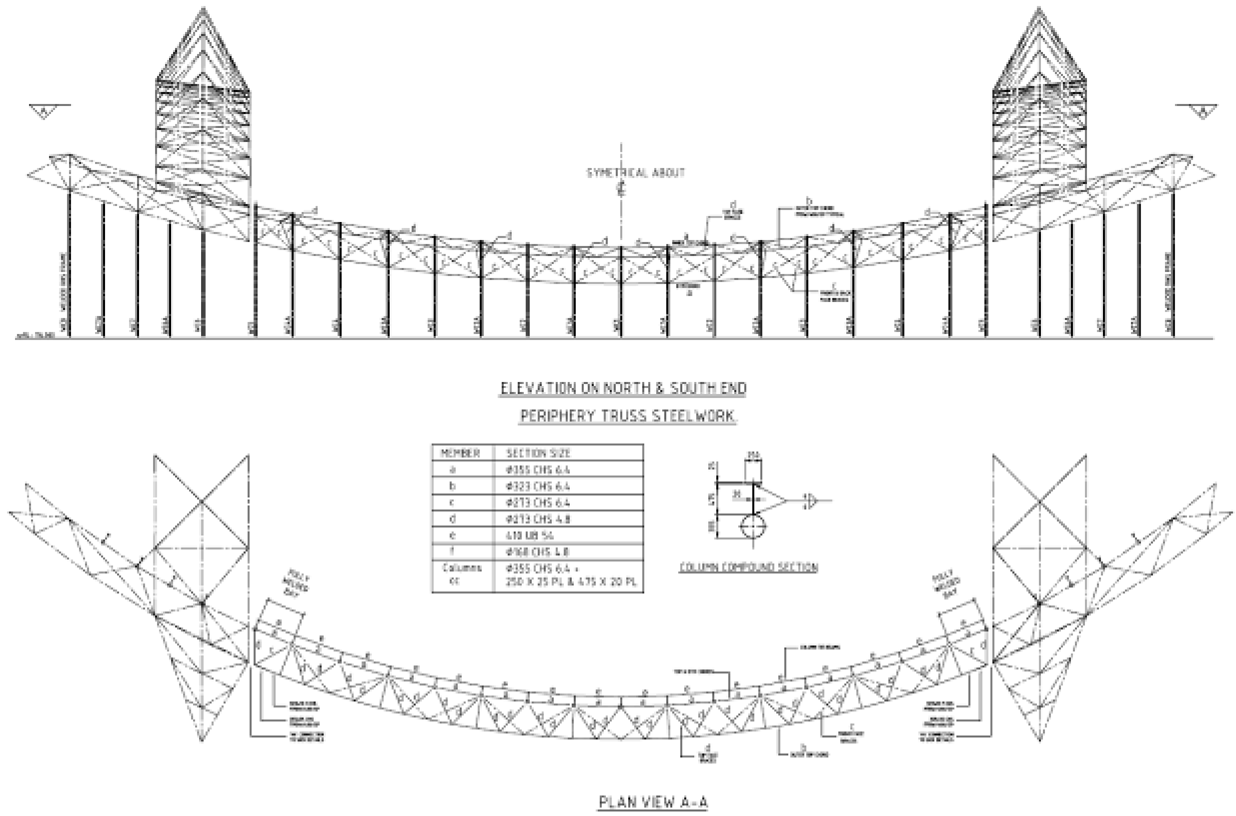


Figure 3 Peripheral truss with outer chords

Specially designed aluminum extruded glazing sections

The existing roof structure contained a series of glazing sections and leaked in several places. Multiplex, as the primary contractor, and the stadium owners were very conscious of this problem and wanted to ensure that it did not occur with the extended roofing structure. Ahrens identified the flaws in the original roof design that were responsible for the leaks. They then worked closely with the other parties in the project to determine how best to seal the roof i.e. the best material and methods, and then set about to design and organize the actual manufacture of the rubber seal itself.

Ahrens designed and developed a special aluminum extrusion section to form the actual rubber seal that sits within the extruded section. They also produced the actual extruded section and rubber mould (rubber seal). Initially a sample was produced and tested to see if it was water proof. A test that it passed with flying colours.

Similarly, there were some issues with the method used to fasten the existing roof sections. Accordingly the design of the new roof sections was changed to allow for a better fastening system, more of and simpler and more accessible fixing points and better seal performance. The material used was carbon plate which was easy to install, easy to seal and easy to remove (for maintenance purposes). Similarly, specially designed aluminum extruded glazing sections were developed for fixing and sealing the poly carbonate roof sheet (see Figure 4).

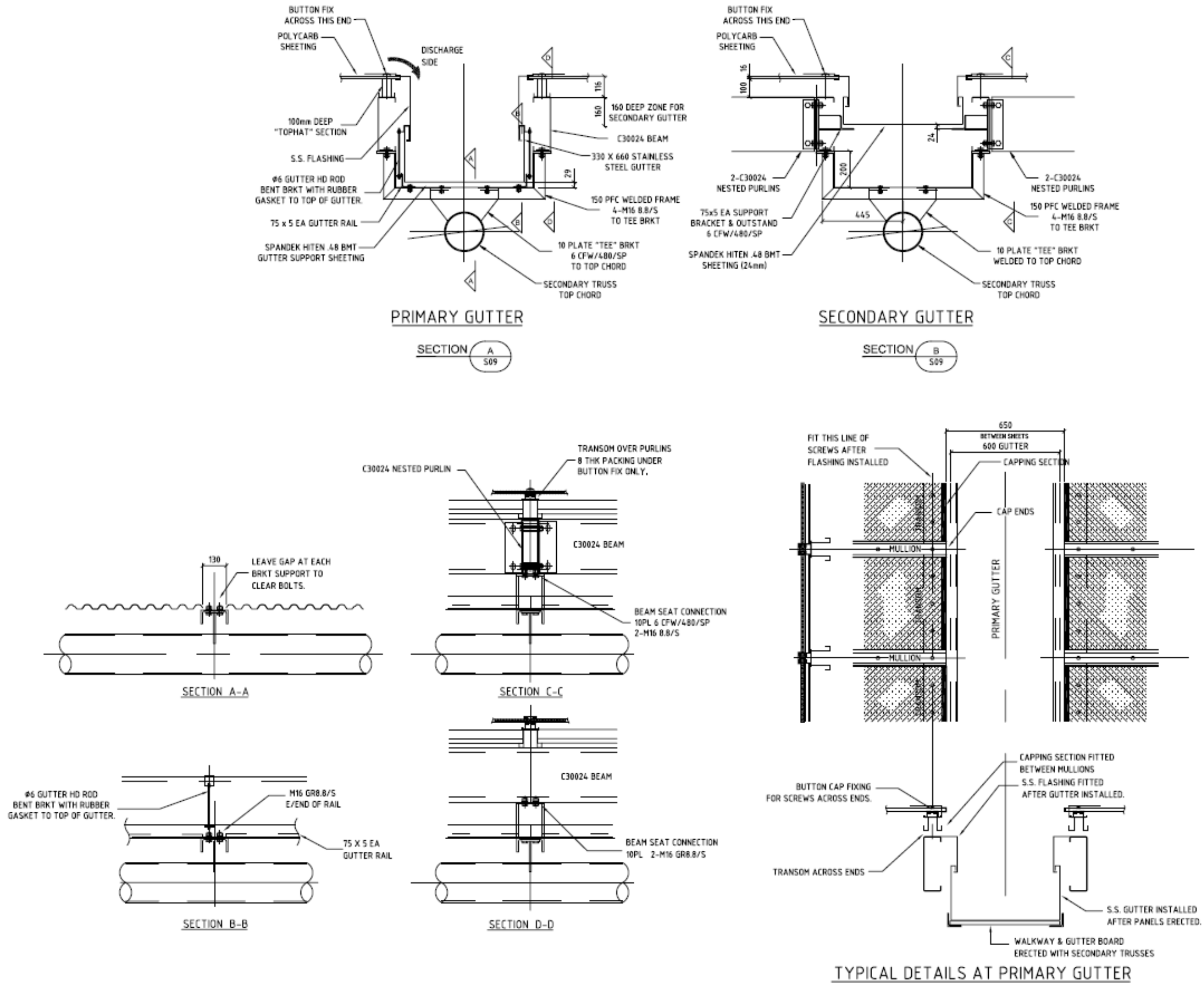


Figure 4 Aluminium extruded glazing sections

Innovative design

The trusses used in the existing roof were welded on-site. This on-site welding process for 18.9m lengths of trusses was a time consuming operation, especially with a project as large as this. The Ahrens solution for the new roofing section comprised of one section that was welded on-site, whilst all the intermediate sections were fully bolted with covering sleeves so that the end result gave an appearance identical with that of a welded truss solution (see Figure 3). This was a simple, yet innovative solution which led to considerable time savings. Given the tight construction program for the project, this was a particularly important aspect of this project. A 3D modelling system was used to check the design. This system allowed for rendering of the various individual components so that any clashes between the truss components could be easily detected. Figure 5 demonstrates the existing truss strengthening.

Figure 5 Bolted intermediate sections

On-site assembly

Ahrens used AutoCAD to lay out the roof. This enabled each panel to be measured exactly, thereby minimising the amount of waste that is usually associated with the more conventional approach, and also ensured that Ahrens had an appropriate supply chain of material for the project. This was particularly important because the material was very expensive and any errors in take off would have resulted in increased costs in either excess material (waste) or time lost whilst waiting for extra material to be delivered. The success of this approach was evident at its conclusion when it was found that the amount of waste that had been generated was less than 2%, an exceptionally low figure for this type of construction.

The roof structure components were designed and detailed to be fabricated in Ahrens's fabrication plant in South Australia and then transported in piecemeal sections to the site in Sydney, New South Wales. The structures, including the main triangular trusses of some 7m by 7m in cross section, were all preassembled on site and then lifted into position by cranes.

The poly-carbonate roof panels were bought from various suppliers, for instance, Bluescope Steel supplied the 10m by 10m C section panels, and they were all pre-assembled on site. The challenge that confronted Ahrens in this regard was to ensure that the Poly-carbonate panels were available on time. Initially the panels were to be sea freighted but this would have taken 12 weeks and result in a delay to the project. Accordingly Ahrens made the decision to pay a \$200,000 premium and air freight some 7000m^2 of poly-carbonate panels from Holland. The process of lifting and installation of the poly-carbonate roof panels can be seen in Figure 6.

Figure 6 Lifting and installation of the poly-carbonate roof panels

Case 2: Riparian Plaza Spire

The Riparian Plaza Spire project comprised the construction of a 70metre high cylindrical structural steel tower on top of the Riparian Plaza building, whilst that building was still under construction (see Figure 7). This Landmark structure was the tallest structure in Brisbane at the time and provided an enhanced level of communication for a national communication network.

The 50 tonne communication spire was placed on top of the Riparian Plaza at level 50 making the structure some 250m high i.e. the tallest in Brisbane at that time. The Spire was erected by pre-fixing individual mast sections off site.

Largely manufactured in South Australia by Ahrens, the sections were transported to Brisbane and further assembled prior to their progressive pre-dawn arrival on site as nine enormous steel units.

Figure 7 Riparian Plaza Spire

The construction process for this project is illustrated in Figure 8. The fabrication, off site pre-assembly and erection installation took 12 weeks, 6 weeks and 10 days respectively.

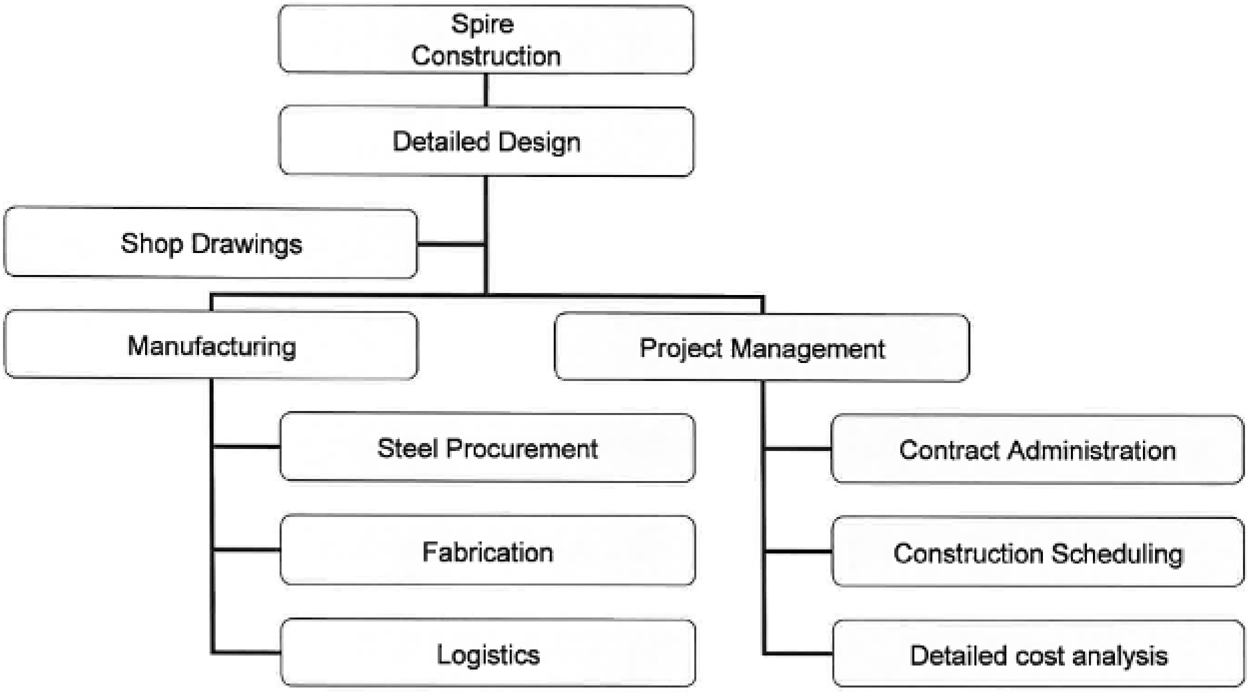


Figure 8 The construction process of the Riparian Plaza Spire project

The community and the client's needs were met by the innovations as described below.

Innovative design

The Ahrens design approach for this project centred on simplifying the on-site construction process. The original design proposed a fully welded tower which required a series of individually welded sections being transported to the site and then being joined by welding to form a continuous tower. The Ahrens solution proposed that the prefabricated sections were to be bolted together internarlly on site rather than being welded. This simplification resulted in a more cost effective design and construction for the Spire.

Because the project involved working at height, Ahrens needed to consider the issue of safety as well as time, site availability and cost. The site contained two tower cranes that were being used for the construction of the Riparian Plaza building. Accordingly these cranes were not freely available to Ahrens and they were forced to negotiate their usage for a time that did not interfere with the construction of the building. Given the safety issues involved in working at heights, Ahrens minimised this risk by redesigning the tower to have internally bolted connections which meant that access during both construction and maintenance could be via an internal ladder within the actual tower itself

Section 4 (Figure 9) was the most complex in terms of fabrication. It took 10-12 weeks to fabricate and required specialised surveying to ensure that the stresses generated by the heat of the welding process did not affect the alignment of the component sections. In addition, the sections that made up the spire were fitted with the various services and service runs within the actual tower sections so as to make them easily accessible from service personnel from inside the tower. This simplified the maintenance procedure and reduced the long term risk exposure to service personnel having to work at heights.

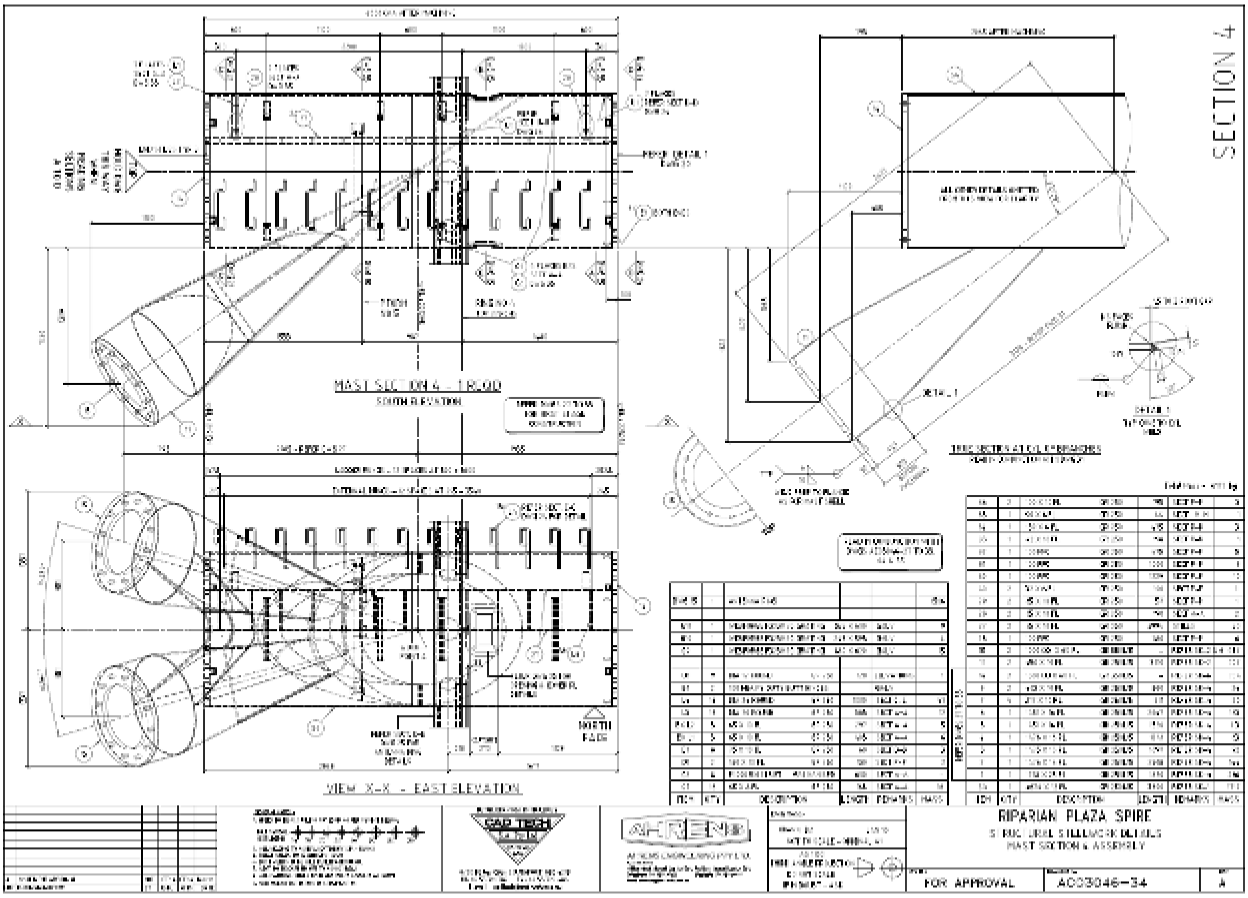


Figure 9 Structural steel work details – Mast Section 4 assembly

The design also considered the maintenance requirements for the spire. There was the initial requirement for 3 inspections over the first 2 years in order to check the bolt tensioning, to ensure that no movement had occurred and that the bolts were not overstressed etc. The long term maintenance schedule requires the next inspection to occur in 2020. To facilitate the maintenance process and to minimise the risk of working while exposed at height, the tower was fitted with an internal ladder system and bottom access door (see Figure 10 & 11).

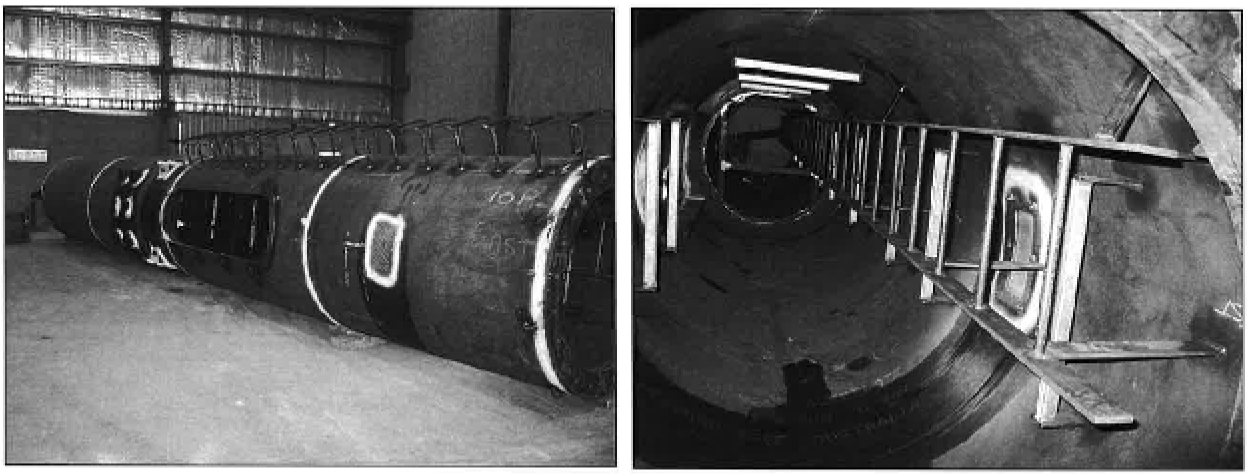


Figure 10 Internal access ladders

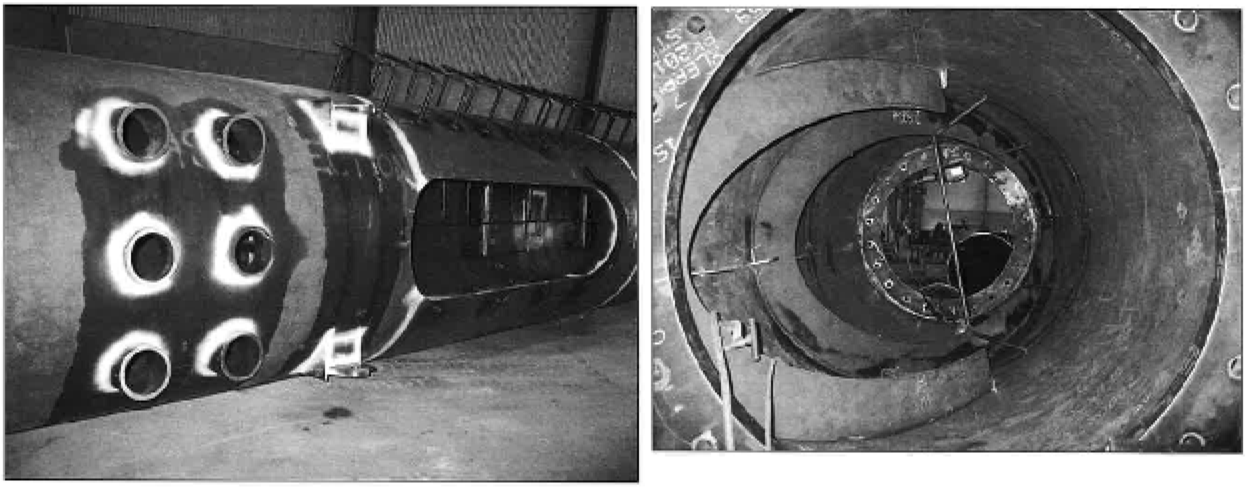


Figure 11 Bottom access door / mid section for strut connection

Transportation

A specialised tank carrier was used to transport the spire sections from the painters to the site (see Figure 12).This tank carrier transported the sections in one day during the hours of 2am to 6am to avoid causing traffic congestion.

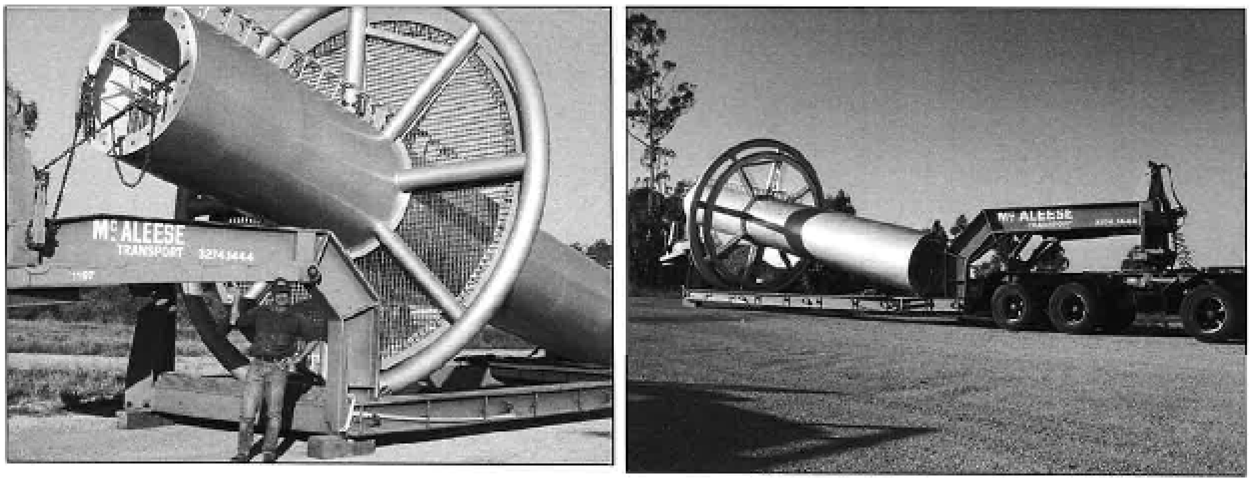


Figure 12 Transportation of the spire section to the site

On-site assembly

The two tower cranes on the site were used to lift and assemble the spire (see Figure 13). The size and weight of the individual sections was determined by the capacity of the tower cranes which was restricted to a maximum lift of 8 tonnes.

Figure 13 On-site assembly

.

Results and Business Impacts

Key Findings

For the Stadium Australia project, Ahrens, in conjunction with the structural engineer, were able to provide innovative design solutions to facilitate the roofing configuration. These achievements included:

- The client saving 2/3 of the cost of the original design.
- The construction not disrupting the operation of the stadium at any time;
- The owner achieving an increased stadium capacity (30000 extra undercover seats).
- All roofing sections were fabricated in Adelaide in transportable sections.
- The peripheral truss was made in transportable sections with bolted connections for ease and speed of erection onsite.
- Specially designed aluminum extruded glazing sections were developed to enable the fixing and sealing of the poly carbonate roof sheeting.

Other innovations that were realized by this project included: new use of materials and new fabrication.

For the Riparian Plaza Spire project, the achievements included:

- Cost effective construction
- Innovative design solutions
- Simple fabrication techniques
- Sustainable product design
- Significant architectural impact on the community
- Landmark structure (Tallest structure in Brisbane at the time.
- Providing an enhanced level of communication ability for the national network
- The facilitation of the tower maintenance system as part of the design consideration.

Business Impacts

Although both projects were comparatively small in terms of budget (neither project exceeded A$10million), they were good examples of how the application of Open Building Manufacturing principles can achieve significant community benefits.

Ahrens gained significant economic benefits from both projects and was able to provide extra jobs with increased skill sets. Similarly, both the industry and the broader community benefited from the innovations that emanated from the projects which are being adopted d by the industry at large thereby bringing about changes in construction and design practice.

Conclusions

This research employed a case study approach to investigate the adoption of open building manufacturing practices in two small scale projects, namely the Stadium Australia re-configuration and the Riparian Plaza Spire. The results indicate that Ahrens, albeit a relatively small company, has developed and embraced open building manufacturing techniques and uses them in their construction projects. Being a vertically integrated company with its own manufacturing facility has provided Ahrens with an advantage in this process. The adoption of open building manufacturing practices has played a significant role in the success of both projects for Ahrens. Interestingly it was the success that Ahrens had with this approach in the Stadium Australia project in Sydney that led to them being awarded the contract for the Riparian Plaza Spire project in Brisbane. It would be fair to say that Ahrens have developed a reputation for being innovative and being able to handle complex construction projects. Their ability to use open building manufacturing techniques has been a significant driver in Ahrens achieving this reputation and is now making them a highly sought out contractor.

The changes in construction and design practice that are emanating from the adoption of open building manufacturing techniques are also having an impact on the community at large as more and more organisations adopt the new techniques.

There are significant research opportunities to investigate how better to engage Small and Medium Enterprises (SMEs) in open building manufacturing practices and how to better adopt these practices in small scale projects. Further projects should be studied in order to obtain more empirical evidence.

Practical Tips

- The industry needs to be encouraged to expand its adoption of open building manufacturing practices from large scale projects to include small scale projects.
- The builder needs to understand the client's needs as early as possible in order to facilitate the incorporation of open building manufacturing strategies in the project.
- The builder needs to work more collaboratively with the architects, engineers and suppliers in order to realize the benefits of adopting open building manufacturing processes.
- The development of in-house research and development resources by builders helps to achieve the objectives and requirements of open building manufacturing.

Acknowledgements

The authors would like to acknowledge Mr. Murray Ellen, from s2 Corporation as the structural designer of the northern and southern roof structures for the Stadium Australia Re-configuration project. Similarly, the authors acknowledge the Ahrens Group for their approval to access and use the relevant project documents.

References

Eichert, J. & Kzi, A.S. (2007) *Vision and strategy of Manubuild – Open Building Manufacturing*, in Kazi, A.S., Hannus, M., Boudjabeur, S., and Malone, A. (ed.) Open Building Manufacturing: Core Concepts and Industrial Requirements, ManuBuild. ISBN: 978-951-38-6352-4 (Print); ISBN: 978-951-38-6353-1 (Electronic).

Manley, K. (2006) Post-tensioned steel trusses for long span roofs, The BRITE project: Innovation Case Study 9, CRC Construction Innovation, Icon.Net: Brisbane.

Tam, V.W.Y. & Tam, C.M. (2007) *Cutting construction waste by prefabrication*, in Kazi, A.S., Hannus, M., Boudjabeur, S., and Malone, A. (ed.) Open Building Manufacturing: Core

Concepts and Industrial Requirements, ManuBuild. ISBN: 978-951-38-6352-4 (Print); ISBN: 978-951-38-6353-1 (Electronic).

Thompson, S. (2007) Creating Places: Sustainable Communities Using An Open Building Manufacturing Approach, Proceedings of the 1st Manubuild International Conference, The Transformation of the Industry – Open Building Manufacturing, Doelen Congress Centre, Rotterdam Netherlands, 25th – 26th April 2007.

Van Wyk, L. (2007) A framework for open building manufacturing systems in South Africa, Proceedings of the 1st Manubuild International Conference, The Transformation of the Industry – Open Building Manufacturing, Doelen Congress Centre, Rotterdam Netherlands, 25th – 26th April 2007.

Zuo, J. and Zillante, G. (2007) *The Project Culture – Forces behind the Optimum Project Performance*, in Kazi, A.S., Hannus, M., Boudjabeur, S., and Malone, A. (ed.) Open Building Manufacturing: Core Concepts and Industrial Requirements, ManuBuild. ISBN: 978-951-38-6352-4 (Print); ISBN: 978-951-38-6353-1 (Electronic).

Author Biographies

Dr Jian Zuo has a PhD from the University of South Australia and a Masters degree in Engineering from Wuhan University, in the Peoples Republic of China. Currently he is a lecturer and researcher in the School of Natural and Built Environments His main research interests relate to the impacts of cultural factors and procurement approaches on the performance of construction projects.

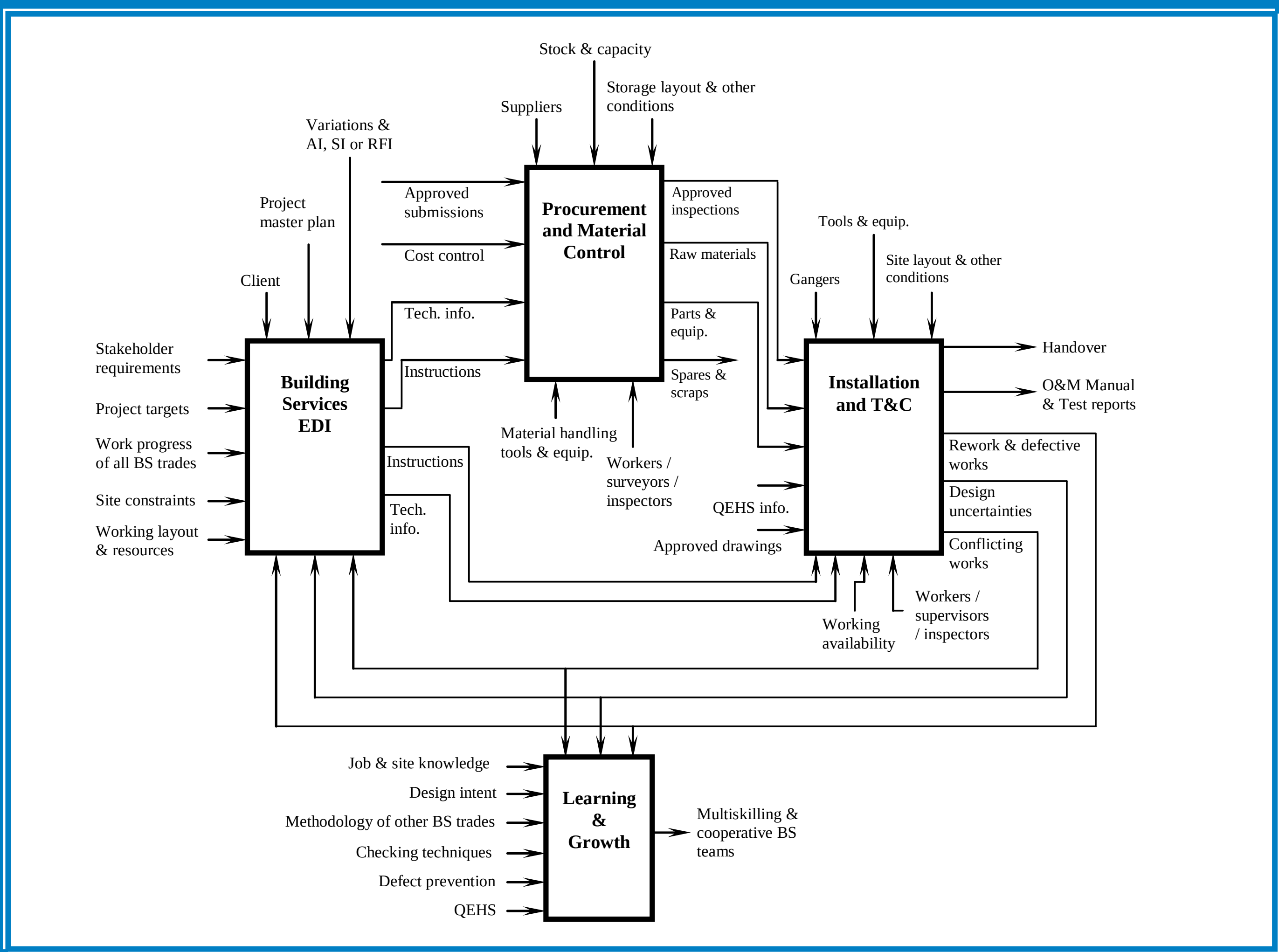
George Zillante is Associate Professor and Head of Building at University of South Australia. He has qualifications in Architecture, Urban & Regional Planning, Building Surveying, Business Administration and Construction and has worked (and continues to work) at the professional level in those fields. 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 and Organisational Change. George is also a member of several Professional Bodies (RICS, AIBS, AIB, ACCE etc) and serves on a number of Education and Accreditation Committees.

Mark Smeaton, Construction Director, takes the lead role in the Ahrens Construction Division and also serves on the Ahrens Board of Directors. Mark joined Ahrens in 1998, offering 20 years worth of practical construction industry experience and specialist expertise in industrial building design and construction. Starting as company Project Manager in 1998, Mark was quickly promoted to Senior Project Manager. Five years of consistent and impressive performance culminated with the completion of several complex and challenging projects and in 2004 Mark was asked to take on the role of Construction Manager. His innovative approach and ability to lead the construction teams to achieve consistent delivery of quality projects consolidated Ahrens reputation as a competent, solutions oriented construction company, a company with the capability to deliver anywhere in Australia including remote and rural environments. In 2007 Mark was promoted again, developing a National construction strategy and overseeing all operational activities in the rapidly expanding Ahrens Design and Construct division. As leader of the Ahrens Construction teams, Mark is an experienced and skilled leader who combines specialist technical expertise with excellent people management skills to produce the teamwork and customer service that is the Ahrens trademark.

6

Industrial Management Approaches for Improving Building Services Works in Hong Kong

Sammy K. M. Wan, Mohan M. Kumaraswamy, and Davis T. C. Liu



Industrial Management Approaches for Improving Building Services Works in Hong Kong

Sammy K. M. Wan, Analogue Group of Companies, Hong Kong (sammywan@atal.com.hk)

Mohan M. Kumaraswamy, The University of Hong Kong, Hong Kong (mohan@hkucc.hku.hk)

Davis T. C. Liu, Construction Workers Registration Authority, Hong Kong (davisliu@cwra.org.hk)

Abstract

Few studies have been done on the causes of production shortcomings of the building services subsector in the construction industry in Hong Kong despite its comparably poor performance in this respect, and secondly its contribution in terms of volume of material wastes dumped in landfills. This chapter will present the findings of a Hong Kong based survey of the major production shortcomings in this subsector during the various stages of construction. It is shown how these production shortcomings may be reduced by introducing and applying modified industrial manufacturing management concepts in this subsector, as consolidated in a 'dynamic production cell' that is presented in this chapter. The adaptation of several industrial management principles and tools such as, 'material tracking system', 'dynamic coordination buffering' and 'self-governing' are described from a conceptual-academic starting-point. With the successful application of these industrial management approaches, together with rapidly emerging open building manufacturing concepts, it is submitted that the volume of production shortcomings in the building services subsector can be substantially reduced. This should increase production efficiencies, thereby reduce wasted time and resources, as well as reduce physical material waste / debris contributions to the environment.

Keywords: building services, dynamic coordination buffering, hybrid push-pull system, industrial management, open building manufacturing

Background

Industrial Context

In a traditional manufacturing plant, production shortcomings, which are termed 'production wastes' in this chapter, tend to increase the overall cost without adding any value to the end product as perceived by end-user customers (Ohno, 1988; Emiliani, 1998; Womack and Jones, 1996). Once production shortcomings are identified, they can then be minimized via the adoption of industrial considerations or knowledge (Going, 1977). Construction can be viewed as another type of manufacturing, in converting raw materials into final products. It is therefore not surprising that the construction industry has already borrowed manufacturing concepts, such as in 'lean production', adapting and applying them as 'lean construction'. However, given continuing discontent with performance levels in many construction projects, recent initiatives in 'open building manufacturing' may also be studied and adapted to provide further impetus towards increased efficiencies and reduced waste in the construction industry.

Given increased demands for comfortable, safe, sustainable and functionally superior environments for work, living and leisure, the building services subsector plays an even greater role in the construction industry. However, it seems that few previous studies have probed this complex subsector and specific studies on the possibilities of applying 'industrial construction' approaches to this subsector are particularly rare. As this subsector involves the mobilisation of multiple specialist contractors with high interdependencies in the construction context, the coordination problems are more intense and challenging (Tommelein and Ballard, 1997). Any design change and/or error, in particular of ductwork or pipework installations, will lead to much repetitive works, reworks or non-value-adding demolition and replacement. On the other hand, when conflicts are discovered in the field, it is usually too late to avoid some form of interruption and delay (Riley and Horman, 2001). It was therefore felt that studying the production shortcomings of this subsector in Hong Kong may draw out some appropriate mitigation measures. Turning to the manufacturing industry, wise use of 'dynamic buffering' (i.e. providing variable buffer sizes) can protect the project from being disrupted by failures through earlier coordination with other trades in this subsector, rather than accumulating and passing on problems to subsequent activities. The adaptation of this conceptual buffer by a 'self-governing' work team, with reliable information exchange during production can be revamped for 'smoothing' repetitive building services production in typical construction units with multiple feedback and learning in order to encourage 'fairly' repetitive open manufacturing in the construction industry. In this context, the ManuBuild open building manufacturing system also provides inspiration and examples of synergising business processes and production technologies (e.g. Gibb et al., 2007), to provide more agile and value-driven approaches to greater efficiencies and less waste in the building services subsector.

The authors hypothesize that improved (more 'open' and better co-ordinated) management at various stages can help 'attack' major production shortcomings and contribute to enhanced efficiencies, as well as reduced debris. This chapter addresses the aforesaid research gap from a conceptual-academic perspective, by investigating relevant critical production shortcomings, that occur frequently and in turn generate construction debris in building services works in Hong Kong, while developing useful counter-measures that are selected and adapted from relevant industrial management initiatives.

Problem

This chapter will address the following main questions and related issues:

- What are the main causes of production shortcomings generated during the various construction stages in the building services subsector of the construction industry in Hong Kong ?
- What are the relevant industrial manufacturing concepts that may be applied in the building services subsector of the construction industry to tackle the problem of unnecessary and/or avoidable generation of production shortcomings ?
- How may the identified traditional concepts be modified to fit into the peculiarities of the building services subsector of the construction industry ?

Potential Solution

Key Requirements

A carefully designed questionnaire was issued to experienced industrial practitioners to survey the main causes of production shortcomings in the building services subsector of the construction industry during different construction stages. While the former yielded a quantitative profile, this was complemented by a qualitative 'overlay' from interviews with practitioners to collect their views on these production shortcomings.

The authors then proceeded to identify and modify relevant industrial manufacturing principles, as well as 'open building manufacturing' approaches that might help alleviate the main problems arising out of such production shortcomings.

Open Building Manufacturing

The introduction of 'open building manufacturing' approaches (see http://www.Manubuild.org), heralds a new paradigm by combining highly efficient production techniques, building concepts and business processes for improving the construction performance. It was learnt from the present multi-pronged study that a variety of industrial management strategies could be employed to improve the general production environment, in particular of the building services subsector. However, it may create other problems if the strategies are wrongly implemented without suitably attacking the critical causes of the problems. The appropriate strategic decisions should be able to pull together and motivate all employees to achieve shared objectives and create synergy (Hanna and Newman, 2003) and ultimately, develop a new 'open building manufacturing' culture among the organization.

In this paper, a 'dynamic production cell' is developed to build a foundation for us to move to a dynamic design of production investigating each area of cell operation and control, together with the building concepts of the complex building services subsector under the variable conditions likely to be encountered. By integrating all production processes as a whole, a variety of manufacturing practices are modified and adapted in an 'open building manufacturing' approach to building services installations. This should improve the flow through the system, although further research efforts are required, ideally followed by pilot testing exercises.

Providing a flexible 'cushion' against the negative impact of production disruptions and variability requires 'dynamic buffering' (Stein, 1997). Wise use of modified 'dynamic coordination buffering' protects the project from being disrupted by failures in coordinating with other high interdependent trades and/or crews in predecessor and successor activities, in particular focusing on the ceiling and crossover areas, and tight spaces and complex configurations. Barcoding is helpful for easy identification and retrieval of materials (Stukhart, 1990). This may be incorporated in the system to schedule the procurement process, and track and deliver major components and equipment strategically, with necessary support by the principal contractor for facilitating suitable access paths and handling methods. The concept of 'mistake proofing' has long been applied in the manufacturing industry to target zero defects in the production line (Shingo, 1986). To propel a 'hybrid push-pull' production environment, a 'self-check' mechanism is proposed to facilitate the immediate capture of fabrication mistakes before they become defects. A 'total productive maintenance' environment is helpful for cross-functional training and motivation of the entire workforce, in particular of the interdependent subsector trades that should be coordinated well in concurrent ceiling and routing assemblies. ‘Cross-trade checks’ can be developed based on a well-designed registration structure for skilful workers in Hong Kong.

All in all, successful adaptation of the ‘open building manufacturing’ system requires fundamental enhancement in the management skills of the building services teams, including team empowerment and development of a learning culture. Each of these requirements points to the imperative for a more interdependent, flexible and responsive structure that can accommodate with capacity to ‘push to prepare’ and ‘pull to produce’ with an open feedback and learning culture, so as to absorb conflicts, uncertainties and quality problems.

Approach

A thorough literature review was conducted to identify the factors that affect work performance as recognized by researchers and practitioners in the building services subsector. Next, a preliminary survey was conducted with 200 questionnaires sent to the senior practitioners of this subsector. A tailor-made questionnaire with a 1 to 5 scale of magnitude was used in the survey. A total of 37 questionnaires were returned and the highly rated production shortcomings in between 4 and 5 score were classified as positive responses and the survey showed that ‘coordination problem’, ‘change of design’, ‘rework and/or variation work’, ‘ineffective and/or unclear communication’, ‘delay of work activities’ and ‘excessive inspections and/or supervisions’ were found to be the most critical factors compared as perceived by the respondents, and these items contribute nearly 30% of the total production shortcomings. The study was then extended to capture the views of experienced frontline site supervisors, on production shortcomings that can be encountered at each of the different stages of the whole process flow of building services projects. These stages were defined as ‘design’, ‘submission’, ‘procurement’, ‘material control’ and ‘site installation’ (including testing and commissioning processes). Before arranging interview surveys with these frontline supervisors, a brainstorming exercise was carried out to identify the factors that affect present performance. The results of the exercise were recorded in a cause and effect diagram or ‘Ishikawa diagram’. The effect is the existence of critical production shortcomings in a building services project and the contributory causes are shown as the branches of the diagram.

The above ‘Ishikawa’ diagram was the reference tool used for interview surveys, observations and dialogues with frontline site supervisors in order to trace the real life critical production shortcomings frequently occurring at different stages of the whole process flow. An in-depth and field-based structured interview survey was conducted and 15 experienced site supervisors with around 8 to 17 years of on-site experience involved in the building services subsector were interviewed. The interviewees were asked to comment on the extent of the frequency of occurrence of production shortcomings and the importance of these causes that contribute to construction debris at various construction stages. A tailor-made questionnaire with a 1 to 5 Likert scale was used in the interview study and site observations were conducted in parallel with the interviews. The causes were analyzed by using ‘Potential Significance Index’ or ‘PSI’ ranking techniques (Enshassi et al., 2007; Kometa et al., 1994; Tam et al., 2000) to evaluate the overall rankings. While collecting and compiling the above findings, it was considered important, as also advocated by Meredith et al. (1989), to understand how industry practitioners view the findings and also the measures suggested to address some of the identified issues. A specially convened focus group meeting of senior, mid-level and frontline building services practitioners was organized to discuss the findings and review and refine the appropriateness of improvement strategies. The subsequent analysis of interview findings together with deductive reasoning in this chapter lead to the development of a dynamic production cell and recommendations of a set of 'open building manufacturing' type industrial improvement approaches for the building services subsector.

Analysis

As shown in Table 1, this chapter focuses on presenting and discussing the most critical causes of production shortcomings where the PSI ('Potential Significance Index') values are larger than 0.55 as perceived by the interviewees.

Table 1. PSIs of production shortcomings at various construction stages

Item	Description of causes	Frequency		Importance		Significance	
		Std. dev.	Mean	Std. dev.	Mean	PSI	Rank
Design Stage							
D01	Poor coordination of processes or trades	0.87	3.53	0.86	3.38	0.70	1
D03	Wrong sequence of work activities	0.70	2.82	1.09	3.27	0.60	3
D06	Poor allocation of works or resources	0.50	2.98	0.79	2.84	0.59	4
D07	Design changes and/or errors	0.57	3.09	0.71	3.53	0.65	2
Submission Stage							
S03	Design changes and/or errors	0.40	3.20	0.50	3.42	0.66	1
S05	Waiting for approval or instructions	1.07	3.26	0.60	1.87	0.55	2
Procurement Stage							
P01	Poor coordination of processes or trades	0.85	3.34	0.78	2.86	0.63	2
P04	Design changes and/or errors	0.61	3.09	0.89	3.54	0.65	1
Material Control Stage							
M01	Poor coordination of processes or trades	0.69	3.01	0.93	2.87	0.59	1
M02	Poor layout for material handling	0.79	3.09	0.45	2.29	0.56	4
M03	Unnecessary, excessive or incorrect materials	0.82	2.79	0.82	2.79	0.56	5
M10	Inadequate protection of materials	0.71	2.98	0.70	2.64	0.58	3
M11	Inappropriate site storage	0.71	2.97	0.83	2.76	0.58	2
Site Installation Stage							
I01	Poor coordination of processes or trades	0.86	3.24	0.72	3.34	0.66	2
I02	Poor layout for site installation	0.73	2.70	0.87	3.03	0.59	6
I11	Design changes and/or errors	0.90	3.02	0.99	3.24	0.63	4
I12	Errors in site fabrications	0.85	2.69	0.84	3.02	0.58	7
I13	Poor workmanship	0.50	3.01	0.60	2.88	0.59	5
I14	Defective work	0.78	2.87	0.87	3.74	0.69	1
I15	Rework or variation work	0.60	2.86	0.86	3.37	0.64	3

On the whole, the PSI values at the ‘site installation’ stage are rated higher. Apart from calculating the relative significance ratings, the degree of correlation between the rank-order of ‘frequency’ and ‘importance’ was checked statistically by means of the Spearman’s rank-order correlation coefficient. It could be concluded that the interviewees who rank high on ‘frequency’ may not tend to rank high on ‘importance’ with any strong significance. It is understandable that some causes could not reasonably produce construction debris even though the causes may occur frequently. It appears that the interviewees demonstrated their judgement based on site experience when responding to the survey. After the analysis of the findings in the subsequent section, appropriate manufacturing approaches are proposed taking into account the feedback received from the specially convened focus group meeting. Generally speaking, the suggested manufacturing decisions should be able to pull together and support / reinforce every employee to achieve shared objectives and create synergy (Hanna and Newman, 2003), and ultimately, develop a new culture of ‘industrial construction’ in this subsector.

Results and Business Impacts

Key Findings

Arising from the series of structured interviews, it was found that ‘poor coordination of processes or trades’ and ‘design changes and/or errors’ are considered the significant causes of production shortcomings at various stages. A few interviewees expressed that most of the building services trades in Hong Kong are subcontracted down to several tiers as a price-based package and the subcontracted workers often have no particular motivation to coordinate early at the planning stage on which they are working. Meanwhile, some interviewees pointed out that most of the specialist contractors are not involved in any design process, but they are required to produce shop drawings based on the designs and specifications and coordinate further installation works. The upstream design changes and/or errors, in particular of ductwork or pipework installations, will lead to much repetitive works and reworks. On the other hand, the interviewees emphasised that building services installations require good coordination, in particular of routing and coordinating pipework and ductwork. They like to have clear, responsive and consistent instructions. If not, some trades may try to work fast based on their specialist knowledge, but with probable conflicts being undetected and/or other specialist’s works being unattended. In those circumstances where the sequence of work is not strictly performed as planned, eventually, the interdependent trades may need to modify the installed works. This contributes to construction debris arising out of demolition, replacement and rework. All these negative effects in the subsector may result in poor building quality. A few interviewees explained that poor coordination may also result from conflict with other services because ductworks, pipeworks, conduit works, connecting boxes, cable trays, etc., may be shown to be neatly connected in a shop drawing, but in reality this may require significant amounts of extra space or variation works to other services in order to achieve the designated layout. Some site supervisors might dictate the actual routing and site layouts observed on site and clarification about intended routes with other trades will occur only when the services clash. These results are consistent with the findings of Tommelein and Ballard (1997) that coordination of specialist contractors is a challenging task, as most of them will be performing work concurrently and competing for site resources.

From another angle, it is also useful to consider and compare the corresponding Hong Kong survey based observations at the ‘procurement’ stage. More than 70% of the site supervisors interviewed commented that design changes can cause variations to previously approved equipment submissions, and those can well affect their procurement. Much extra time is spent by the site supervisors for investigating, administering and coordinating these varied procurement works, while on-site monitoring of the installation activities may be delegated to inexperienced or unskilled foremen. This can therefore contribute to more defective works or even reworks as the inexperienced or unskilled foremen may not be capable of identifying minor defects at the source before they develop into large defective works. It is worthwhile to mention that 'wrong selection of suppliers or subcontractors' is one of the major causes, because substandard suppliers or subcontractors are not equipped to organize and execute their works in a professional manner, hence triggering further problems such as defects, inadequate protection, excessive on-site fabrication, and poor work control. This is especially true where the specialist contractors procure materials and/or equipment for lower-tier subcontractors. Such inadequate incentives to avoid production shortcomings and protect the procured equipment or materials may attribute to more problems at other stages.

As depicted at ‘material control’ stage in Table 1, it was identified that ‘inappropriate site storage’ and ‘inadequate protection of materials’ were highly rated as perceived by the interviewees. It is believed that the site storage layout is probably arranged by the main contractor or other upstream parties, and the lack of coordinated planning with subcontractors for material handling leads to argument, waiting, interference with other trades and even damage to materials and equipment. Some 93% of the interviewees agreed that it was time consuming to collect and transport materials, tools and equipment as most of them were delivered and deposited in such a random manner. A few interviewees opined that most of the on-site storage areas were temporary, uncertain and poorly protected. Such poorly thought out on-site storage and repetitive handling of materials caused interference with other trades and/or crews and an increased risk of material damage, deterioration and misuse. This also explains why ‘poor layout for material handling’ was also highly rated in the survey.

Meanwhile, it was identified that ‘defective work’ and ‘rework or variation work’ were highly rated as major causes at ‘site installation’ stage. Nearly 87% of interviewees expressed their dissatisfaction about poor working conditions arranged by the main contractor or other upstream parties because of limited work spaces and poor work arrangements. Untidy and congested working conditions could contribute to poor workmanship and even defective works. A few supervisors pointed out that many of them might also be engaged in administrative works such as procurement, submissions, coordination meetings, logistic arrangements, etc., instead of concentrating only on on-site installation activities. This might contribute to potential defective works or even reworks if the early fabrication errors or mistakes are not captured early enough by experienced site supervisors. Additionally, some interviewees opined that the quality of skilled workers is inconsistent and no multi-skilling approaches are adopted. Several different gangs of tradesmen were observed in the study to be erecting pipe hangers during galvanised steel pipe installations. When questioned, it was evident that they had not been briefed about the existing concurrent and probable conflicting works of interdependent trades and/crews in the vicinity. The lack of knowledge of other building services trades might add to fabrication errors and potential service clashes in particular of complex routing assemblies rather than anticipation at source. Most of the site operatives received safety toolbox talk training regularly provided by the main contractor but as learned from the study, neither training nor feedback sessions was provided with respect to site constraints, workmanship, methods, daily targets, lessons learned, job progress and time arrangement. All these result in more defective works, demolition, replacement and more construction debris at the landfill sites.

Dynamic Production Cell

The lean production in the manufacturing industry combines basic industrial management principles and techniques related to production processes to reduce production wastes and improve productivity (Shingo, 1988; Schonberger, 1990; Plossl, 1991). The focus group referred to the above findings and the pillars of 'Just-In-Time' in the manufacturing industry. They went on to suggest a three-pronged guiding principle for the subsector. What seems to be important is 'do it right the first time', 'do only when necessary and conflict-free' and 'do only what will add value unless inevitable' for the entire process flow. This also relates to a 'dynamic production cell' as illustrated in Figure 1 after investigating each area of complex linkages and relationships among various stages in a typical construction cycle under the constraints of this subsector. By regarding this 'cell' as a manufacturing cell, it may provide necessary guidelines for the dynamic control of production shortcomings, which help alleviate and reduce the impacts of the most significant causes as identified in the study. There will be inputs and outputs in connection with the identified four major phases, namely, 'building services engineering design interpretation', 'procurement and material control', 'installation and testing & commissioning', and 'learning and growth'.

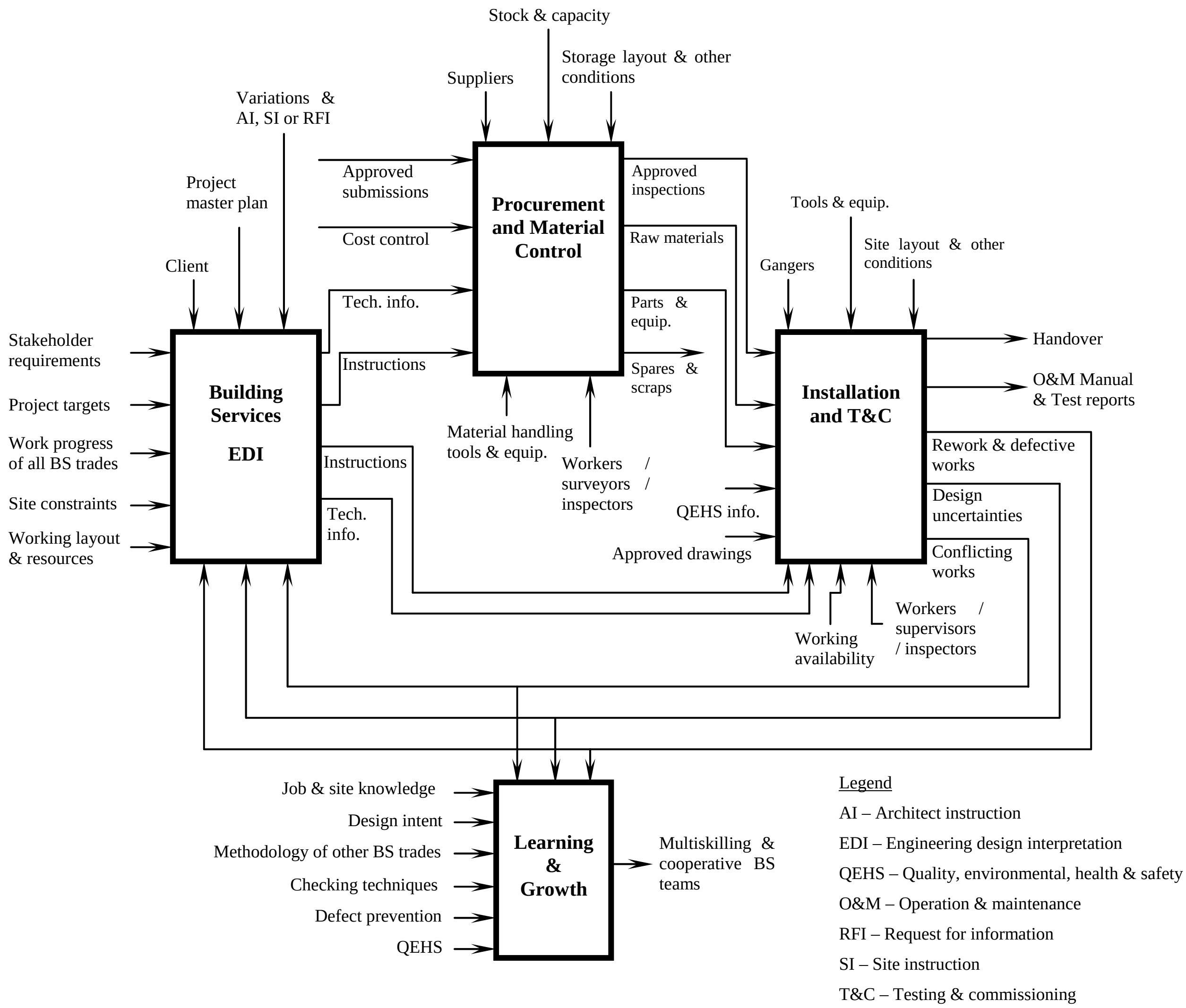


Figure 1. The dynamic production cell of the building services subsector

At the ‘engineering design interpretation’ phase, carefully chosen, expert and timely information is fed to the design team to avoid potential design changes and/or errors, delayed instructions and approval and consequential wrong sequence of work activities. Such information may include stakeholders’ requirements from the end-users, the government, or even the general public, project plans and targets as developed by the design and construction teams from time to time, regular feedback from the construction team to the design team, important knowledge gained in the different phases, etc. The design team will make accurate, clear, substantial and timely information to the construction team, including approval, instructions, variations, etc.

At the ‘procurement & material control’ phase, the construction team will take the lead to work closely with the design team to clarify any design changes and ambiguities in the associated technical information, and with the prospective suppliers to develop the necessary equipment, materials, products, tools, etc., to be delivered to site on time and in order for installation, with an aim to accommodate the inevitable design changes and/or errors, to avoid defective, excessive, incorrect or unnecessary deliveries, and to eliminate rework or variation work. The construction team will also coordinate among themselves in respect of the storage layouts, delivery schedules and inspection schemes with better and improved communication channels and information to reduce damage to stored items and installed works.

At the ‘installation and testing & commissioning’ phase, the construction team will play an aggressive role in securing the approved submissions from and clarifying any design changes and unclear information with the design team so that the potential problems pertinent to design may be resolved as early as possible to avoid rework or variation work. The construction team will also make efforts in coordinating the works among themselves with committed and true partnership spirits to produce a comfortable and harmonious working environment.

It will be an utter waste if the teams have not undergone the ‘learning and growth’ phase during and after the construction cycle. Any single piece of learnt information may be worth reviewing in this phase so that a real knowledge centre is created for the benefit of the current and future projects to bring about the ultimate goals of multi-skilling and cooperative building services teams.

Industrial Management Approaches

Following the guiding principles as illustrated by the ‘cell’ above, and necessary deductive reasoning, appropriate industrial management approaches were selected and proposed to address the identified major causes of production shortcomings when planning and executing a building services project.

A few researchers acknowledge that design coordination is more important to allow each trade of the building services subsector to plan collaboratively for the materials and processes that are intended for shared spaces and resources in a building to make sure they will not conflict physically, or impair the installation and maintenance of subsequent systems (e.g. Ahmed, 1992; Mokhtar et al., 1998; Riley, 2000; Riley and Horman, 2001, etc.). However, unless exact field dimensions are obtained, it does not appear possible for the specialist contractors to complete design details (Tommelein, 1998). Meanwhile, building services projects are always associated with interdependent activities to be completed both consecutively and concurrently. Very often, the contractors in this subsector are required to deliver more than one project at the same time, whereas resources are rarely shared properly among projects.

To alleviate the problems, the barcode asset management system that has been recommended in the ‘BSRIA Guidance Note – ACT 5/2002’ can help to streamline the processes of procurement, delivery, installation and inspection on site, and to reduce time on site collecting, handling, monitoring, controlling and re-ordering effectively and productively (Dicks, 2003). Applying deductive reasoning, it is proposed that large building services component and equipment items may be coded and ‘tagged’ so that their status can be retrieved readily on line to save a tremendous amount of time and efforts in scheduling procurement processes, tracking construction materials, delivering directly to point of use or planned strategic locations, taking into account access paths and handling means, and transferring real-time data of receiving inspections via intranet and/or internet. As a result, the opportunities for damage, misuse, over-supply and vandalism can be significantly reduced, and more resources can then be diverted to the value-adding works to improve work productivity. The ‘material tracking system’ is conceptualised to assume the responsibilities of the ‘material adviser’ as long advocated by Illingworth and Thain (1987). This may contribute to manage information relating to the material schedule, storage plan, inspection plan, site and resources availability, weather and traffic condition, etc., before making appropriate delivery and storage decisions and generating reports and inspection logs.

The project buffer is designed to protect against variations of either special causes or common causes in the critical chain activities and this project buffer is traditionally allocated at the end of the activity as a contingency. However, Sterman (2000) pointed out that people may always perceive that there is extra time for completing the activity and they tend to defer the activity until the 'last minute' (Park and Peña-Mora, 2004). ‘Dynamic buffering’ is one of the methods used to improve the buffering process in manufacturing (Stein, 1997). In order to systematically protect the whole project schedules, Park and Peña-Mora (2004) made an inspiring suggestion on adopting a ‘reliability buffer’ for advancing ‘dynamic buffering’ by flexibly releasing project buffers that are fed explicitly or implicitly into individual activities and feeding those buffers (termed as ‘reliability buffer’) in front of the successor activity. This reliability buffer can deal with the issue of ill-defined tasks in the successor activity. The suggestion of Park and Peña-Mora is extended by the authors of this paper to develop a ‘dynamic coordination buffer’. Based on deductive reasoning, this is useful for absorbing variations and/or uncertainties.

By introducing a coordination buffer in front of the initially planned activity, it is possible to thoroughly review and resolve all design or related uncertainties, allocate adequate resources, and prepare and coordinate with other trades and/or crews to reduce any interference or conflict at the same work area, in particular of concurrent ceiling works, ductworks, pipeworks and conduit works, prior to the start of activities. On the other hand, there would be another coordination buffer as a ‘self-check’ buffer that can enable early capture of any process errors and/or mistakes, rather than accumulating problems to the subsequent activity. In this way, the location and size of buffers are dynamically updated based on the actual coordination performance. It may overcome the ‘last minute syndrome’ as people may realize that they have less time to complete an activity. Of course, if the preceding activity finishes early, the buffers are adjusted dynamically to take advantage of such an early finish without probable conflicts and/or services clashes, and the whole programme may move quickly to the next activity.

Some interviewees identified in the study that some trades in the subsector may try to work fast if the resources are available even if the exact location of various services are not clearly defined. An extreme case as quoted during the structured interviews related to a large-scale plumbing and drainage installations at a new residential development in Hong Kong where two ‘workteams’ worked in parallel to install horizontal and vertical pipes at different blocks. Even though they were working at typical floors, deviations still occurred between these two teams, which ended up with non value-adding demolitions and modifications. This leads us to consider the proposed ‘dynamic coordination buffer’ in not limiting to resolve uncertainties, conflicts and tolerances among interdependent trades prior to installation works, but in also using it to activate a communication and cooperative culture where workers are encouraged to work together and interact across small ‘workteams’, including across functions / trades, levels, and work areas (including apartments / floors).

Without reliable and predictable flow, lean production is probably doomed to failure. The building services installations in typical construction units, start from the lowest floor and then continue upwards unit by unit, can be seen as repetitive and overlapping production in which repetitive manufacturing can be employed. Having set up the framework of ‘dynamic coordination buffer’, a ‘pull’ system looks at the production process from the other end from the perspective of the successful finished task of each construction unit. As a ‘hybrid push-pull’ system as shown in Figure 2, if the activities finish on time without conflict and uncertainty, then the buffers allocated will still have to be updated dynamically.

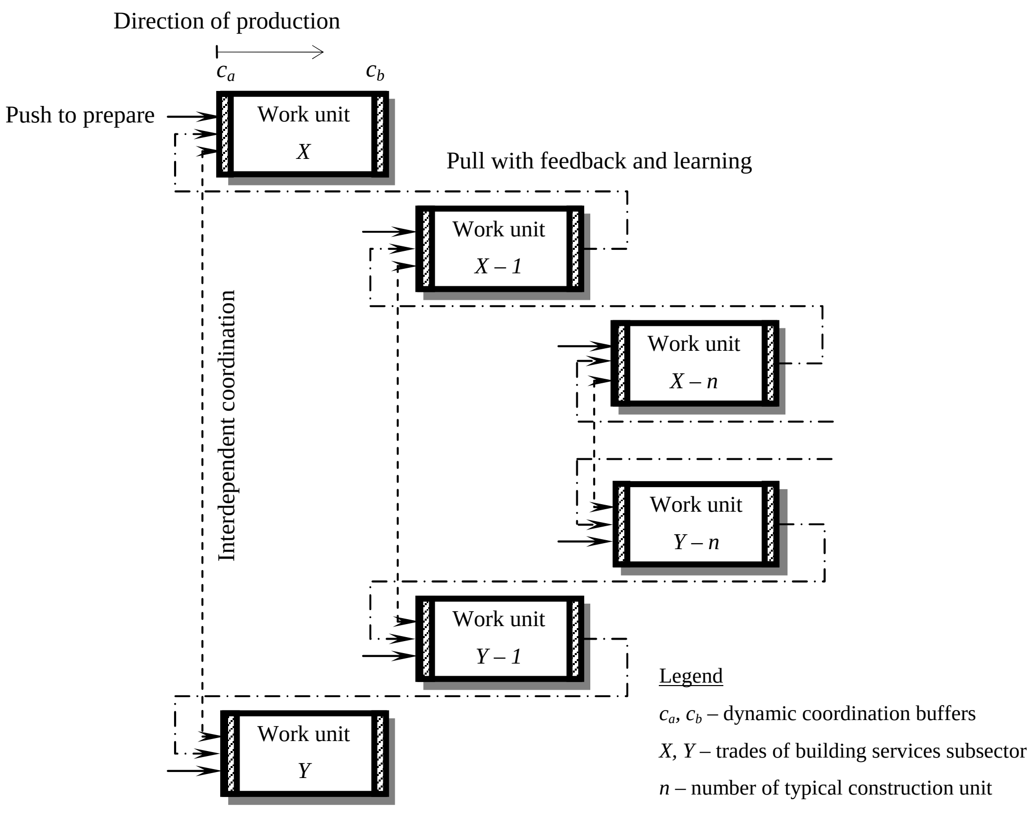


Figure 2. Adaptation of industrial flow pattern for repetitive production of typical units

The resources can move straight away to the similar activities of another unit, thus pulling that unit tasks earlier in time with a similar buffer updated dynamically. The c_a allows us to ‘push’ the engineer-in-charge to thoroughly review and resolve all uncertainties or interdependent conflicts and allocate adequate resources prior to the start or ‘pulling’ of activities. Multiple feedback and learning between construction units help continuously improve the workmanship and more importantly, inform instantaneously any probable interdependent assembly conflicts, fabrication errors and design changes, and share coordination experience among other trades at the site in order to avoid the same problems in other units, and to reduce the opportunity of construction failures. This attempts to support the arguments as made by Kumaraswamy et al. (2004) that late or absence of notification of design changes and reliable construction information may increase the incidence of wastage due to rework at site, and Sacks and Goldin (2007) that works should be pulled according to the maturity of the client's design changes. The c_b acts as another buffer for 'self-check' or 'cross-check' to capture errors and/or mistakes rather than accumulating problems. This relates to the mistake proofing checks that may be employed in reducing construction project failures as claimed by Wan et al. (2006) This also attempts to link and mobilize the long established mistake proofing concept in manufacturing to target zero defects (Shingo, 1986).

Of course, a 'self-governing' work team is required to conduct the aforesaid 'self-check' and/or 'cross-check'. Actually, multi-skilled deployment of tradesmen is valuable in identifying fabrication errors and potential service 'clashes' arising from interdependent subsector trades (Hawkins, 1997). The Construction Workers Registration Scheme, launched recently in Hong Kong, is valuable for maintaining the basic skill levels of building services workers, before acquiring extra skills for mistake proofing checks, as in those largely applied in the manufacturing industry to improve production reliability and smoothness. As the first region adopting such a registration scheme in the world, the legislation backed scheme is useful for improving the quality of construction works through assessment and certification of the skill levels of all trades, albeit not limited to building services workers such as fitters, wiremen, assemblers, jointers, mechanics, plumbers, drainlayers, etc.

With an efficient 'material tracking system', 'dynamic coordination buffering' and 'self-governing' multi-skilled work teams, a more reliable production system may be achieved. By setting up a daily production rate for repetitive production of typical construction units at the same building, the pace of production depends on the smoothness of the works. Conflicts and quality problems may slow down the production rate or even suspend the work by allocating resources to resolve troubles immediately and updating buffers and time of 'push to prepare' dynamically. Typically, the building services installations may start in parallel for typical units by a few teams, or start by one team at a rate of unit by unit. Each unit may act as a 'rope' to 'pull' the preceding unit working in parallel to adjust the production rate and allocate buffers, or 'pull' another unit not yet commenced to start installations with updated parameters. Through the feedback and learning mechanism in the system, it means that neither the unit nor the work team should produce services or work faster. The pace of production depends on the absence of design and/or other uncertainties, thoroughness of client and/or site instructions and robustness of the site installations. An open learning culture is envisaged in this conceptual model where workers are encouraged to benefit from learning among 'intra' and 'inter' dependent teams. This ties in well with the 'open building manufacturing' approaches, while tallying with the 'intra- and inter-team communication systems' in concurrent project management (Jaafari, 1997). This also builds up an environment for fairly repetitive manufacturing by transferring smoothly between different units of the building.

Business Impacts

The findings and proposed industrial management approaches widen our understanding of production shortcomings and their degrees of significance in the building services subsector in Hong Kong. While the weightings of the attributes were based on the perception of the present respondents, these can be adjusted to suit different scenarios. Furthermore, all the findings could be a useful comparative reference for other countries, where the study methodology may be replicated to generate region-specific findings. By applying the suggested proposals at various stages of a construction project, this important, but little studied subsector can contribute to both reducing production shortcomings, and lessening the burden on local landfills. The proposed approaches may assist in capturing the process errors and mistakes early enough, in order to protect a project against variations in the critical chain activities. At the same time, the 'self-checks' and 'cross-checks' provide instantaneous feedbacks at site installation stage before defects materialize. The recently launched workers registration scheme in Hong Kong and emerging material tracking system are also valuable in facilitating the proposed industrial improvement approaches. All these ultimately lead to the proposed 'hybrid push-pull' system that combines the best features of the two separate systems in this particular subsector. Under this system, most 'conflicts' between competing resources and storage areas, including dimensional tolerance conflicts and design misinterpretations should be rectified before site installation. This contributes to the early mobilization of specialist contractors to resolve uncertainties and reduce rework and synchronization of sub-processes between trades and/or crews. The manufacturing industry has started a long journey toward lean production. The use of the proposed 'dynamic production cell' and other proposed approaches in this chapter may help to move towards the waste-reducing and value-adding systems of 'industrial construction', although further research efforts are still required and indeed ongoing.

Conclusions

While the construction industry itself has come under criticism for under-performance in many countries, it is also generally acknowledged that its building services subsector is not performing well, and is one of the major contributors to construction debris dumped into landfills. It was identified in a recent Hong Kong based survey that production shortcomings in the building services subsector were mainly caused by 'poor coordination of processes or trades', 'design changes and/or errors', 'defective work' and 'rework or variation work'.

Drawing on long established industrial management principles and more recent 'open building manufacturing' approaches, some particularly useful concepts have been selected and modified in this chapter for tackling the identified problems and causes of production shortcomings. The authors advocate adoption of a 'material tracking system', 'dynamic coordination buffering' and 'self-governing' multi-skilled work teams with reference to a 'dynamic production cell'. If implemented as envisaged, this could herald a new era of 'industrial construction' with a revamped and far more efficient production system, benefiting from open building manufacturing approaches, and reducing both physical and production wastes.

Practical Tips

- The major production shortcomings to be overcome in the building services subsector at its various construction project stages are: ‘poor coordination of processes or trades’ and ‘design changes and/or errors’.
- The major production shortcomings to be overcome at the ‘material control’ stage in particular are: ‘inappropriate site storage’ and ‘inadequate protection of materials’.
- The major production shortcomings to be overcome at the ‘site installation’ stage in particular are: ‘defective work’ and ‘rework or variation work’. .
- The proposed ‘dynamic production cell can be beneficially applied, together with ‘open building manufacturing’ approaches in the building services subsector to provide guidelines for the dynamic control of the identified production shortcomings.
- A more reliable production system can be achieved through the adoption of the proposed ‘material tracking system’, ‘dynamic coordination buffering’ and ‘self-governing’ multi-skilled work teams.

Acknowledgements

The authors are grateful to the industry practitioners who contributed their time and knowledge to this case study. Grant HKU7138/05E of the Hong Kong Research Grants Council, Analogue Group of Companies and Construction Workers Registration Authority are also acknowledged.

References

Ahmed, S. (1992) Transaction Issues in Collaborative Engineering, *Journal of Computing in Civil Engineering*, Vol. 124, No. 1, pp. 18-24.

Dicks, M. (2003) Innovative M&E Data Sheets, *BSRIA Guidance Note ACT 5/2002*, Berkshire: BSRIA.

Emiliani, M.L. (1998) Lean Behaviours, *Management Decision*, Vol. 36, No. 9, pp. 615-631.

Enshassi, A., Mayer, P.E., Mohamed, S., and El-Masri, F. (2007) Perception of Construction Managers Towards Safety in Palestine, *The International Journal of Construction Management*, Vol. 2007, pp. 41-51.

Gibb, A., Austin, S., Dainty, A., Davison, N. and Pasquire, C. (2007) Towards Adaptable Buildings: Pre-configuration and Re-configuration – Two Case Studies, *Proceedings of the ManuBuild 1st International Conference on The Transformation of the Industry: Open Building Manufacturing*, 25-26 April 2007, Rotterdam, pp. 1-12.

Going, C.B. (1977) Principles of Industrial Engineering, New York: McGraw-Hill.

Hanna, M.D., and Newman, W.R. (2003) Operation Management, Upper Saddle River, NJ: Prentice Hall.

Hawkins, G. (1997) Improving M&E Site Productivity, *Technical Note TN 14/97*, Bracknell, Berkshire: BSRIA.

Illingworth, J.R., and Thain, K. (1987) The Control of Materials and Waste, *CIRIA Special Publication 56*, Berkshire: CIRIA.

Jaafari, A. (1997) Concurrent Construction and Life Cycle Project Management, Journal of Construction Engineering and Management, Vol. 123, No. 4, pp. 427-435.

Kometa, S.T., Olomolaiye, P.O., and Harris, F.C. (1994) Attributes of UK Construction Clients Influencing Project Consultants' Performance, *Construction Management and Economics*, Vol. 12, No. 3, pp. 433-443.

Kummaraswamy, M.M., Ng, S.T., Ugwu, O.O., Palaneeswaran, E. and Rahman, M.M. (2004) Empowering Collaborative Decisions in Complex Construction Project Scenarios, *Engineering, Construction and Architectural Management*, Vol. 11, No. 2, pp. 133-142.

Meredith, J.R., Raturi, A., Amoako-Gyampah, K., and Kaplan, B. (1989) Alternative Research Paradigms in Operations, *Journal of Operations Management*, Vol. 8, No. 4, pp. 297-326.

Mokhtar. A., Bedard, C., and Fazio, P. (1998) Information Model for Managing Design Changes in a Collaborative Environment, *Journal of Computing Civil Engineering*, Vol. 12, No. 2, pp. 82-92.

Ohno, T. (1998) Toyota Production System, Portland, OR: Productivity Press.

Park, M., and Peña-Mora, F. (2004) Reliability Buffering for Construction Projects, *Journal of Construction Engineering and Management*, Vol. 130, No. 5, pp. 626-637.

Plossl, G.W. (1991) Managing in the New World of Manufacturing: How Companies can Improve Operations to Compete Globally, Englewood Cliffs, NJ: Prentice-Hall.

Riley, D.R. (2000) Coordination and Production Planning for Mechanical, Electrical and Plumbing Construction, *Proceedings of the ASCE Construction Congress VI*, Orlando, FL.

Riley, D.R., and Horman, M.J. (2001) Effects of Design Coordination on Project Uncertainty, *Proceedings of the 9th Annual Conference of the International Group for Lean Construction (IGLC-9)*, Singapore.

Sacks, R., and Goldin, M. (2007) Lean Management Model for Construction of High-rise Apartment Buildings, *Journal of Construction Engineering and Management*, Vol. 133, No. 5, pp. 374-384.

Schonberger, R.J. (1990) Managing in the New World of Manufacturing, Englewood Cliffs: Prentice Hall.

Shingo, S. (1986) Zero Quality Control: Source Inspection and the Poka-yoke System, Cambridge, MA: Productivity Press.

Shingo, S. (1988) Non-stock Production, Cambridge, MA: Productivity Press.

Stein, R.E. (1997) The Theory of Constraints: Applications in Quality and Manufacturing (2nd ed.), NY: Marcel Dekker.

Sterman, J. (2000) Business Dynamics: System Thinking and Modelling for a Complex World, NY: McGraw-Hill.

Stukhart, G. (1990) Bar-code Standardization in Industrial Construction, *Journal of Construction Engineering and Management*, Vol. 123, No. 2, pp. 171-180.

Tam, C.M., Deng, Z.M., Zeng, S.X., and Ho, C.S. (2000) Quest for Continuous Quality Improvement for Public Housing Construction in Hong Kong, *Construction Management and Economics*, Vol. 18, No. 4, pp. 437-446.

Tommelein, I.D. & Ballard, G. (1997) Coordinating Specialists, Technical Report 97-8, CEM Program, University of California, Berkeley.

Tommelein, I.D. (1998) Pull-driven Scheduling for Pipe-spool Installation: Simulation of a Lean Construction Technique, *Journal of Construction Engineering and Management*, Vol. 124, No. 4, pp. 279-288.

Wan, S.K.M., Liu, D.T.C. and Kumaraswamy, M.M. (2006) Reduction of Accidents in Construction Industry Through Mistake-proofing Skills to Promote Lean Production, *Proceedings of the 22nd Annual Conference of the APOSHO*, Bangkok.

Womack, J.P., and Jones, D.T. (1996). Lean Thinking: Banish Waste and Create Wealth in Your Corporation, New York, NY: Simon & Schuster.

Author Biographies

Sammy K. M. Wan

Head of Quality, Safety & Environment

Analogue Group of Companies

A qualified quality, safety and environmental practitioner engaging in building services engineering. He has been serving on numerous study groups and public committees of the construction industry in Hong Kong.

Mohan M. Kumaraswamy

Professor

The University of Hong Kong

A chartered engineer, builder and arbitrator with considerable experience in industry and academia. He is a renowned researcher in the international construction engineering and project management community.

Davis T. C. Liu

Chief Operating Officer

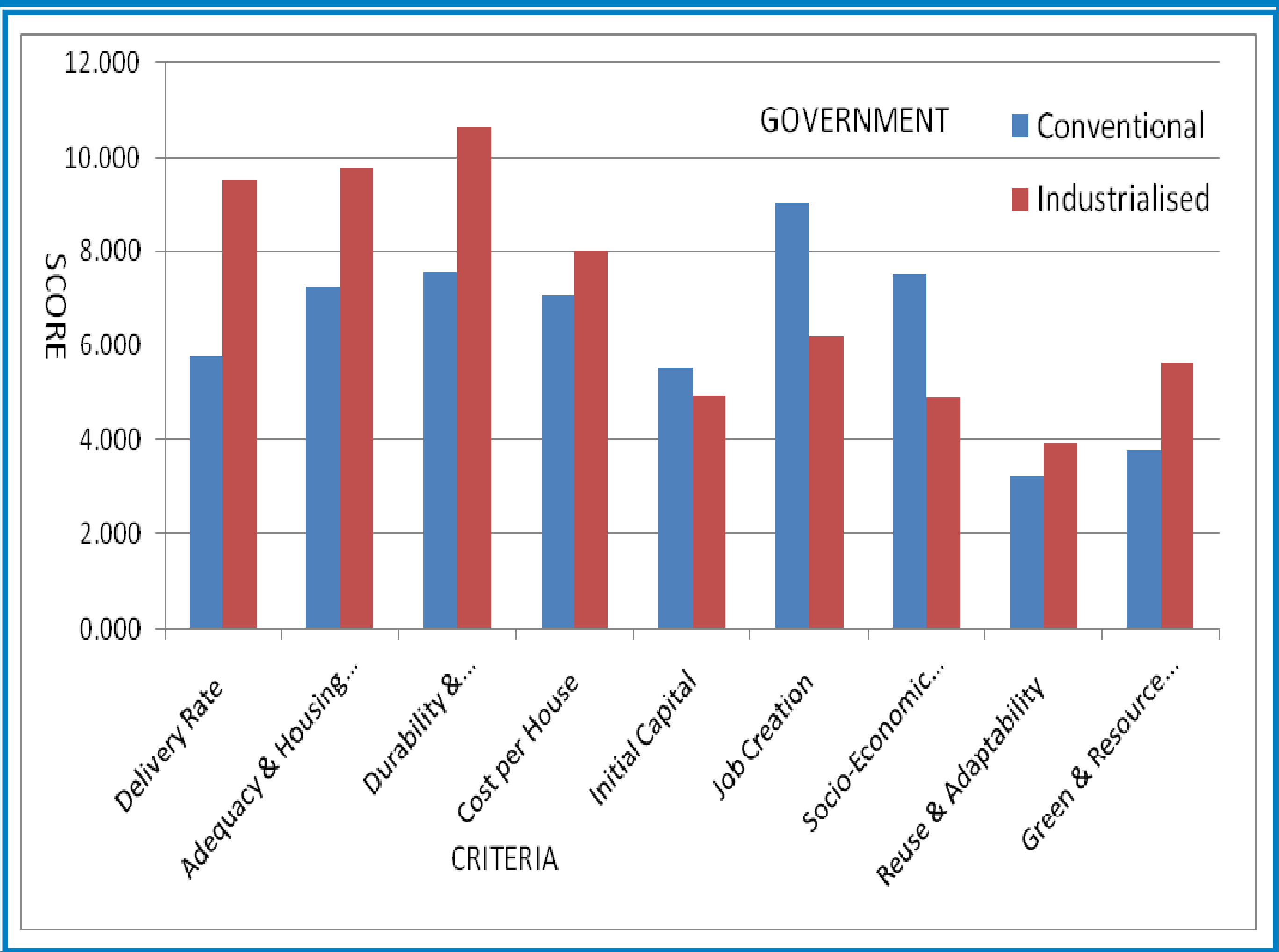
Construction Workers Registration Authority

A chartered building services engineer, quality professional and safety practitioner with a wide range of practical experience and knowledge in construction. He joined the Authority in 2007.

7

Investigating the Feasibility of Industrialised Low-Cost Housing in South Africa

Ayman Ahmed Ezzat Othman,
and Stefan Mathias Conrads



Investigating the Feasibility of Industrialised Low-Cost Housing in South Africa

Ayman Ahmed Ezzat Othman, University of KwaZulu-Natal, South Africa (aaeothman@gmail.com)

Stefan Mathias Conrads, University of KwaZulu-Natal, South Africa (stefconrads@gmail.com)

Abstract

At the dawn of democracy in South Africa in 1994, there was 1 formal brick house for every 43 Africans. Hence, the new government inherited an estimated housing backlog of 1.5 million units. Since that time, the African National Congress (ANC) adopted Reconstruction and Development Programme (RDP) which is a policy framework for socio-economic integration aimed to build 320,000 houses annually and at least 1million houses over five years. Between 1994 and 2001 about 1.129 million houses have been built, despite these efforts 2 to 3 million houses were still needed. In 1994, the Department of Housing initiated the 'White Paper' legislation which explained the situation of low cost housing in South Africa and highlighted the issue of inadequate supply and constraints of housing provision. In addition, it suggested a number of development initiatives and indicated the need for more rapid construction of houses. In spite of the current Conventional Building System (CBS) is associated with a number of problems such as slow delivery rate, poor quality standards and inefficiency, it has the benefit of creating more jobs, design flexibility and less skill dependency. Because of its capabilities to erect mass projects faster than CBS, Industrialised Building System (IBS) was used to meet the desperate need for housing the homeless followed the Second World War in many of its affected countries. Although IBS was not used widely in South Africa, it is expected to deliver fast, affordable, quality, sustainable houses that meet or exceed the expectations of end-users. To gain the benefits of both building systems, a hybrid system, that utilise the qualities of IBS and CBS, needs to be developed in order to suite the South African context. Adopting such system will achieve the government goals, benefit contractors and satisfy the needs of end-user.

Keywords: Industrialised Building Systems, Conventional Building System, Industrialised Construction Projects, Low-Cost Housing, Feasibility, South Africa.

Background

Industrial Context

Industrialised Building System is difficult to define as it can apply to such a broad spectrum in construction and therefore a variety of definitions have arisen. Kitchener (1979 cited Reddy, 1987) defined IBS as technological and managerial procedures for the repetitive manufacture and erection of buildings that are unique to and can be identified with particular building companies attached to them. Warswaki (1999 cited Hong, 2006) stated that Industrialised process is an investment in equipment, facilities, and technology with the objectives of maximising production output, minimising labour resources and improving quality while a building system is a set of interconnected elements that joint together to enable the designated performance of a building. The Malaysian construction industry defined IBS as a construction system in which components are manufactured in a factory, on or off site, positioned and assembled into structure with minimal additional site work (CIDB, 2003 cited Hamid et al., 2007). Within this chapter IBS is described as a system, that utilise technology advancement and management capabilities, to produce mass low-cost housing projects that are fast, affordable, quality, sustainable housing projects that meet or exceed the end-users expectations.

Industrialisation in building is not a new thing it has been a subject of a growing process over many years (Culpin, 1970). A long time ago in the history of the art of building, prefabrication was used in the construction of Egyptian temples and Roman edifices (Hong, 2006). The first panelised wood house was shipped from England in 1624 to provide temporary housing for fishing fleets (Culpin, 1970). In 1830s John Manning manufactured ‘Portable Colonial Cottages’ for the West coast area of Australia (Herbert, 1984). In the USA around the 1920s and the 1950s the "Packaged House" companies produced ‘factory made’ steel singular houses (Herbert, 1984). After the Second World War the immense housing shortage needed to be overcome. At this time construction methods were to a great extent craft production, which forced governments and housing producers to search for more efficient and faster methods to be able to cope with the situation. As many European countries lacked labour as well as building materials which strained the building capability. Industrialised mass production as a new construction approach offered a way to increase productivity utilising relatively minimal resources and thus seen as a viable solution to meet the enormous housing shortage (Unger, 2006). The history of prefabrication has been described as a record of successful response to the challenge of recurring crises, when local demand exceeds the local capacity to supply (Herbert, 1984).

Problem

Housing the Poor

A Global Perspective

Housing the poor is one of the greatest challenges facing the governments around the world, especially the developing countries. Slums are intolerable human dwellings, of which a few can be called houses, these are shacks or shelters that are constructed by materials found on rubbish dumps, self built and are unfit for human dwelling. These slums are inadequate and unsafe building structures, lack of basic services, especially water and sanitation, insecurity of tenure, overcrowding and located on hazardous land (UN Habitat, 2003). A house is essential for the human being to survive as food and oxygen would be, yet it is not only a physical need but is also vital for the social and physiological health of a human being. A house is a place to live our lives, to interact with others, to rest, to nurture and feed ourselves, therefore adequate houses are for our well being (Neuwirth. 2006). In 2001, 924million people, which are 31.6% of the world’s total urban population, live in slums. This is mainly due to the developing countries of which 43% of the urban population live in slums, where in contrast only 6% are slum dwellers in the developed countries. The sub-Saharan African region has the largest slum proportion of 73.2%, however Asia has the largest slum population of 554million (UN Habitat, 2003).

The Housing Problem in South Africa

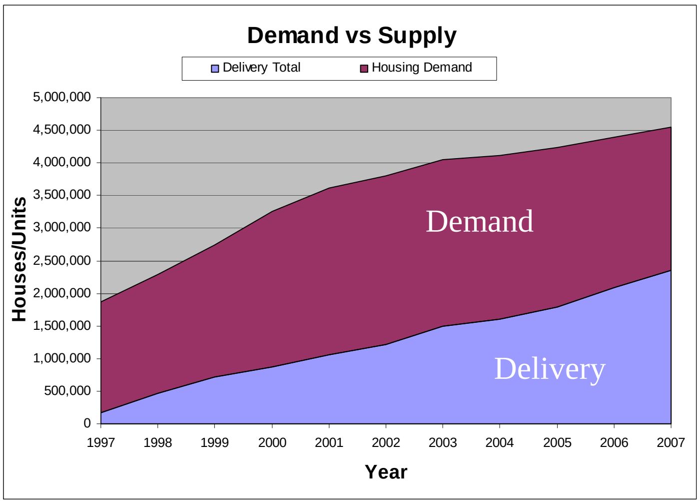
The Apartheid’s Group Areas Act was a law of segregation allocated areas according to race groups. Blacks could not live in white areas and were forced to move to townships, which were located on the outskirts of the cities. The apartheid regime built very few houses for the Blacks such that in 1994 it was estimated that only 1 formal brick house was built for every 43 Blacks, this was less than 10% of what was needed (Knight, 2001). At the dawn of democracy in South Africa in 1994 the new government inherited an estimated housing backlog of 1.5 million units.

Since that time, the African National Congress (ANC) adopted the Reconstruction and Development Programme (RDP) which is a policy framework for socio-economic integration aimed to build 320,000 houses annually and at least 1million houses over five years. Between 1994 and 2001 about 1.129 million houses have been built, a far miss from the set target (ESSA, 2005; Knight, 2001). In 1994, the Department of Housing initiated the 'White Paper' legislation which explained the situation of low cost housing in South Africa and highlighted the issue of inadequate supply and constraints of housing provision. In addition, it suggested a number of development initiatives and indicated the need for more rapid construction of houses (Department of Housing, 1994). Despite the government initiatives, many South Africans are still homeless, settlements are located far from job opportunities, shelter performance is poor, layouts are monotonous and services are inadequate (Department of Housing SA, 2002). The housing problem in South Africa has four dimensions, namely: housing delivery, cost employment and quality.

(a) Housing Delivery

The slow delivery of houses mentioned above raised the question of: "are the government delivery targets set too high or are the policies, plans, procedures and implementation thereof not efficient enough?" The 1994 delivery target, according to the National Housing policy, was calculated as follows:

- The housing backlog in 1994 was estimated at 1.5 million units. The goal was set to build 150,000 houses a year to overcome this backlog over a period of 10 years.
- New housing formation, in terms of population growth and urbanisation, required an additional delivery rate of 150,000 houses a year so that the backlog would not increase.
- The target was set to build 300,000 to 350,000 units per annum.



This gives reason for the stated delivery targets yet its reality was uncertain at the time (Department of Housing SA, 1998). In 2001, the housing backlog was estimated to be 2.5 million houses, which is a 66% increase from the initial backlog. This could have been predicted as the housing delivery rates were half of what was planned as only 1.1 million houses were built instead of 2.1 million.

Figure (1) shows the housing delivery, in 1998 as 295,811 units were built and in 1999 248,391 units. This proves that the target of 300,000 units is possible. However, 1998 was the highest delivery and the housing delivery averaged 208,856 where most years delivered less than 200,000 units. This shows that the target could not be sustained and may after all be difficult to provide.

(b) Cost

Building cost inflation is a hindrance to housing delivery as the allocated housing budgets could deliver more houses over time if this inflation were to remain steady. The building cost index showed levels of 13% and 20% during 2002, end of 2004 and throughout 2005 have experienced levels from 16% to 20%. (BER, 2007 cited by Department of Housing, 2007). Escalating prices increases the cost of delivering housing, thereby reducing the value of subsidies. This necessitates the department to adjust subsidies by a higher margin to ensure that the housing quality is not compromised. The housing subsidy per unit has increased from R23100 in 2003 to R36528 in 2006. Furthermore, the inflation rates decrease the profit margins of the developers as the subsidies are only adjusted annually making the public housing market unattractive during inflationary times (Department of Housing, 2007).

(c) Employment

The construction sector contributed 8% of the total employment of the country with 1,024,000 people in 2006. Out of the total number of people employed in the construction sector 45,676 (4.5%) are job opportunities created by the government subsidised market during 2006-2007 (Department of Housing, 2007). During this period 274,219 houses have been produced and therefore an average of 6 houses per job per year. This employment to productivity ratio has been consistent from 2000 to 2007.

(d) Quality

The issues of the housing standards in terms of the technical aspects are as follows:

- Most houses lack internal finishes, bare concrete block walling is not aesthetically pleasing (Monkhi, 2007).
- The RDP houses lack thermal insulation. In a research conducted by Makala (2006), which compared RDP houses with traditional stone-clay houses, found that the traditional houses present better thermal conditions (up to 7°C) than the RDP units. The reasons were: corrugated iron roof sheeting, the absence of ceilings and the use of thin concrete block walls which lacks thermal insulation.
- Ineffective management and construction supervision caused poor quality houses. The main structural problems are sagging of foundations resulting in cracking walls, poor sealing between frames and walls and the use of poor materials. ESSA (2005) argues that the private sector who build the houses seem to use improper building techniques and standards to cut costs and time.
- The RDP square single standing houses are 30m^2 in size. An average of 4 people per house which is about 7.5m^2 per person, this is inadequate for a family dwelling (Monkhi, 2007).

Potential Solution

Key Requirements

Could the Industrialised Building System be a feasible approach for solving the housing problem in South Africa? The key requirements expected from the Industrialised Building System is to deliver fast, affordable, quality, sustainable housing projects that meet or exceed the end-users expectations.

Open Building Manufacturing

Building Systems Approach

There are two building systems; the Industrialised Building System (IBS) and the Conventional Building System (CBS). The following section illustrates the characteristics of both building systems and compares them in terms of mass low income housing. IBS as production has a relevant trade-off between mass production and product variety. Mass production of a standardised product can increase production efficiency but decrease the ability to change aspects of the product with ease as conventional building can offer. The characteristics of IBS are:

(a) Employment

- On average about 70% of the labour consumption is in the factory, 30% for transportation and on the building site.
- Industrialised building systems offer higher productivity per labourer with the same amount invested. The onsite production is substantially less than conventional and the factory workers are generally more productive per house produced, this is the reason why the productivity levels are higher for IBS than for conventional (Monsted and Percinel, 1982).

(b) Management and Professionals

- Industrialised building requires less managers and professionals per project. This is because plans and drawings are reused, the building process is well rehearsed, less labour is employed which requires less employee management and facilities.
- Inspections and quality control can be better implemented as the product quality is better controlled on a systematic and standardised production line process (Thanoon et al., 2003).

(c) Cost

- Industrialised building offers savings for finishes compared to conventional building as the concrete panels are cast on a smooth surface in a factory. This is an advantage as costs are saved by eliminating the need for plastering, touch ups and further finishing.
- In the third world, the timber consumption is about 2-3 cubic meters per apartment of 100 square meters making it an expensive item, where industrialised system would not need timber at all. Waste for materials in industrialised building is about half that of traditional building (Monsted and Percinel, 1982).

(d) Large initial Capital outlay

- In order to implement industrialised building system for large scale housing projects a large initial capital outlay is required to finance a factory and its pricy manufacturing machinery, tools and the training of specialists that will manage the factory (Hashim et al., 2002).

(e) Material Price Hikes

- Industrialised building can run on pre ordered materials and therefore material price hikes can be more forgiving on the cost of the building as the pre orders can be increased at set prices when a major escalation is expected. Since the use of mostly precast elements, the shelf life exceeds that of dry cement thus more able to bulk buy in advance. (Gelman, 1988).

(f) Rapid Production and Onsite periods

- The builder can take more contracts at a time with less plant, labour and equipment than conventional construction. This is because the rapid production utilises less resources per building and less on site erection periods which makes plant, labour and equipment more available (Thanoon et al., 2003).

(g) Weather delays

- Industrialised construction is less weather dependant than conventional construction, as most of the building is built in a factory and less time is spent on site where conventional would spend more time on site thus more reliant on the weather. This is a contingency cost and building duration advantage (Thanoon et al., 2003).

(h) Standardisation

- Mass production requires the standardisation of the product, with no exception to industrialised buildings. In order to maximise production efficiency elements of the building product need to be standardised, so machinery and worker’s training can be best absorbed to the characteristics of the product (Thanoon et al., 2003).

- Conventionally constructed current low income houses are completely standardised, one RDP block house is nearly identical to the next.

(i) Lean Construction

- Lean production philosophies can be better applied to industrialised construction as opposed to conventional. This is because industrialised building system is more of a manufacturing orientated process, where conventional is service orientated. The materials are standardised and supply deliveries are easier to manage, wastage is minimised and production is more efficient (Gann, 1996; Howell and Ballard, 1999).

A study by Hashim et al., (2002) carried out in the Malaysian construction industry aimed to compare between IBS and conventional construction showed that IBS construction cost is substantially less, high delivery rate and less employment of labour.

The abovementioned characteristics of the IBS showed that it can deliver fast houses due to its rapid production system, less weather dependent and design standardisation. In spite of the large initial capital outlay needed to establishing IBS for mass production, IBS can provide affordable house through eliminating the need of plastering, touch ups and further finishing, reducing material wastage and avoiding the hikes of material prices. In addition, IBS is capable to deliver quality products because of the implementation of proper inspection and quality control carried out during the production process. One of the important advantages of IBS is its capability to deliver sustainable houses in terms of material use and waste, durable, easy to maintain, adaptable to future user requirements. Constructing houses that possess these characteristics helps meet or exceed end-users expectations.

Approach

The abovementioned aim called for a research strategy that could gather data sufficiently rich to investigate the feasibility of industrialized building system as a strategic approach for housing the poor in South Africa. The research methodology to achieve this aim consists of four phases: Plan, Do, Study and Act, see figures (2&3). It is called the PDSA Cycle which was firstly developed by Shewhart and then modified by Deming. The PDSA cycle is an effective problem solving technique and essential tool for continual improvement of process management (Besterfield et al., 1999). The PDSA is used as a model for continuous improvement, establishing new improvement project, developing a new or improved design of a process, product or service, defining a repetitive work process, planning data collection and analysis in order to verify and prioritize problems or root causes, implementing change procedure. The PDSA is an ongoing process where the cycle continues to repeat as an approach for improvement.

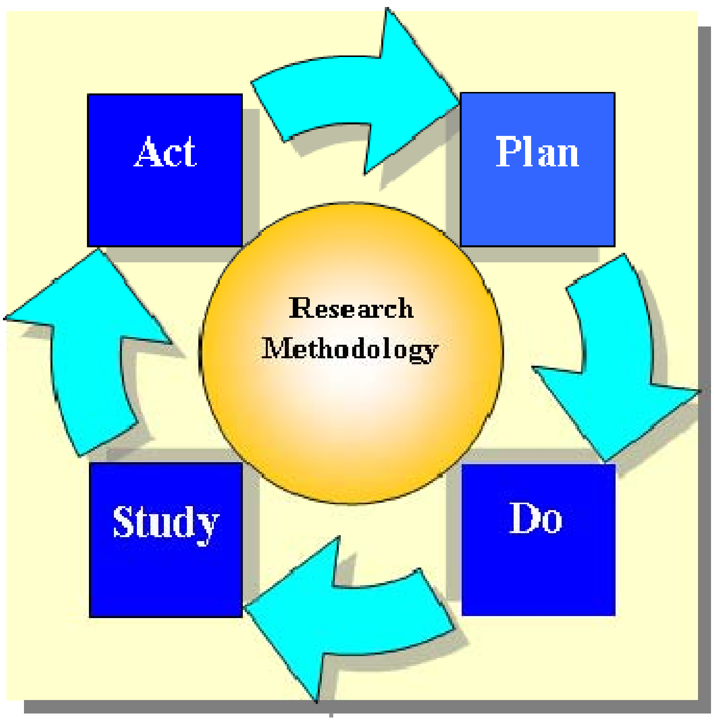


Figure (1) PDSA Cycle

Plan Phase

The objective of this phase is to identify and prioritise opportunities for improvement. It aims to identify the problem and define exactly what needs to be done in order to achieve a specific task effectively and efficiently. Examples of questions that should be answered include: “what are we trying to improve?”, “What data do we need to collect?” “Where will we find this data?”. During the course of this research, the plan phase was used to identify the research problem and rationale, establish the research aim and objectives, design the research methodology and methods appropriate for achieving the research aim and objectives.

Do Phase

The objective of the “Do Phase” is to implement the abovementioned plans and execute the required processes using the research methods selected. This stage requires the researcher to observe the results once the plan has been put into operation. During this phase, Firstly, literature is used to: (i) build a comprehensive background of the housing situation in South Africa, the conventional and industrialised building systems for low-income housing projects and sustainable development, (ii) Identify the criteria for comparing between the conventional and industrialised building systems, and (iii) develop a decision making tool called the *Multi Criteria Comparative Feasibility Matrix (MCCFM)* to facilitate making an informed decision. Secondly, interviews are used to weight the importance of each factor of the identified criteria. Three different perspective groups, namely: government (initiator and developer), contractor (service provider) and end-user (resident) are interviewed to weigh their own criteria respectively. The sample size of the interviewee was 15 persons. Finally, survey questionnaires are used to utilise the weights gained from the interviews and apply the developed decision making matrix in order to rate the performance of conventional and industrialised building systems according to each factor of the criteria identified. The questionnaires are sent to a sample of contractors who are directly involved with industrialised and conventional building systems in South Africa. The sample size of the questionnaire was 12 contractors, this being the total identified population size of the industrialised housing contractors throughout South Africa (Yellow Pages, 2008).

Study Phase

The “Study Phase” aims to observe the effects of the course of actions taken, analyse the results gained, identify the lessons learned and expect what can be predicted. Within this research, data analysis helped identifying the causes of housing the poor in South Africa and areas of pitfalls and shortcomings, so particular course of action could be taken for improvement. Collected data is analysed quantitatively and qualitatively. Quantitative analysis is achieved through calculating the sum of multiplying the average of rates given by respondents for every building option by the appropriate criteria weight gained from the interviews. This will help arriving at a summary matrix where the results of each group is presented. Results will be analysed qualitatively to explore the reasons behind scoring some factors higher than others.

Act Phase

The objective of the “Act Phase” is to highlight research findings and apply actions needed for improvement. This necessitates that changes required need to be identified and implemented in order to improve the process and solve the problem in hand (Bounds at al., 1994). During the course of this research, the research findings are identifies, the suggested building system is explained and recommendations for the industry and further research are summarised.

Validity and Reliability

In order to increase the validity and reliability of research methods and findings, ranking and rating questions in both the questionnaires and interviews helped minimise the risk of potential subjectiveness and biasness towards the factors analysed and the particular building systems. Furthermore, meeting people who are directly related to the research problem (i.e. government housing officials, housing contractors and community resident officials) helped increase the reliability and validity of collected data and research findings.

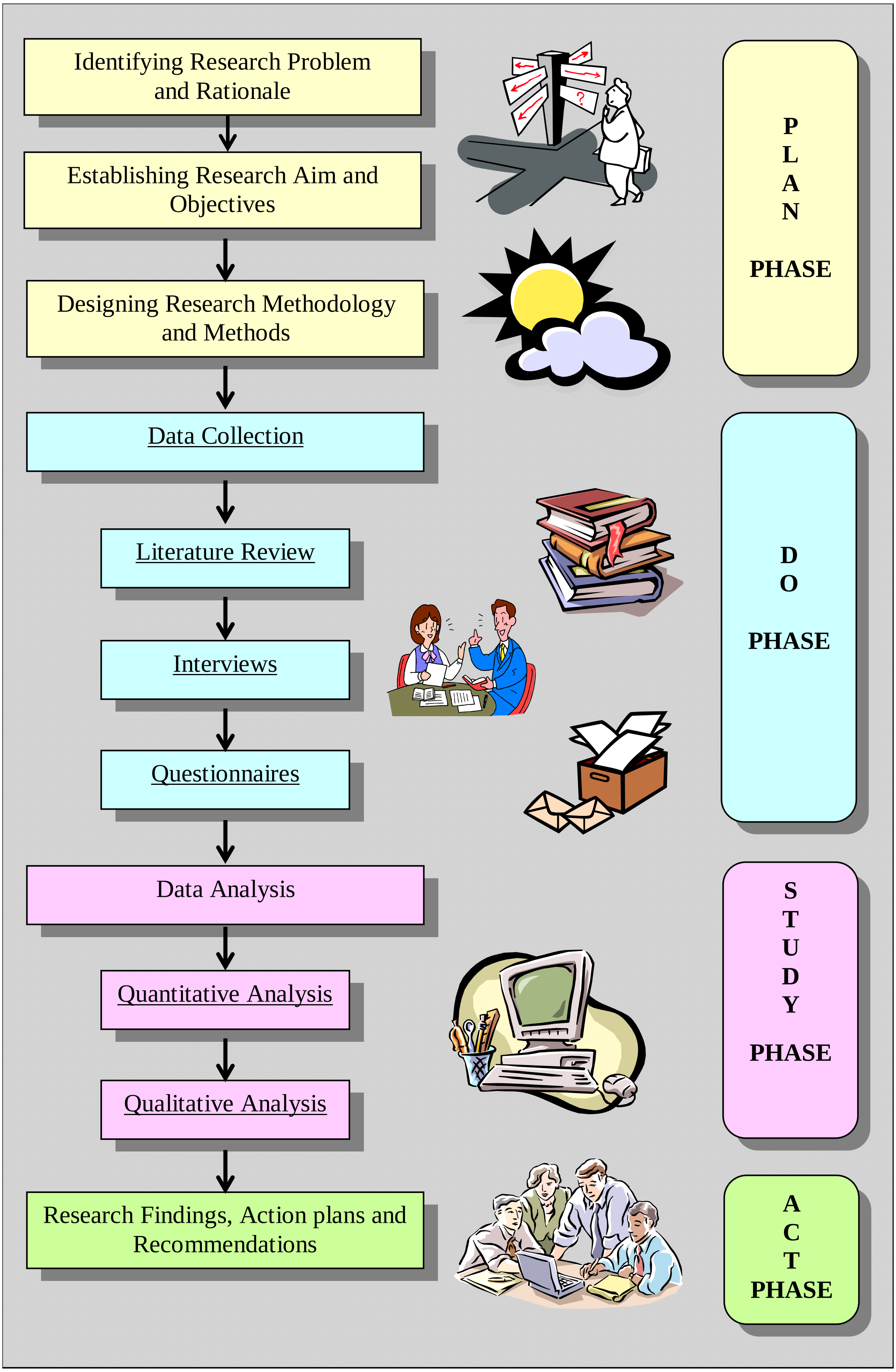


Figure (2) Research activities and PDSA Cycle

Analysis

Analysis of Survey Questionnaires Responses

Out of 12 survey questionnaires sent to a sample of contractors who are involved in both building systems, only 5 were completed and returned which represent 42%. The respondents are asked to rate each factor from 10 to 100 for both conventional and industrialised building systems, in terms of their performance (10 being the least and 100 being the most), see table (1)

Table (1) Rating criteria factors for CBS and IBS

Group	Primary Factor	Secondary Factor	Conventional	Industrialised
GOVERNMENT	Housing Provision	Delivery Rate	46	76
		Adequacy & Housing Quality	58	78
		Durability & Structural Quality	54	76
	Affordability & Job Creation	Cost per House	60	68
		Initial Capital	58	52
		Job Creation	70	48
	Sustainable Development	Socio-economic Growth	53	29
		Building Reuse & Adaptability	44	54
		Green & Resource Efficiency	47	70
CONTRACTOR	Production	Production Cost	60	70
		Initial Capital Outlay	60	40
		Production Rate	46	76
		Product Quality	58	78
	Management	Manageability	46	68
		Production Control	44	79
		Quality Control	40	74
		Skills Dependency	68	56
		Labour Intensity	70	62
	Physical Implications & Sustainability	Design Flexibility	82	66
		Construction Complexity	54	52
		Carbon Footprint	62	66
		Resource Efficiency	48	70
END-USER	Time & Future Value	Delivery & Waiting Period	46	76
		Adaptability & Alteration	52	56
		House Value	60	40
	Cost	Affordability	60	68
		Maintainability	60	54
		Life Cycle Period	36	52
	Quality	Diverse Design & Aesthetic	82	66
		General Quality of House	54	76
		Adequate Service Provision	40	74

Generally industrialised housing can offer more advantages than conventional housing, however the certain but few advantages that conventional construction can offer are important to government subsidised housing in South Africa such as labour intensity, job creation, and less skills dependency. Yet the importance of each factor must be considered together with this rating from the questionnaires to derive a valid conclusion of which building system would more functional for housing the poor in South Africa.

Analysis of Interviews Responses

Out of 15 interviews planned to be achieved, 12 were conducted. The purpose of the interviews is to value the importance of the criteria for each perspective group. This is done by weighting each factor of the criteria on a scale of 10 to 50 (10 being the lowest and 50 being the highest). These results are then calculated to a relative norm and converted to weighted averages, see table (2). These weighted values are then multiplied with the values of performance form the questionnaires to derive a score which is expressed in MCCFM tables (3, 4, 5&6).

Table (2) Weighting factors by three Perspective groups

Group	Primary Factor	Secondary Factor	Rate
GOVERNMENT	Housing Provision	Delivery Rate	0.125
		Adequacy & Housing Quality	0.125
		Durability & Structural Quality	0.140
	Affordability & Job Creation	Cost per House	0.118
		Initial Capital	0.095
		Job Creation	0.129
	Sustainable Development	Socio-economic Growth	0.114
		Building Reuse & Adaptability	0.073
		Green & Resource Efficiency	0.080
CONTRACTOR	Production	Production Cost	0.118
		Initial Capital Outlay	0.096
		Production Rate	0.070
		Product Quality	0.101
	Management	Manageability	0.073
		Production Control	0.080
		Quality Control	0.080
		Skills Dependency	0.056
		Labour Intensity	0.061
	Physical Implications & Sustainability	Design Flexibility	0.058
		Construction Complexity	0.051
		Carbon Footprint	0.099
		Resource Efficiency	0.058

END-USER	Time & Future Value		Delivery & Waiting Period	0.134
			Adaptability & Alteration	0.129
			House Value	0.082
	Cost		Affordability	0.129
			Maintainability	0.098
			Life Cycle Period	0.088
	Quality		Diverse Design & Aesthetic	0.099
			General Quality of House	0.103
			Adequate Service Provision	0.137

Table (3) MCCFM Matrix - Government

Government	**Housing Provision**			**Affordability & Job Creation**			**Sustainable Development**			
Factors	Delivery Rate	Adequacy & Housing Quality	Durability & Structural Quality	Cost per House	Initial Capital	Job Creation	Socio-Economic Growth	Building Reuse & Adaptability	Green & Resource Efficiency	**Total**
Weighing	0.125	0.125	0.140	0.118	0.095	0.129	0.114	0.073	0.080	1.000
Conventional	46	58	54	60	58	70	70	44	48	508
Score	5.760	7.262	7.557	7.073	5.514	9.051	7.989	3.206	3.858	57.271
Industrialised	76	78	76	68	52	48	48	54	70	570
Score	9.516	9.767	10.636	8.016	4.944	6.206	5.478	3.935	5.626	64.124

Table (4) MCCFM Matrix - Contractor

Contractor	**Production**				**Management**					**Physical Implications & Sustainability**				
Factors	Production Cost	Initial Capital Outlay	Production Rate	Product Quality	Manageability	Production Control	Quality Control	Skills Dependency	Labour Intensity	Design Flexibility	Construction Complexity	Carbon Footprint	Resource Efficiency	**Total**
Weighing	0.118	0.096	0.070	0.101	0.073	0.080	0.080	0.056	0.061	0.058	0.051	0.099	0.058	1.000
Conventional	60	60	46	58	46	40	40	68	70	82	54	62	48	734
Score	7.053	5.779	3.225	5.831	3.354	3.189	3.189	3.834	4.287	4.735	2.728	6.169	2.772	56.145
Industrialised	70	40	76	78	68	74	74	56	62	66	52	66	70	852
Score	8.229	3.852	5.328	7.842	4.958	5.899	5.899	3.158	3.797	3.811	2.627	6.567	4.042	66.010

Table (5) MCCFM Matrix – End user

End-User	**Time & Future Value**			**Cost**			**Quality**			
Factors	Delivery/ Waiting Period	Adaptability & Alteration	House Value	Affordability	Maintainability	Life Cycle Period	Diverse Design & Aesthetic	General Quality of House	Adequate Service Provision (L&W)	**Total**
Weighing	0.134	0.129	0.082	0.129	0.098	0.088	0.099	0.103	0.137	1.000
Conventional	46	52	60	60	60	36	82	54	40	490
score	6.178	6.699	4.934	7.713	5.910	3.177	8.092	5.577	5.495	53.775
Industrialised	76	56	40	68	54	52	66	76	74	562
Score	10.207	7.214	3.289	8.742	5.319	4.590	6.513	7.849	10.166	63.888

Table (6) MCCFM Summary Matrix

Final Matrix	Government	Contractor	End-User	**Total**
Conventional CBS	508	734	490	1732
Score	57.271	56.145	53.775	167.190
Industrialised IBS	570	852	562	1984
Score	64.124	66.010	63.888	194.022

Analysis of Government Response

Figure (3) illustrates the scoring difference between conventional and industrialised housing for the government sector. The following points are noted for the four most important factors:

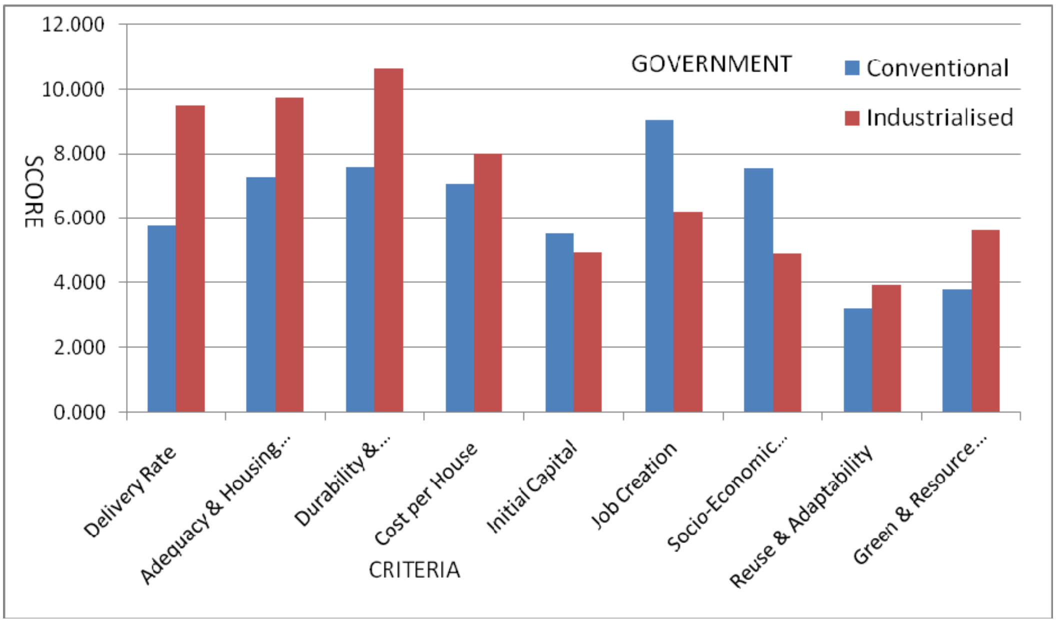


Figure (3) Government Scoring for CBS and IBS factors

- **Delivery Rate** – This factor shows a substantial difference between Industrialised and conventional. Industrialised has the higher score as the construction of an industrialised house is quicker than that of a conventionally built house. In terms of mass low income housing delivery rate is an important factor to consider and is amongst the top three most important for government. Hence the high score.

- **Adequacy & Housing Quality** – This is an important factor for housing and shares the same level of importance as Delivery Rate. The difference between the two building systems is considerable. The standard of the house in terms of adequate finishes and services is of crucial importance. As these houses are built for the poor only adequacy and not luxury can be expected. However, this standard of services and finishes must still serve it functional use well enough to last a generation. The other issue is the time taken for the services to be installed and connected as this is currently a problem for government subsidised housing. IBS can offer installation of services before the assembly of the house, which optimises time and delivery of the services.

- **Durability & Structural Quality** – This is different to the previous factor as this involves the physical aspects of the building where Adequacy and Housing Quality regards matters such as finishes, lights, water and layout design. This factor has a considerable difference in favour of industrialised. The reason for this is that currently in South Africa conventional building system is used to construct the low income houses and since the use of poor materials and mostly unskilled labour which results in a poor product. Industrialised offers better quality control measures and requires less labour and skills, it uses standardised materials and is said to be more durable. This factor is the most important for government and is thus the highest scored.

- **Job Creation** – This is an important requirement for government. The contractors who build government subsidised houses are required by government to employ a certain percentage of labourers from the community in which the houses are built. This is to increase job creation and to maximise wealth distribution. Conventional has outperformed industrialised by a considerable margin for this factor. This is seen as the as the strongest drawback for industrialised since job creation is rated one of the top requirements for housing. The reason for this is that industrialised is a manufacturing orientated construction and through efficiency and mechanisation it decreases the need for employment which is in direct contrast with conventional.

Analysis of Contractors Response

Figure (4) illustrates the scoring difference between conventional and industrialised housing for the contractor sector. The following points are noted the three most important factors:

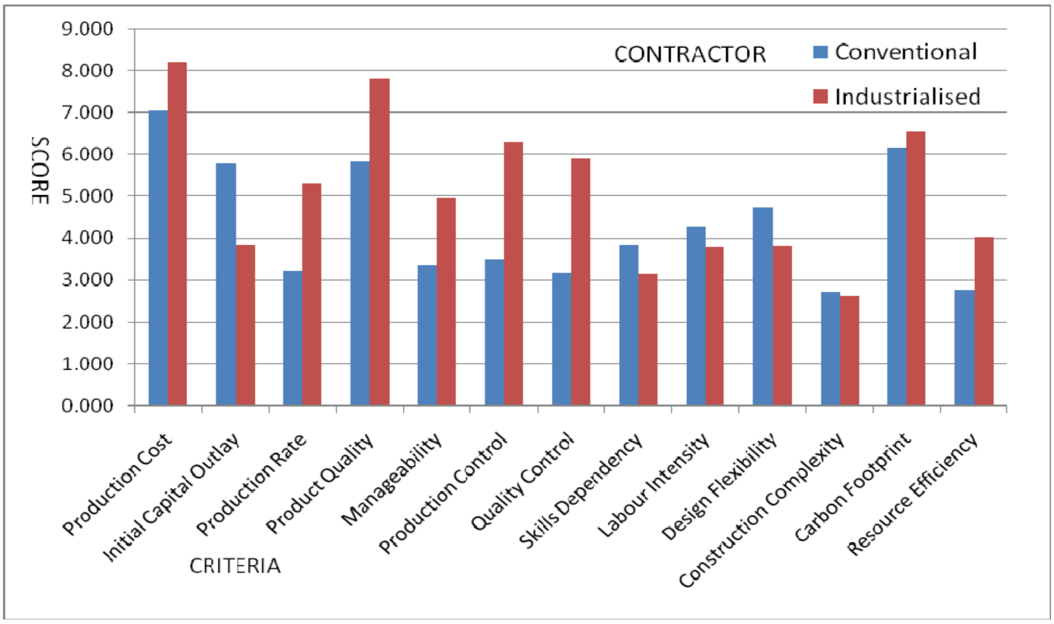


Figure (4) Contractors Scoring for CBS and IBS factors

- **Production Cost** – This is an important factor to consider as the cost of producing houses needs to be within the government subsidy margin and must still make a profit. The cheaper the production cost the more profitable the production becomes. This factor is the most important for contractors, this is shown on the graph as it has the highest score. The difference, although only marginal, is in favour of industrialised. This is because industrialised offers a lower production cost per unit due to its high production capacity, production rate and efficiency. Conventional has a cheap production cost through utilising cheap materials, cheap labour and minimising the use of machinery.

- **Product Quality** – This factor measures the general quality of the product, form a contractor's perspective. This is an important factor as contractors aim to produce a product that would please their clients and ensure future contracts. Industrialised has a considerably higher score than conventional in this regard. This is mainly because industrialised produces standardised products which are, to a large extent, identical. Standardisation and less onsite construction provides greater quality assurance. On the other hand, conventional is largely onsite construction which leaves more room for error, although building plans and processes are standardised product quality outcome is more likely to vary. Conventional is more dependent on onsite labour quality, and since labour with no experience is employed the housing product quality reflects the standard of workmanship.

- **Carbon Footprint** – This is factor is a corporate requirement and is chosen in the light of environmental issues. This is a factor that is rated as the third most important, which shows that it is considered for low income housing. The graph shows this by its high rating. Industrialised has been scored higher than conventional for this factor. This is because industrialised is generally more resource efficient and has less of an impact on the building site. Industrialised also includes a factory which produces the components which impacts on the carbon footprint of this system. Conventional, on the other hand, doesn't have a factory but has a greater impact on the environment of the building site and is more wasteful.

Analysis of End-User Response

Figure (5) illustrates the scoring difference between conventional and industrialised housing for the End-User. The following points are noted for the three most important factors:

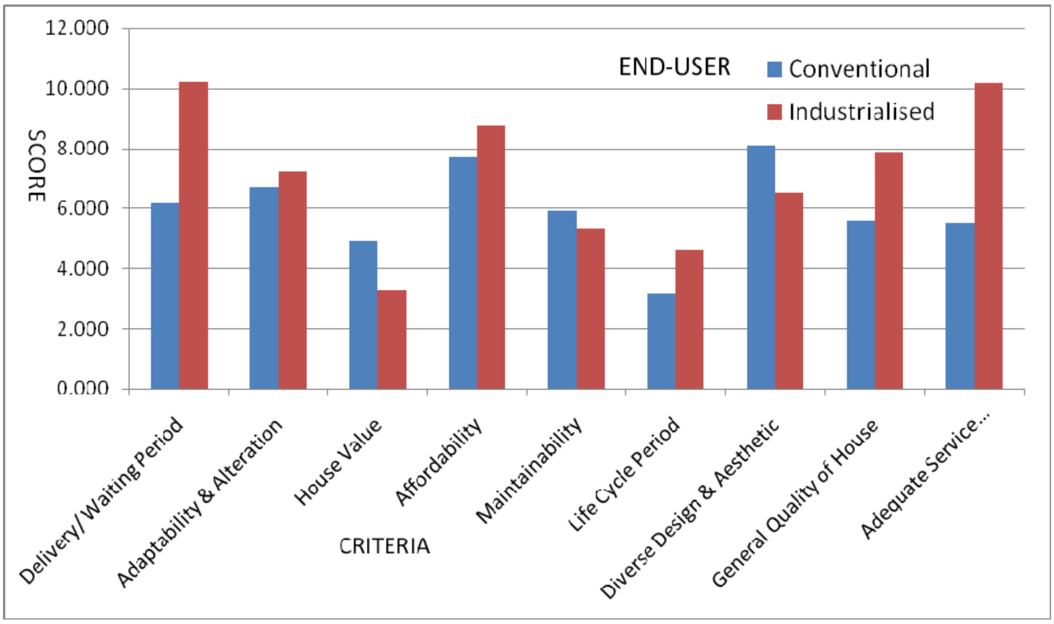


Figure (5) End-Users Scoring for CBS and IBS factors

- **Delivery /Waiting Period –** This is the average waiting period for the housing applicant to receive their government subsidised house. This factor is related with the production rate and delivery rate in the contractor and government sectors respectively. This factor is one the top three rated factors for the end user. Industrialised has scored considerably more than conventional. This is because industrialised is capable of a higher production rate, better manageability and transparency, making the process from production to delivery more efficient.

- **Affordability –** This factor measures the cost aspect of not only the houses but also the cost of alterations and finishes. As the government subsidised houses are built with the intention that the residents will add their own improvements. This is a considerably important factor, because cost is the main concern for the end user. Industrialised has a higher score than conventional but only by a small margin. Industrialised can offer cheaper houses and cheaper extensions on an existing building. This cost advantage is achieved through larger building components and panel building. However, this cost advantage must be set against the initial capital required, this is why the difference in cost in smaller. Conventional houses are cheap but not as cheap as industrialised could offer. It must be kept in mind that the initial capital outlay for conventional is significantly less than industrialised, which would directly impact on the cost of the houses.

- **Adequate Services (Lights & Water)** – The reason why this factor has been separated from the previous factor (General Quality of House) is because the services in the houses is an aspect which currently is not adequate enough. It on its own is an important factor for the end user, hence it has one of the highest scores. Industrialised has considerably out scored conventional. The main reason for this is because the conventional building method separates the construction of the houses with the provision of the services, which is why the conduits and plumbing lines have to be chased into the walls afterwards. This delays the process and is impractical for mass low income housing. Industrialised, on the other hand, can combine the construction (production) process with the installation of services. This is done by fitting the conduits and plumbing lines into the wall before it is cast or made. Fittings and lines are connected during the assembly process. This ensures that the services are in place, it is also cost effective, practical and shortens construction periods. Most of all it shifts the responsibility to one contractor who doesn't have to rely on subcontractors.

Summary and Discussion

Figure (6) summarises the scoring difference between conventional and industrialised housing for each perspective group.

- **Government** - Generally, regarding all factors of the government industrialised is considered to be the better building method for low income housing. The only set back is that industrialised underperforms through job creation which is an essential requirement for government. If job creation becomes a factor of less importance then industrialised would be fitting for low income housing. Otherwise if an industrialised system could be developed that offers a higher degree of job creation without compromising delivery rates, adequacy and durability, then this system would stand a chance of overcoming the housing shortage. Despite job creation industrialised has generally performed better than conventional and this should be reason enough to consider industrialised building system for government subsidised housing in South Africa.

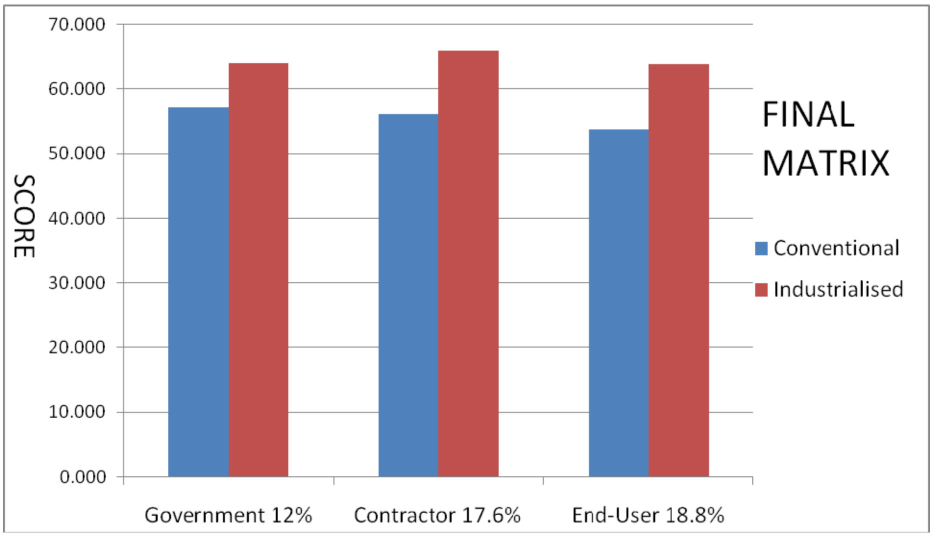


Figure (6) Summary of Scoring for CBS and IBS factors

- **Contractor** - The factors which industrialised can offer a considerable advantage over conventional is manageability, production control, quality control, resource efficiency, product quality, production cost and production rate. These are the factors that make industrialised attractive for housing contractors. However, there are some drawbacks for the contractor, initial capital outlay is the strongest disadvantage for industrialised for the contractors sector. The initial capital outlay is a strong barrier for entry into the industrialised construction industry. A considerable amount of capital is needed to establish all the facilities, machinery and equipment needed to operate an industrialised production line. Design flexibility, labour intensity and skills dependency are factors which are favoured by conventional and may dis-encourage industrialised as a building system. Mechanisation, to a certain extent, is disapproved by government because it denies potential employment especially for a country with high unemployment rates. The other issue is that South Africa has relatively cheap labour which may make labour intensive processes cheaper than mechanised processes.

- **End-User -** Adequate Service Provision is the end users most important factor which is substantially higher for industrialised than for conventional. It seems that industrialised is the better building method for the end user. However, there are some drawbacks. Diverse design and aesthetics is favoured by conventional which can have an implication on the user friendliness of industrialised. In countries where industrialised building systems have been extensively used for low income housing have received complaints and a general negative approach towards this type of building system, although it has managed to house the population. This study speaks for itself as industrialised does indeed provide a better opportunity to eradicate the housing backlog in South Africa. The end user should be pleased with their house if it caters for all their needs.

The Analysis clearly shows that IBS is more feasible than CBS for all three perspectives. The sum of the scores of all the three perspective groups is 166.972 for conventional and 193.850 for industrialised, this is a 16.1% difference. Overall IBS is a more feasible option for government subsidised housing in South Africa. However, this analysis only focuses on the performance of both building systems with respect to the requirements of social housing. If IBS were to be implemented for government subsidised housing in South Africa then more direct considerations need to be taken. Since this analysis only regards the concept of the two building systems, so the actual application of IBS would need to consider a particular design of an industrialised building. This particular design would need to be tailored for the South African environment, must suit the important criteria of the government especially job creation and it must incorporate materials suitable for the South African climate and resource capacity.

Results and Business Impacts

Key Findings

The key findings of this chapter are derived from the data analysis and compared with some aspects of the literature review. The key findings are:

- Generally, IBS is more feasible than CBS as it offers more advantages than CBS for low income housing.
- The main advantages that IBS offers in terms of social housing in South Africa are delivery rate, production control, quality control and adequate services.

- The main advantages that CBS offers in terms of social housing in South Africa are job creation, socio-economic growth and diverse design and aesthetics.
- For the government sector:
  - IBS would be most successful towards delivery rate and durability.
  - IBS would be a hindrance towards job creation.
- For the contractors sector:
  - IBS would be most successful towards production cost and product quality.
  - IBS would be a hindrance towards initial capital outlay and design flexibility.
- For the end-user sector:
  - IBS would be most successful towards adequate services and delivery period
  - IBS would be a hindrance towards diverse design and aesthetics

Business Impacts

As this chapter investigated the feasibility of IBS for housing the poor in South Africa and because it carried out a comparison analysis between IBS and CBS form the perspective of the three main role players within social housing in South Africa, therefore this study can offer beneficial information to each of the three role players.

For Government

In terms of the potential implementation of IBS for social housing, out of the three role players, the government is the most important as they are the project initiators and funders of social housing. Thus, if government decided to implement IBS the contractors and end-users will follow suit. The government is a strong role player in the private social housing field. The results of the study do not only show which building systems is more beneficial but also what requirements or criteria conflict and hinder each other's success. A prime example is that the government requires the employment of labour within the community of the housing project with the noble intention of creating jobs and therefore socio-economic upliftment. However, this job creation incentive is a hindrance to the quality and production rate of the houses. Therefore, the results of this study can show what the government criteria is contradictory and can allow the reconsideration of the importance or extent of implementation of certain factors of their criteria.

For Contractors and Other building professionals

This study can be applied to other mass housing industries, form high density apartment developments to high income estate developments. Therefore in this regard the contractor can benefit from the results of this study. This study showed what advantages IBS can offer and in what circumstances it would be most beneficial. This is potentially valuable information to, not only the contractors, but also property developers, building material suppliers and construction professionals, as each of these organisations seek similar criteria within their line of work. Furthermore, the MCCFM analysis framework can be adapted to suit personal requirements, as only relevant criteria can be selected and the MCCFM will derive comparative feasibility analysis.

End-User and Residents

The residents of the houses can utilise this information as grounds for decision making. Since there is talk of a negative perception against prefabricated or industrialised houses the potential home owner can make justified decision whether an industrialised built home might not be more beneficial than a conventionally built home. This does not only apply to residential buildings but to any other type, be it commercial, industrial or retail. The uses and class of IBS for housing in various countries are of a different nature. For example in Japan a prefabricated industrialised house is highly sought after, where in France industrialised from the bulk of housing (Conrads and Othman, 2008).

Conclusions

Housing the poor is one of the greatest challenges that face the South African Government. It is a broad issue and requires the efforts of every sector to be utilised if this problem to be solved. Since South Africa is a developing country and thus shares similar issues, problems and socio-economic environment with other developing countries, the results of this research can therefore be applied to developing countries in general. The main issue of housing the poor addressed in this chapter is the low delivery rate, the increasing cost of houses, low quality level and being unsustainable.

Data analysis showed that CBS received an unfavourable score for all three perspectives. This building system is associated with a number of problems such as slow delivery rate, poor quality standards and inefficiency. On the other hand, it is has the benefit of creating more jobs, design flexibility and less skill dependency.

The IBS received a better overall score. This showed that this system is the favourable building system. IBS could help produce cheaper mass housing projects, faster delivery rate, at high quality standards and generally more efficient. On the other hand, the shortage of research on the use of IBS for low income housing in developing countries has made it difficult to predict the fate of IBS for housing the poor in South Africa. Factors where CBS would perform better such as Job creation, skills dependency and capital outlay are strong drawbacks towards implementing IBS for a developing country.

In terms of the social housing situation in South Africa, the government set a goal to replace all informal houses with formal houses by 2015. This requires a delivery rate of about 600,000 houses per annum from 2008. Currently the social housing delivery rate averages 250,000 per annum. Clearly the delivery rate would need to be drastically increased in order to reach the goal. The conventionally built houses cannot offer a sufficient delivery rate for housing, where IBS offers a greater delivery rate it would make sense that this building system should be adopted if the government's goal is likely to be achieved.

The South African government requires that the social housing contractors employ a certain number of labourers from the community where the houses are built. The purpose of this is to create more jobs and for socio-economic progression within these communities. The implication of this noble incentive is that it compromises the product quality and delivery rate of the houses as these employed labourers are mostly unskilled and inexperienced. Since these houses are built for the employed people they determine their own quality of the houses. Furthermore, these jobs will only lasts until the housing project is completed, since humans are gifted with perceptibility, the labourers will purposely work slowly so to delay the completion and in turn extend their employment. Clearly this is not sustainable instead a socio-economic progression factors should be implemented through entrepreneurship, self dependent communities and skills development.

This analysis is seen as the first stage of developing an optimum building design. The analysis regards the requirements of each perspective group which identifies precisely what the building system would need to achieve. This analysis also but more importantly, distinguishes the direction of which building system would be the most suitable, thus either the industrialised system or the conventional system. Since both of these systems are essentially different it is important to know on what building system the optimum building design should be based on. At this stage the analysis can only recommend a most suitable building system from a technical perspective. Ideally, certain qualities form both IBS and CBS would need to be amalgamated into one hybrid building system that is most suitable to the South African environment. The analysis proves that IBS offers more advantages than CBS for social housing and therefore the optimum building design should adopt greater degree of industrialised and only certain elements of conventional.

Practical Tips

- The poor, worldwide, resort to all sorts of means to house themselves in the face of a housing industry and policies that fail to provide them with affordable options.
- The importance of housing for the poor contrasts sharply with housing conditions and official policies that exist in many developing countries. One billion people, a sixth of the world's populations live in slums, 90 percent of them in developing countries.
- A House is far more than living space and shelter. It is vital for the social and physiological health of a human being. A house is a place to live our lives, to interact with others, to rest, to nurture and feed ourselves, therefore adequate houses are essential for our well being.
- The South African government set a goal to replace all informal houses with formal houses by 2015. This requires 600,000 houses per annum have to be built from 2008. The current delivery rate averages 250,000 per annum. A different approach has to be adopted if the government goals to be achieved.
- The CBS is associated with a number of problems such as slow delivery rate, poor quality standards and inefficiency. On the other hand, it is has the benefit of creating more jobs, design flexibility and less skill dependency.
- The IBS could produce cheaper, fast mass housing projects at high quality standards and generally more efficient. Contrarily, the shortage of research on the use of IBS for low income housing in developing countries has made it difficult to predict its fate in South Africa.
- A new hybrid system that utilise the qualities of both IBS and CBS has to be developed. The new system should adopt greater degree of industrialised and only certain elements of conventional system to suite the South African environment.
- There is a need for more research in the area of adoption and implementations of Industrialised Building System in developing countries.

Acknowledgements

The authors are grateful to the government officials, contractors and end-users who participated in this study.

References

Besterfield, D. H., Michna, C., Besterfield, G. H. and Sacre, M. (1999) Total Quality Management. 2nd ed. New Jersey: Prentice Hall.

Conrads,S.M. and Othman.A.A.E.(2008) Industrialised Building: Investigating its feasibility to house the poor in South Africa: Cato Manor as a case study. Proceedings of the Quantity Surveying Conference, Midrand, South Africa, 10 October 2008, pp. 42-52.

Culpin, C. (1970) Basic Principles of Industrialised Building, *A Paper submitted to the National Congress of Industrialised Concrete Building, Johannesburg, October 1970*.

Department of Housing SA. (1998), Housing Code: Draft1 November 1998.

Department of Housing SA. (2002) Towards Sustainable Settlements: Case studies from South Africa, STE Publishers.

Department of Housing (1994) White Paper: A New Housing Policy and Strategy for South Africa. Pretoria.

Department of Housing SA. (2007) Annual Report 2006- 2007.

Gann, D. M. (1996) Construction as a manufacturing process? Similarities and differences between industrialised housing and car production in Japan. *Construction Management and Economics*, Vol. 14, pp. 437-450.

Gelman, M. (1988) An economic appraisal of industrialised building technique in South Africa.

Hamid, Z. A., Ghani, M. K., Rahim, A. H. A. and Kamar, K. A. M. (2007) Industrialised Building Systems (IBS): Current Shortcomings and the Vital Roles of R&D, *Construction Research Institute of Malaysia (CREAM), Kuala Lumpur*. http://www.cream.com.my/images/news/IBS%20Shortcomings%20and%20Vital%20Roles%20of%20R&D.pdf (accessed 11/04/08).

Hashim, A.H. Abdul Kadir, M.R. and Badir, Y.F. (2002) Industrialized Building Systems Construction in Malaysia. Journal of Architecture and Engineering ASCE Vol. 8, No.1, pp.19-23.

Herbert, G. (1984) The Dream of the Factory Made House, the MIT press, USA.

Hong, O. C. (2006) Analysis of IBS for School Complex , *University of Technology Malaysia*. http://www.efka.utm.my/thesis/IMAGES/3PSM/2006/1JSB/PART6/ongchinhongaa010410d06tht.pdf (accessed: 11/04/08).

Howell, G. and Ballard, G. (1999) What kind of production is Construction?. http://www.leanconstruction.org/pdf/BallardAndHowell.pdf (accessed 17/03/04).

Knight R. (2001), Housing in South Africa. http://richardknight.homestead.com/files/sisahousing.htm (accessed 06/02/08).

Makala, G. (2006) Temprature stability of traditional and low-cost modern housing in the Eastern Cape, South Africa, in *Journal of Building Physics* Vol. 30 No. 1, pp.71-86.

Monkhi, M. (2007) An assessment of low income housing programmes in providing adequate dwellings for the urban poor – A case study of Cato Crest Greenfield, Cato Manor. Honours Dissertation, University of KwaZulu-Natal, Durban, South Africa.

Monsted, J. M. and Percinel, O. (1982) The Technical and Economic Advantages of Industrialized Building Methods. *Construction Methods and Delivery Systems pp. 54-59.*

Neuwirth, R. (2006) Shadow Cities. Routledge

ESSA. (2005) Economic Society of South Africa: An Analysis of the South African Government Low Cost Housing Provision Strategy (2005), [Electronic]. Available: http://www.essa.org.za/download/2005Conference/Radikeledi.pdf (accessed 20/02/08).

Reddy, A.M. (1987) A critical analysis of industrialised building method in South Africa.

Thanoon, W. A., Peng, L. W., Kadir, M. R. A., Jaafar, M. S. and Salit M.S., (2003) The Essential Characteristics of Industrialised Building Systems, *International Conference on Industrialised Building Systems, Kuala Lumpur, Malaysia, 10-11 September, 2003 283*. http://leewp33.tripod.com/sitebuildercontent/sitebuilderfiles/characteristic-ibs.pdf (accessed 04/04/08).

Unger, C. (2006) Industrialised house building – fundamental change or business as usual? *Doctoral Thesis, KTH School of Industrial Engineering and Management*, Stockholm. http://www.diva-portal.org/diva/getDocument?urn_nbn_se_kth_diva-4120-2__fulltext.pdf. (accessed 20/02/08).

UN-Habitat. (2003), The Challenge of Slums, Global Report on Human Settlements 2003: UN-Human Settlement Programme. Earthscan Publications

Author Biographies

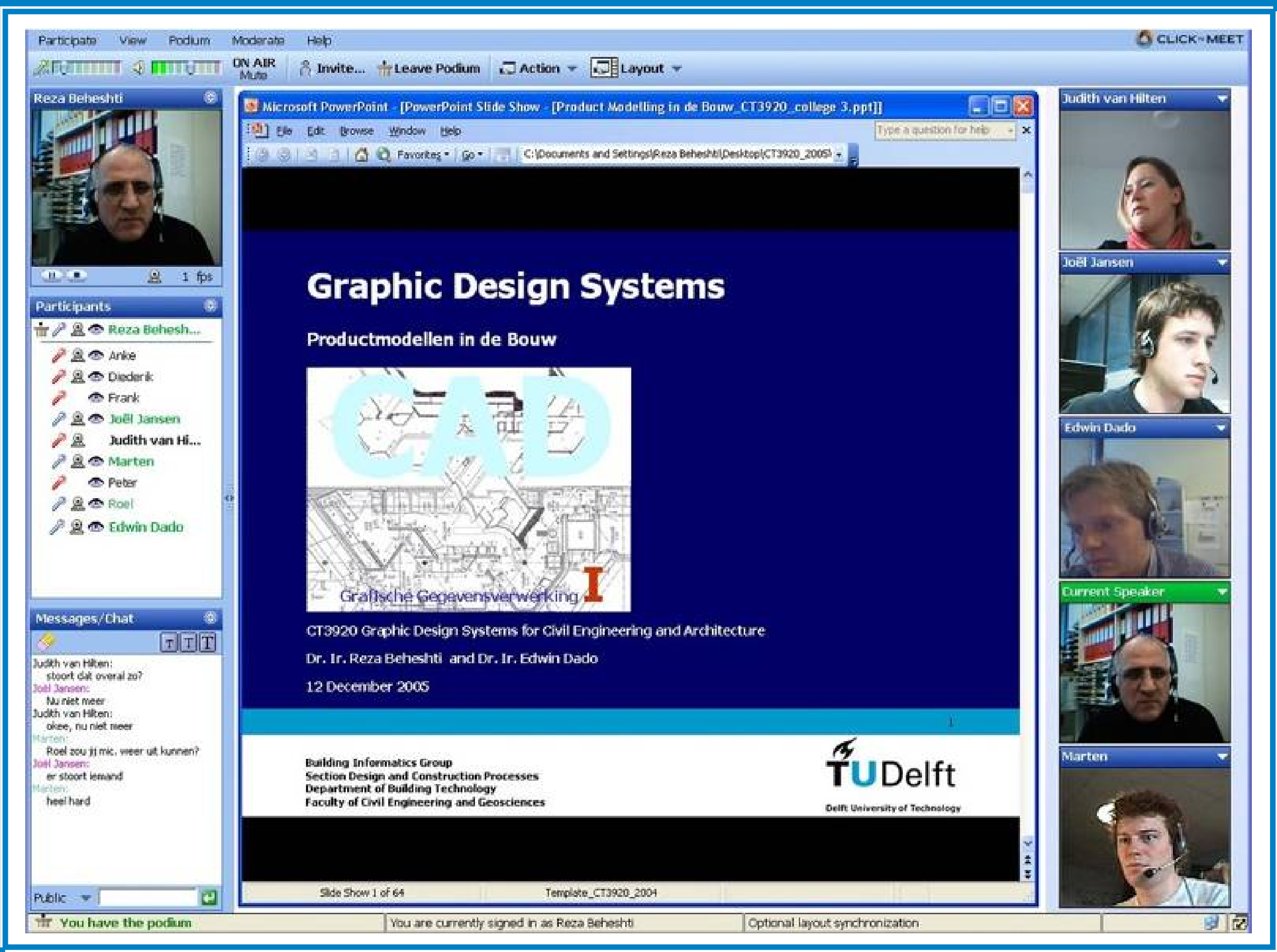
Dr. Ayman Othman is a Senior Lecturer at the School of Civil Engineering, Surveying & Construction, Faculty of Engineering, University of KwaZulu-Natal, South Africa. He obtained his B.Sc. in Architectural Engineering from Assiut University, Egypt in 1991. Then he worked as an architect and project manager in different national and international architectural design firms and government authorities in Egypt, Saudi Arabia, and the United Arab Emirates. He got his M.Sc. and Ph.D. in Construction Management from Heriot-Watt University and Loughborough University, UK in 1999 and 2004 respectively. Dr. Othman published more than 30 academic papers in refereed journals and conferences. He is a referee and member of advisory board of a number of academic journals. His area of interest includes: value and risk management, dynamic brief development in construction, sustainability, corporate social responsibility, partnership, client satisfaction, information management and technology, and maintenance management.

Mr. Stefan Conrads holds a B.Sc. Honours in Construction Management and a B.Sc. in Property Development from the University of KwaZulu-Natal, South Africa, in 2007 and 2008 respectively. His area of interest includes: Market dynamics, dynamic industrial business models, industrialised building systems and aviation.

8

Development of Digital Learning Environments for the BC industry

Reza Beheshti, Edwin Dado, and
Martinus van de Ruitenbeek



Development of Digital Learning Environments for the BC industry

Reza Beheshti, Delft University of Technology, The Netherlands (m.r.beheshti@tudelft.nl)
Edwin Dado, The Netherlands Defence Academy, The Netherlands (e.dado@nlda.nl)
Martinus van de Ruitenbeek, TUDelft, The Netherlands (h.k.m.vanderuitenbeek@tudelft.nl)

Abstract

The increasing market and society demands are causing the Building and Construction (BC) industry to change from a traditional into an innovative industry, characterised by co-operation, efficiency and competition. The Open Building Manufacturing initiative (ManuBuild) anticipates on the new situation but it requires a change in the needs of skills and knowledge of (future) employees working in today's BC industry. The future demand for just-in-time learning and training asks for a solid technical backbone which can serve a rich variety of reusable learning and training material which is independent of but expressible in various pedagogical approaches and interfaces, as to support initiatives similar to ManuBuild. In this regard the Delft University of Technology demonstrated the potential of eLearning through the application of state-of-the-art eLearning technologies such as virtual classrooms and learning portals in a number of real-life case studies, which were a success for both the lecturers and the students but also showed its limitations with regard to the socio-cultural aspects.

In future we may expect virtual actors in the role of teachers (or experts). We forward several prerequisites for such "living", intelligent, self-aware and social beings that we call Learning and Training Agents (LTAgents). Several prerequisites are basic computational power, self- and social awareness and finally learning and training capabilities. The BC industry future might face a rich variety of both human and digital actors that are immerged into a lifelong personalized, just-in-time learning and training environment. These environments facilitate custom-tailored blended modes of learning and training that are time and place independent.

Keywords: Building and Construction industry, Agents, blended mode of learning and training, lifelong, just-in-time, custom-tailored, time and place independent

Background

Industrial Context

Compared to the pace of innovation in other industries, the Building and Construction (BC) industry is rather traditional [Molen, et al, 2005]. In the last two decades however, increasing market and society demands are forcing the BC industry to change from a traditional industry branch, characterised by fragmentation and bewilderment into an innovative industry branch, characterised by co-operation, efficiency and competitiveness. In order to cope with the increasing demands, the BC industry is adopting new techniques and technologies in the field of management, organisation, manufacturing and ICKT. In this respect, a number of trends are noticeable including a number of reform programmes that have been initiated by national governments to facilitate this change such as the Rethinking programme[1] in the United Kingdom

[1] More information: http://www.rethinkingconstruction.org/

and the PSIBouw programme[2] in the Netherlands as well as the European Open Building Manufacturing initiative (ManuBuild). The Open Building Manufacturing (OBM) is an attempt to bring some of the salient features of efficient manufacturing to the BC sector. According to the ManuBuild consortium, OBM is a new paradigm for building production and procurement by combining highly efficient manufacturing techniques in factories and on construction sites as well as an open system for products and components offering diversity of supply and building component configuration opportunities in the open market [Kazi et al, 2007]. This new paradigm together with other proposed reformations places heavy demands on the competence of the BC industry and its employees - a new type of competence that is not the same as it used to be. These types of changes require a change in ways of “deciding, doing, acting and responding” within the industry, i.e. it requires a change in the needs of skills and knowledge of (future) employees working in today’s BC industry.

Allowing for specific definitions of some terms used in this chapter will help to clear understanding of concepts that are introduced later on:

- Learning is the act of acquiring an active knowledge of technical issues related to the changing BC skills
- Training is the act of acquiring performances that are required for the application of new BC skills
- Blended learning and training policy refers to the necessity of simultaneous availability of a blend of various modes of learning and training for new BC skills as well as favourable working environments and working cultures for BC disciplines
- ICKT refers to the Information, Communication and Knowledge Technology

Problem

The aforementioned changes pose a real challenge for traditional (higher) educational institutes in terms of education delivery. Following a higher education for a couple of years and afterwards having a job for life is a picture that belongs to the past. In order to provide an answer to the continuing changes of skills, competences and knowledge, the BC industry (including educational institutes) have adopted the concepts of lifelong or continuous learning[3]. As stated by Abbott [SkillSoft, 2006]*:*

“The future will all be about just-in-time training, training that people can take out in the field, at home or wherever they happen to be. So, increasingly, I think what’s happening is that we’re turning to things like eLearning and bite-sized learning”.

In this context eLearning refers to the application of advanced information, communication and knowledge technologies (ICKT) and digital media which have created excellent conditions for profoundly improving the traditional learning and training environments in the BC industry. New modes of learning and training can enhance one’s ability to proactively construct his or her personal learning environment capable of surmounting the barriers of time and location. These developments have contributed to the uptake of on-line learning or eLearning systems that have become widely (commercially) available and accessible. A survey conducted by e-BusinessW@tch in 2006, showed an increasing use of eLearning systems within the BC industry. According to this survey, 30% of the large companies (250+ employees), 14% of the

---

[2] More Information: http:/www.psibouw.nl/.

[3] A survey carried out in 2006 by SkillSoft in the UK with over 5000 employees, all of whom were in full time employment, ranging from junior positions to managers and director level employees, regarding their views on the lifelong learning/training programmes revealed significant insight into the necessity and advantages of such programmes but also showed a great many obstacles when traditional means for learning and training were employed (SkillSoft, 2006).

medium companies (50-249 employees) and 7% of the small companies (10-49 employees) reported eLearning practices. From a technological perspective, many commercially available eLearning (and eTraining) systems support many of the specific requirements of the BC industry, but from a socio-cultural perspective they are not well tailored to the working and thinking culture of the BC industry [Beheshti et al, 2007].

Potential Solution

Key Requirements

In order to overcome the aforementioned limitations of the current generation of eLearning/eTraining systems we need to enhance existing eLearning systems with respect to didactical, social and technical aspects. Essentially the BC industry needs continuous, up-to-date and dynamic learning and training environments that offer time and place independent just-in-time delivery of learning and training material, presented in an appropriate didactical form. Consequently educational institutes will need to thoroughly change their (rather static) educational programmes and other learning/training schemes to facilitate these future demands.

Open Building Manufacturing

Open Building Manufacturing and other developments can only be successful if we can change skills and knowledge of (future) employees working in today’s BC industry. Although digital learning and training environments are able to provide a sound basis for transferring new knowledge from research to practice, the current generation of supporting eLearning and eTraining systems are still very limited from a socio-cultural perspective and are not well tailored to the working and thinking culture of the BC industry.

Approach

In order to anticipate on the rapidly changing learning and training requirements in the BC industry, we analyze the didactical, pedagogical and technical backgrounds of learning/training environments, and support the discussion with three case studies. Finally we discuss virtual actors in the role of teachers (or experts) as to maximise the benefits of OBM and other developments. We forward several prerequisites for such “living”, intelligent, self-aware and social beings that we call Learning and Training Agents (LTAgents).

Analysis

Didactical and pedagogical backgrounds

The main actors in the learning process are students supported by teachers/tutors and ICKT tools. Different learning characteristics according to Montgomery [1995] are: ‘Processing, Perception, Input and Understanding’. This emphasizes that we must harmonize the course materials to different types of student minds and learning styles. In our case the ICKT supported learning material for the BC industry must facilitate different pedagogical approaches, human computer interactions and working culture of BC enterprises.

Method of education	Average retention
Traditional lectures	5 %
Reading	10 %
Audio-visual	20 %
Demonstration	30 %
Discussion group	50 %
Practical applications / exercise	75 %
Self teaching	80 %

Figure 1 The Learning Pyramid of Bales [2001] indicates that the traditional lecture as mode of teaching provides the least retention of knowledge.

The Learning Pyramid of Bales emphasizes the importance of self teaching (learning and training) and advocates self didactic methods. People are different in how they tackle learning and training issues. It seems that 'diverging learning style persons' favour brainstorm, have broad cultural interest, like to gather information and prefer to work in groups. 'Assimilating style persons', on the other hand, prefer information put in concise, logical form and are interested in ideas and abstract concepts. In a learning situation they prefer reading, lectures, exploiting analytical models and require adequate time to think through. 'Converging style persons' like to deal with technical tasks and problems. The 'Accommodating style persons' enjoy challenging experiments and acting on their feelings rather than logical analysis. They also prefer to work with others to get assignments done, to set goals, to do field work and to test out different approaches for completing a project [Kolb & Kolb, 1999/2005].

Nonaka & Takeuchi [1995] suggest the importance of merging tacit and explicit knowledge into creation of new knowledge for organizations with an emphasis on change. This refers to the contexts of learning and training through interaction, followed by an externalization mode triggered by meaningful dialogue or collective reflection, through networking. This is in fact a reference to the necessity of blended modes of learning and training for BC disciplines when autodidact modes are combined with group activities and discussion sessions. It is Kolbs' idea that the ability to both generate and reduce complexity must be a hallmark of academic excellence, which is also crucial for lifelong learning and training of stakeholders of BC disciplines.

Technological backgrounds

The role of educational technology standards in eLearning and eTraining has been the attempt to enable interoperability and compatibility between various available technologies and modes of learning and training. The fundamental concept is reusable ICKT standards focused on semantic information to be attached to these for content management (i.e. idea of Learning Objects, LO). This allows the creation of Sharable Content Objects, which comprise a set of Los, which can be managed as a single entity by an eLearning and eTraining environment. The role of structuring the delivery of the learning content and training skills is currently handled by sequencing specifications that defines through an activity tree how a learner can progress through the content of an eLearning set of knowledge and an eTraining set of skills that can be managed by an Learning Resource Metadata specification (IMS) for learning and training. These standards and specifications are both micro-level specifications, based on LOs and at the macro-level the specifications that address the architecture of learning and training environments. An interesting development relevant to this discussion is Open Knowledge Initiative (OKI) that is developed at

MIT and Stanford as an open-source reference system for Web-enabled education. OKI provides a set of resources with an architecture that is designed to enable the development of easy-to-use, Web-based environments and for assembling, delivering and accessing educational resources. These are useful resources for the realisation of longlife learning and training for BC disciplines.

Hardware requirements for eLearning and eTraining environments

As discussed earlier, eLearning and eTraining are all-encompassing terms generally used to refer to computer-enhanced learning and training. The role of computers in supporting the cause of learning and training processes varies greatly. According to layer 3 of the LTSA[4] (Learning Technology Systems Architecture) standard (IEEE P1484.1) an LTSA-compliant eLearning system consists of a number of computer supported learning processes, information exchanges and storages (components) as shown in Figure 2.

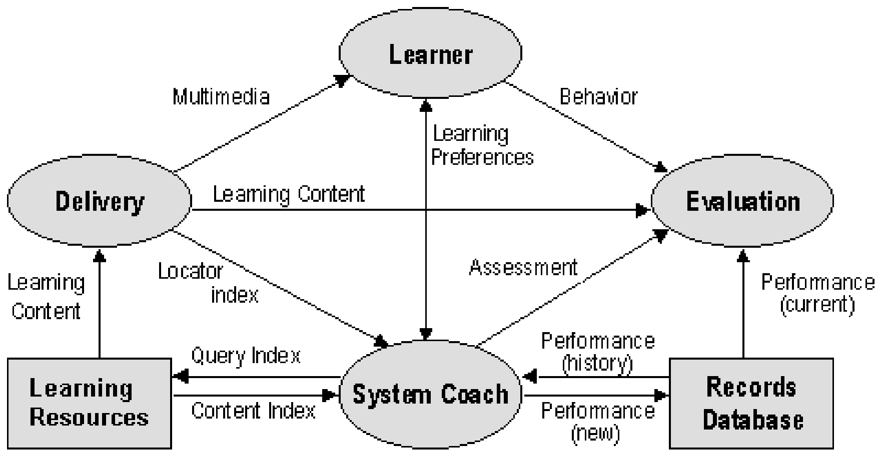


Figure 2 The LTSA system components (source: http://www.informatik.uni-bremen.de/). An oval refers to a process (i.e. Delivery, Learner, Evaluation, and System Coach). A rectangle refers to information storage (i.e. Learning Resources and Record Databases). A line refers to an information exchange component (e.g. Learning Content and Multimedia).

The first eLearning systems were developed in the early 60's of the previous century. The PLATO (Programmed Logic for Automatic Teaching Operations) system developed in 1960 at the University of Illinois at Urbana-Champaign, the first CAI (Computer Aided Instructions) system developed by the Science Research Council and the Wicat system developed by Wicat Systems (later known as Virtual Systems) and based on their authoring tool WISE are seen as the forerunners of eLearning [Sirohi, 2007]. With the advancement of ICKT the possibilities for supporting the learning processes increased dramatically. Currently, a number of state-of-art ICKT is used in modern eLearning (and eTraining) systems such as screencasts, ePortfolios, Personal Digital Assistants, mobile phones, MP3 Players, web-based teaching materials, hypermedia, multimedia, web sites, discussion boards, collaborative software, e-mail, web logs, Wikipedia's, text chat, computer aided assessment, educational animation, gaming and simulation.

In higher education there is an increasing tendency to create so-called Virtual Learning Environments (VLEs) which are 'integrated' eLearning systems incorporating functionalities to interact with existing administrative, student tracking, financial etc., systems. In a VLE all

[4] Note that a number of different eLearning standards are developed or under development, each addressing a specific domain of eLearning. For example, SCORM is a content-related standard with the focus on the portability of eLearning content. Other example is IMS that is a standard with the focus on the learner's profile, learning resource tagging and content packaging. A quick search on the Internet reveals a large number of ongoing, often overlapping, standardisation efforts each addressing a specific domain of eLearning or eTraining.

aspects of a course are handled through a consistent user interface standard throughout the educational institute. Although most VLE systems provide some degree of interoperability, they can be regarded as ’closed’ systems, lacking interoperability with other (educational) systems existing in the same or in different educational institutes. Being able to share digital learning content through open and interoperable eLearning/eTraining systems is a prerequisite for enhancing and strengthening education and training in the BC industry at all levels and in all disciplines.

Blended mode of learning and training environments

Most people consider the elimination of face-to-face contact with trainers and other learners the most serious weakness of eLearning (and eTraining) [Mohaupt, 2005]. In order to overcome the weaknesses and to capitalize the strength of eLearning while maintaining the benefits of traditional (face-to-face) learning, the concept of blended learning has been introduced recently. In the strictest sense, blended learning is when trainers or other learners combine these two methods of education delivery. Several (higher) educational institutes implemented blended learning in dissimilar ways due to a lack of standards. One should be aware that no two blended learning designs are identical and that the combination of eLearning and face-to-face instruction is influenced by many factors such as the course instructional goals, student characteristics, instructor experience and teaching style, discipline, development level and online resources [Osguthorpe & Graham, 2003].

Case studies

This section explains three eLearning experiments that are carried out for three BC related academic subjects. These are respectively the eLearning MSc Programme IT Construction (also known as the ITC Euromaster), an eLearning Parametric Design Course and the MSc Programme Construction Management and Engineering (CME).

Case 1: eLearning MSc Programme IT Construction

The main objective of this project was to develop a curriculum for ‘IT in Construction’ to give students with a university degree in civil, building or structural engineering, surveying, construction or architecture the possibility to extend their knowledge in the application of IT in the BC related disciplines.

One of the immediate positive effects of the project was a continuous cooperation between the partners (10 European universities including TUDelft). A joint teaching experiment between the University of Dresden and the University of Maribor emerged by using videoconferencing and application sharing technology. The main goal of their experiment was to improve the learning and teaching methods and skills with a special focus on Web-based Distant Learning technologies.

The teaching material was presented to the class by a shared presentation application and it was available to the students through the existing web-based platforms of each partner university. Different software (CUSeeme videoconferencing server, VCON MXM server, CUSeeme client, vPoint, client, Click-To-Meet and NetMeeting) and different types of supporting infrastructure were used during the experiment. The separate platforms allowed for individual schedules and additional seminars taught individually. Figure 3 shows the main infrastructure of the course.

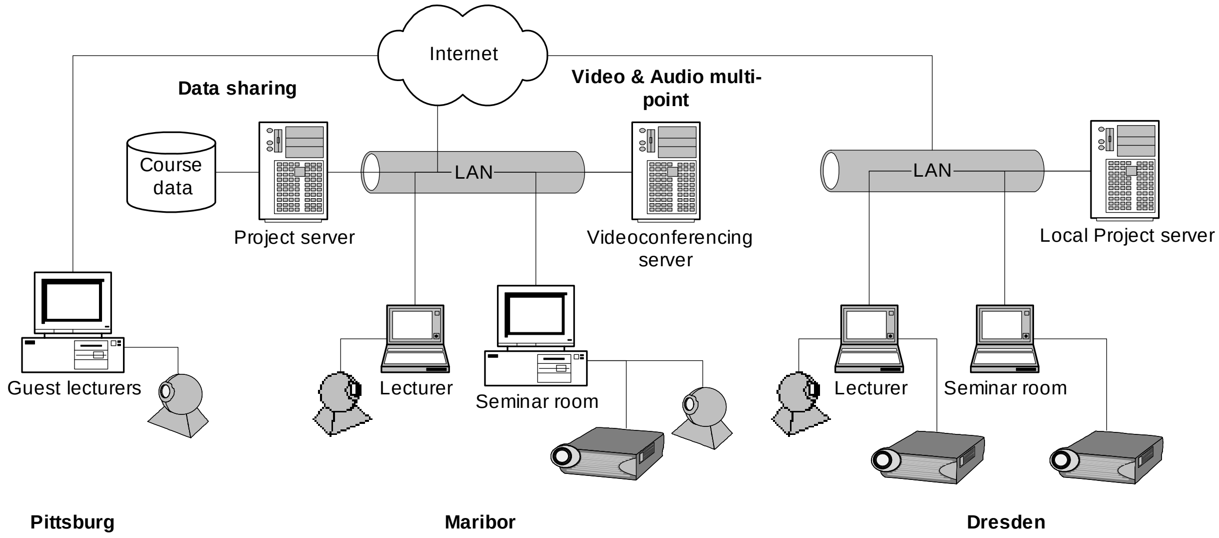


Figure 3 The main infrastructure of the course

The main findings of this experiment revealed the following requirements for eLearning:

- Avoidance of anonymity of the lecturer, by using for example video
- Personal contact with lecturers or teaching assistants for individual guidance
- A sufficient performance of bi-directional audio, video and data transmission
- Application sharing, including the share of control

Case II Parametric Design eLearning Course

The faculty of Civil Engineering and Geosciences at the Delft University of Technology offers elective courses on the application of ICKT for the BC industry. Elective courses are often planned simultaneously with obligatory courses, which prevent students from being present. Following the experience with the ITC Euromaster, an experiment was conducted to tackle the problems of the elective Parametric Design course. The course is meant to teach the basic principles of computer graphics and parametric design systems.

The Click-To-Meet (CTM) environment replaced the lecture hall (Figure 4). CTM is a Client/Server solution for on-line meetings and application sharing. The eLearning environment Blackboard was used to provide the students with all documents related to the course. The lectures were recorded using MS Producer and posted on Blackboard. The students were asked to prepare themselves prior to the eTutorial in their own convenient time. At the communally agreed times (most students were at home) eTutorials were held where the students and the lecturers had animated discussions about the content of the course.

The experience showed that students actually learned the material because they were able to formulate questions and discuss the content of the lecture that increased their insight. One analysis can be that the concentrated attention of the student to the lecture was enforced by a focused look at the screen and any disturbing noises were cut out by the voice of the lecturer in the headphone.

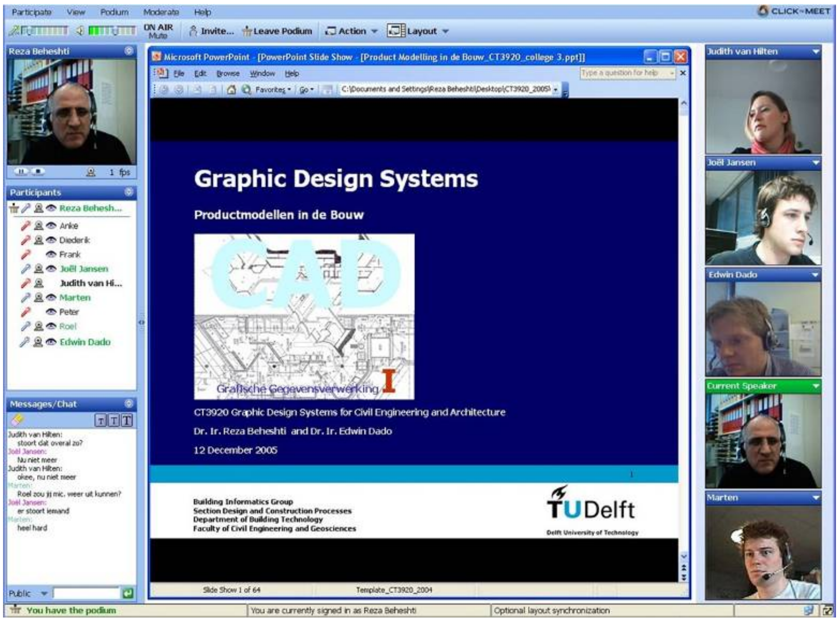


Figure 4 Snapshot of an eLecture session

The enthusiast students noted that they spent time to study on a weekly basis instead of leaving the study to a few days before the examination. Compared with years before the experiment, the students gained a deeper understanding of parametric design systems and computer graphics. They developed insight far beyond the course requirements. In addition the students experienced the proactive participation in the course and the individual time management as beneficial to more effective learning.

The enthusiasm of the students was such that each eTutorial was prolonged beyond the agreed time span of 90 minutes. In particular they noted that for the first time they spent time on studying a course on a weekly basis instead of leaving the study to a few days before the examination. Supervision of exercises was arranged by a small number of eTutorials and by emails (Figure 5).

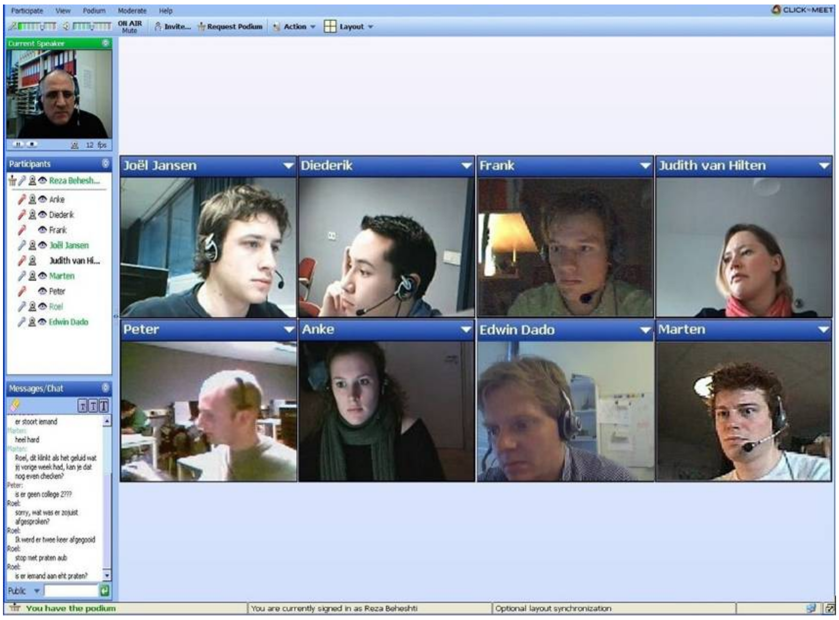


Figure 5 A snapshot of an eTutorial session

Case III: MSc Programme Construction Management and Engineering (CME)

Currently the three Dutch universities of technology have formed a federation (3TU) that facilitates joint education and research programmes in different graduate schools (GS). While most 3TU MSc development groups primarily focused on the development and organization of their curriculum, the ICT & Education and ELO-Groupware (ICT&E) groups tried to sketch a realistic perspective for a future digital learning environment for the 3TU graduate school (GS).

One of the problems of the ICT&E group was that it was not very clear what was needed and when was needed to facilitate the 3TU MSc curricula, which resulted in fragmented solutions. Moreover the three locations of the 3TU GS already implemented different and rather traditional and closed (in terms of interoperability) digital learning environments based on the technology provided by Blackboard (TUDelft), WebCT (TU/e) and TeleTOP (UT). The main idea now is not to replace the existing digital learning environments but to integrate them in such a way that they work together as a single 3TU digital learning environment with a common interface from which students can follow courses independent of location and time. In 2007, the ICT&E group proposed the reference architecture for a future 3TU digital learning environment based on the Service Oriented Approach (SOA). However, at the time writing of this chapter, a common 3TU digital learning environment is still a long term ambition and its development is lacking progress due to financial, technical and political reasons.

For the time being, SURF provides a number of temporary and pragmatic technical solutions. SURF is the higher education and research partnership organization for network services and ICT in the Netherlands. It exploits a hybrid network (SURFnet6) and offers innovative services for security, authorization, middleware, identity management, groupware and videoconferencing. In the academic year 2007/2008 Microsoft SharePoint Portal technology provided by SURF (SURFgroups) became available for central exchange and collection of learning material.

The following conclusions can be derived from a short evaluation about the uptake of the additional digital learning technologies and tools provided by SURF during the first semester of the MSc CME programme:

- Both teachers and students prefer to use their local digital learning environments and functionalities with which they are familiar, above those provided by SURF
- Students from different universities who work together use traditional communication tools such as telephone and e-mail, to discuss and to exchange information rather than using the collaboration tools provided by SURF
- SharePoint Portal technology is being used in only one specific course. However, this technology was not provided by SURFgroups but it was based on the existing course ICT infrastructure at the TU/e
- The differences between the digital learning environments prevented hampered non-native students to use native digital learning environments, even though SURF provides functionalities to transparent access from non-native universities

Prerequisites for BC eLearning and eTraining environments

With the experiences gathered in the case studies, our main objective is to develop a semantic-based, context-aware and cognitive learning and training environment for the BC sector in order to exchange, organise, process and (re)use complex, dynamic construction information and knowledge. In other words our research aims at physically constructing a specific and generic system that can perceive and understand the semantics of construction information conveyed through its perceptual input. This Cognitive Information Environment (CIE) is formed by a community of ‘living’ learning and training agents (LTAgents) that are intelligent, self-aware and capable to exchange information among themselves and towards their environment. This cognitive system will be distributed amongst associated LTAgents that can interact and exchange information. The CIE must evolve (by learning, adapting or improving) in order to achieve a level of autonomy and performance in activities that require context-specific (situation or task) information and knowledge. The CIE aims to maximise automation of the complete information and knowledge life cycle and to achieve semantic, contextual interoperability between actors (teachers and learners on one hand and LTagents on the other hand), in multi-disciplinary processes. Formal learning documentation is kept up to date through content mining (information and knowledge mining) of the dispersed process data, which is available over the Web. Semantic-enabled systems and services are self-organising, robust and scalable. They enable a better mastery of complex, dynamic information and knowledge spaces populated by numerous documents.

Currently formal learning and training documents play a major role in the communication between students and teachers. It forms the information and knowledge spine of these multi-disciplinary and multi-actor learning and training processes. A typical characteristics of the heterogeneous datasets contained in these documents is the uncertain and *dynamic* nature of the information and knowledge. Another important characteristic is that the multimedia content of these learning and training documents is highly interconnected, making it all the more difficult to preserve the integrity of the document base. The inflexibility of traditional eLearning/eTraining and related systems is widely known and it is often the reason that investments do not pay off.

With the arrival of the Next Generation Internet and the Semantic Web, multimedia process information can be based on shared domain-specific ontologies and marked up according to the needs of the receiver (human or machine). The integration of content and services will ensure a continuous and autonomous update of information through various resources over the Web. It thus provides a new way to organize information and knowledge logistics. In addition, recent advances in computational intelligence (including soft computing, distributed artificial intelligence and artificial consciousness) provide a whole new research domain in the area of cognition, self-awareness, perception-guided mental modelling and selective knowledge extraction.

With the starting point described above, one can think of the class of formal LTAgents as context sensitive virtual beings with ‘self-knowledge’, i.e. LTAgents that: (1) update their (multimedia) content if needed, (2) translate and present their content in both human and machine languages, (3) use different multimedia techniques or devices to process and present information and knowledge (even print the content on paper) and (4) behave differently in different circumstances and for different learner’s profiles, for example apply different local rules in different locations or countries or take into account learning capabilities of learners with their own pace of learning. The LTAgent definition goes beyond the paper-based representation of learning and training documents (text, drawing, etc.). It is rather a container to define, represent and present streams of information and knowledge. The semantics of information and knowledge are captured in shared taxonomies and ontologies. In this regard, LTAgents provide a meaningful link between semantics and content.

In this regard two interesting international efforts are Microsoft’s InfoPath and Adobe’s XMP that can be used for preparing learning documents. Both are cutting-edge technologies, based on XML. In both approaches, documents are seen as entities that can understand their content and can act as holders of streams of (multimedia) information. While understanding their content, these LTAgents are able to update their content and represent themselves in multiple ways. Although these new approaches are certainly a good step forward, applying these concepts to complex multi-disciplinary and multi-actor learning environments is extremely difficult as the students and teachers usually have no prior experience of such type of collaboration. Only self-awareness is not good enough: awareness should be extended to a level that the LTAgents are able to understand the surrounding world as well as other LTAgents, humans, machines, etc.

The first prerequisite for an individual LTAgent is a computational base. LTAgent is expected to communicate with humans and therefore it must preferably behave human-like, which will harness considerable processing power. Our brain is a massive parallel distributed computing machine. Possibly the internet with millions of parallel distributed computers can provide this type of machinery. According to computer scientist Gutman [2007], the computer virus Storm Worm Botnet has infected between 1 and 10 million computers and thus the composite system embodies far more than 10 supercomputers. A commercial legal initiative to achieve a similar goal is Seti@Home. A powerful future computer might be a quantum computer. The first commercial 16-qubit quantum exemplar built by the company D-Wave is a fact. A quantum computer with a few thousands qubits (opposed to bits in traditional computers) can solve problems far more complex than current computers can handle. Every extra qubit contributes exponentially to overall performance. It is particularly suitable for complex, inter-related problem solving. However, experts believe that a stable quantum computer with an interesting amount of qubits might still take decades to develop. Computers based on light do provide the principle of superposition but not that of entanglement. Therefore they are not as promising as quantum computers.

A second prerequisite is the ability of self-awareness. LTAgent is no longer a pre-coded situation-specific executable. It rather is a personality that gets moulded by the situation itself, and develops certain skills and interests in time. It does not operate on bit or qubit level but it is a result of the basic system rules. An example is the behaviour of an ant colony, which is far more complex than the behaviour of individual ants that solely obey the rules of odours. Similar is the fascinating behaviour of millions of neurons which again solely obey the rules of electrical conductivity and chemical processes. Both the ant and the brain systems strongly rely on a reliable feedback system (the cerebellum in the brain) that continuously compares intentions with sensory information (cerebellum). Although the basic machinery follows strict rules, the result is a self-aware *spirit*. We consider the feedback mechanism to be the spirit.

The *spirit* focuses on specific learning and training or on instant adaptations as soon as intentions and actual sensory information are too far apart. The ability to focus on the unknown and the unexpected (based on already acquired knowledge) significantly contributes to reduce the complex task of learning and training. Even learning and training themselves strongly rely on feedback mechanisms. One can start learning, do exercises and conclude not to fully understand parts of the material. Consequently one might focus on specific parts of the material to improve skills. Summarized, a *spirit* checks the actual results and focuses on just-in-time self-education or adaptations if needed. If the actual results satisfy the intentions, then the *spirit* might want to share the best practice with others.

The third prerequisite for LTAgent is its social skills and interoperability. A community of interacting actors benefits of far more robustness than a single actor. A single actor that lacks certain skills can query other agents. If collective local knowledge (including archives, etc) fails then LTAgent can query other communities, internet and such. Such queries do require appropriate skills; other actors might be busy, ‘talk’ different languages or simply dislike the inquirer. In this respect, interfaces become important to support social skills. Humans communicate about highly complex matters primarily using voice and vision. This demonstrates that a generic, high-level and imprecise interface (that might not be the most efficient) does fulfil the role of translating high-level instructions into precise lower level ‘machine’ language. It thus eliminates the need for implementing protocols for specific situations. After multiple rounds of time-consuming high-level communication actors might agree on lower level protocols and speed up the process. In fact humans continuously reorganize processes, which is more or less similar to agreeing upon new, faster protocols. The higher communication levels prevent the total organization from failure if low level protocols seize due to unexpected situations. Referring to the ant colony, the colony survives loss of (groups of) ants.

The fourth prerequisite is presence. Research has shown that presence – even in simple forms such as avatars – is very appealing to humans and improves their performance significantly. Androids that use the entire LTAgent environment as a brain can therefore serve as an optimal human-agent interface in learning and training situations. Androids can always communicate mutually even though they have completely different brains, because they will have similar properties (character, skills etc) and a common high-level communication protocol – the human language. Androids might group together to form even higher levels of beings such as specialized companies.

An android has the drawback of necessary physical presence. In the LTAgent environment this is not possible or desirable. Because the LTAgent brain is not restricted to a physical location, it can appear in multiple ways to humans, other androids and LTAgents. They could exchange brains with other androids, appear at multiple locations simultaneously, choose to be an avatar, invisibly work in their virtual workspace and use additional presentation tools such as other devices, systems or environments. The advantage of high-level interfacing capabilities is that a system can always manage lower level interfaces. It will be able to prepare the necessary input and to interpret the outputs. Therefore the LTAgent brain can perform detailed tasks based on high-level semantic interfaces. An example of such a system is one human instructing another using only (imprecise) voice and gestures to analyze the deflections of a bridge in great detail with specific FEM software.

The proposed LTAgent combines semantically enriched learning and training content and methods with multi-agent technology, supported by domain-specific ontologies. These support knowledge-intensive tasks that require reasoning, especially for optimisation of collaboration, communication and control of multi-disciplinary, multi-actor, multilingual, multicultural learning and training processes. The LTAgent addresses the functionality of knowledge systems supporting complex, multi-disciplinary learning and training processes which result in a new generation of tools for supporting automatic acquisition, analysis, annotation, (re)organisation, browsing, filtering, processing and presentation (e.g. as graphs, diagrams, technical drawings or 3D models) of dynamic learning and training.

We propose a new generation of intelligent LTAgents that are self-aware[5], user-aware[6], knowledge-aware[7], process-aware[8], control-aware[9] and content-/context-aware[10]. In a more implicit way, we consider standards and approaches from various trends related to Web content, Web platforms and Web users in order to avoid the mismatch between these trends. The technology to develop such documents is largely available:

- *Cognitive reasoning* based on the newly emerging field of 'artificial consciousness' (AC) and techniques from the field of distributed Artificial Intelligence. Cognition seems to emerge in sufficiently complex distributed systems. Although each individual component cannot build a mental model for its own entity, it can build models for the other entities it distinguishes. Thus the mental model of the whole system is distributed as well. Cognition will enable

[5] Self-awareness is the ability of a learning agent to combine the content with a definition of its internal structure allowing for automatic decoding of the content.

[6] User-awareness is the ability to extract and present information and knowledge for a type of user (i.e. role-based) according to the user profile (e.g. different types of students and teachers).

[7] Knowledge-awareness is the ability to find and retrieve knowledge from knowledge repositories that provide the necessary knowledge about the 'outside' world, including knowledge about the role of the student or teacher in relation to the 'learning agent type(s)' requested by the learner or teacher.

[8] Learning process-awareness is the ability to understand (in addition to knowledge-aware) the business processes, activities and responsibilities attached to user's role.

[9] Control-awareness is the ability to evaluate and implement the degrees of control regarding users (actors and stakeholders) responsibilities and roles in relation to the documents. Furthermore here we refer to the interrelationship between documents themselves regarding communication and collaboration.

[10] Content/context-awareness is the ability to present the content in relation to the context that the content is used in.

LTAgents to visualise such models first for their own contents, then for their environment and their relationship with the other LTAgents.

- *Web content* based on XML technology, can provide the necessary mechanisms for structuring the content of LTAgents. The results of past and ongoing XML-efforts, such as the Semantic Web and the more domain-specific taxonomies and/or ontologies (e.g. ebXML), will enhance the semantic communication between LTAgents.
- *Modelling techniques* (including product-, process- and knowledge modelling), in addition to XML-based taxonomies and ontologies, can provide the necessary mechanisms for structuring multimedia, non-textual data (e.g. shape information), and process and context information of the LTAgents.
- *Web services and platforms* such as .NET and J2EE/JXTA, can provide the necessary ICT infrastructure for the virtual learning environment where LTAgents communicate and exist, including support for the core standards for information and knowledge transfer (e.g. SOAP, WSDL, UDDI and XML).
- *Soft Computing* (artificial intelligence) can provide the necessary mechanisms for LTAgents to act as autonomous intelligent entities that are able to understand the outside world, to be adaptive to changes and to learn from interaction and behaviour of users (learners and teachers) and from other LTAgents. Soft Computing refers to AI-technologies such as data mining, (multiple) Agent Technology, neural networks, fuzzy logic and classifier systems.
- *Mobile communication technology and infrastructure* covers all information resources, channels, processors and interaction devices that can be used to make LTAgents accessible.
- *Text and multimedia recognition* such as automatic text parsing, natural language processing, semantic information extraction, text understanding, and shape and image recognition, can support the construction of self-aware LTAgent components that are able to parse content and information.

The LTAgent's point of view is that any LTAgent can interpret its content by intelligent reasoning and extracting knowledge from it. In this regard, the content of the LTAgent is not static. Self-awareness is of extreme importance in this process because the end-user is not required to participate in the interpretation process. The LTAgent dynamically intelligently decides and restructures itself using an overlay component according to the context, platform and specified conditions at the appropriate time, tailored to end-user characteristics, environment, requirements and specifications. LTAgent as a cognitive being is perceptually enabled and generates appropriate actions and behaviours. In most sophisticated form, a model of situation will be provided by the being that enables reasoning. Also, the perception of LTAgent can directly result in the selection of the appropriate behaviour, execution of an action or a change in focus of attention (with no immediate external manifestation). Arguably the coordination of perception and action in a cognitive system requires reasoning. Such reasoning can occur over multiple time scales and levels of abstraction, exhibiting an appropriate (probably) reflexive behaviour. Also, reasoning may be used to bring actions or behaviour to a desired level or status. Furthermore, the reasoning may also be used to generate new goals or to learn new abilities. LTAgent as a cognitive being is able to form and exploit new concepts by sharing and exchanging concepts with other related LTAgents. Consequently the LTAgent must learn which is not restricted to recognition and categorization. Important areas to address are the ability to learn and coordinate perception-action cycles, to learn procedures to accomplish goals, to learn new concepts, and to learn to improve new plans of actions.

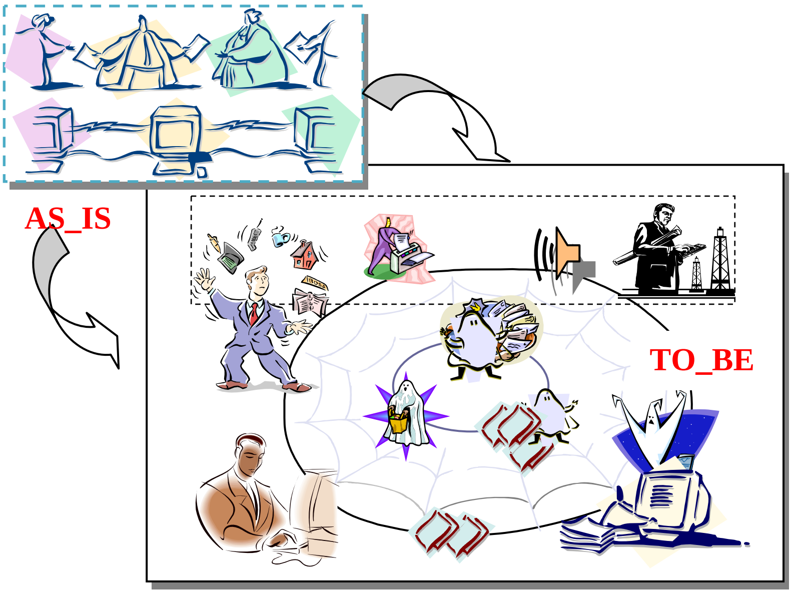


Figure 6 The main idea for LTAgents, explaining the AS-IS and TO-BE situations regarding communication, collaboration and cooperation

A high degree of Soft Computing is involved in this task. First, a learning component is useful since the exact response of the LTAgent to the environmental conditions need not be pre-determined. The response is acquired via an unsupervised interactive incremental learning process that results in a response 'attitude' given certain conditions. The crucial point in this approach is the ability of a LTAgent to transfer (copy or merge) this conditional attitude (i.e. its knowledge) to other LTAgents it interacts with, thus reducing the overall learning curve for a set of interacting LTAgents. Soft Computing is also involved in the reasoning process associated with the LTAgent self-restructuring. The inference engine must be pre-programmed in the LTAgent in order to manage efficiently both the appearance (view) of the LTAgent and the dynamic change of its content. The self-awareness part is constructed using some of the common knowledge representation methods and the science of cognitive reasoning is suitable for this purpose.

The LTAgent paradigm includes the concept of 'responsive' function for improved control of multi-disciplinary, multi-actor, multicultural, multilingual, multimodal processes for learning and training circumstances. 'Responsiveness' here is defined as the LTAgent's ability to act autonomously with respect to its role and goals, which includes reporting the required information and knowledge (also with a multimedia content) to the right receivers at the right time, in the right format and language (both human and machine), on the correct device (i.e. *multimodal*), in the correct media (e.g. voice, text, graphics, VR, etc.) and in the right place (i.e. the correct geographic location). This ability, and the ability to keep their users well informed about their progress, allows the LTAgents to be trusted upon by the users or systems for their reliability and consistency. The following table presents the components and objectives of the LTAgent.

Table 1 Components and objectives of LTAgents

LTAgent
Objectives
This chapter aims to investigate the potentials of a new LTAgent in the form of a *learning and training environment* to (1) *maximise automation of the complete information and knowledge life cycle*, (2) *achieve semantic interoperability between actors* and (3) *improve communication, collaboration and cooperation of complex, multi-disciplinary and multi-actor learning and training processes*. The LTAgent is able to *interpret its content by intelligent reasoning and to extract knowledge from it*. It contains a dynamic overlay component that is able to *re-index the content (and thus the view)* of the LTAgent according to the *contextual conditions*. *Self-awareness is of extreme importance in this process because the end-user is not required to participate in the interpretation process*. The LTAgent *decides and restructures itself according to the context*, platform and *specified conditions at the appropriate time, tailored to end-user's characteristics, environment, requirements and specifications*.
Focus
LTAgent will be equipped with *adapted methodologies, tools and architectures that support the concept of a cognitive, semantically enabled, being*. LTAgent as a *cognitive being* is *perceptually enabled* in order to *generate appropriate actions and behaviours*. In most sophisticated form, *the being that enables reasoning at environmental level provides a model of the situation*. Also, the perception of LTAgent can directly result in the *selection of the appropriate behaviour, execution of goal-oriented tasks or a change in focus of attention* (with no immediate external manifestation). LTAgent as a cognitive being is able to form and exploit new concepts by *communicating, sharing and exchanging of concepts with other LTAgents* in the LTAgent CIE environment.

In the area of fundamental methods, LTAgent puts a new light on the prevailing learning and training paradigm. LTAgent is an innovative new concept of proactive[11], mutually interrogative[12], ambient[13], adaptive[14] and responsive[15] learning documents that are self-aware, user-aware, knowledge-aware, process-aware, control-aware and content-/context-aware. LTAgents can react to information and knowledge mining or analysis requests as well as actively exchange and share both content and knowledge with other LTAgents and their users within the LTAgent CIE environment by hosting various types of (multimedia) content.

[11] 'Proactive' is the ability of a learning agent to learn during the learning life cycle and to act accordingly.

[12] 'Mutually interrogative' is the ability of a learning agent to consult and negotiate with other learning agents and to synchronise and/or update its content. In addition to its 'self-awareness', a learning agent is able to exchange experience with other learning agents.

[13] '*Ambient'* is the characteristic of the *virtual eWork environment* wherein learning agents operate.

[14] 'Adaptive' is the ability of a learning agent to adapt its behaviour or content to changing circumstances, users, conditions, platforms and devices.

[15] 'Responsive' is the ability of learning agents to carry responsibility, i.e., try hard to reach their goals, report the required information and knowledge (multimedia content) to the right users, at the right time, in the right format and language (both human and computer languages), on the correct device (i.e. *multi-modal*), in the correct media (e.g. voice, text, graphics, VR) and at the right place (i.e. the correct geographic location). This ability of learning agents and the ability to keep users well informed about their progress enable users and systems to trust upon learning agents for their reliability and consistency.

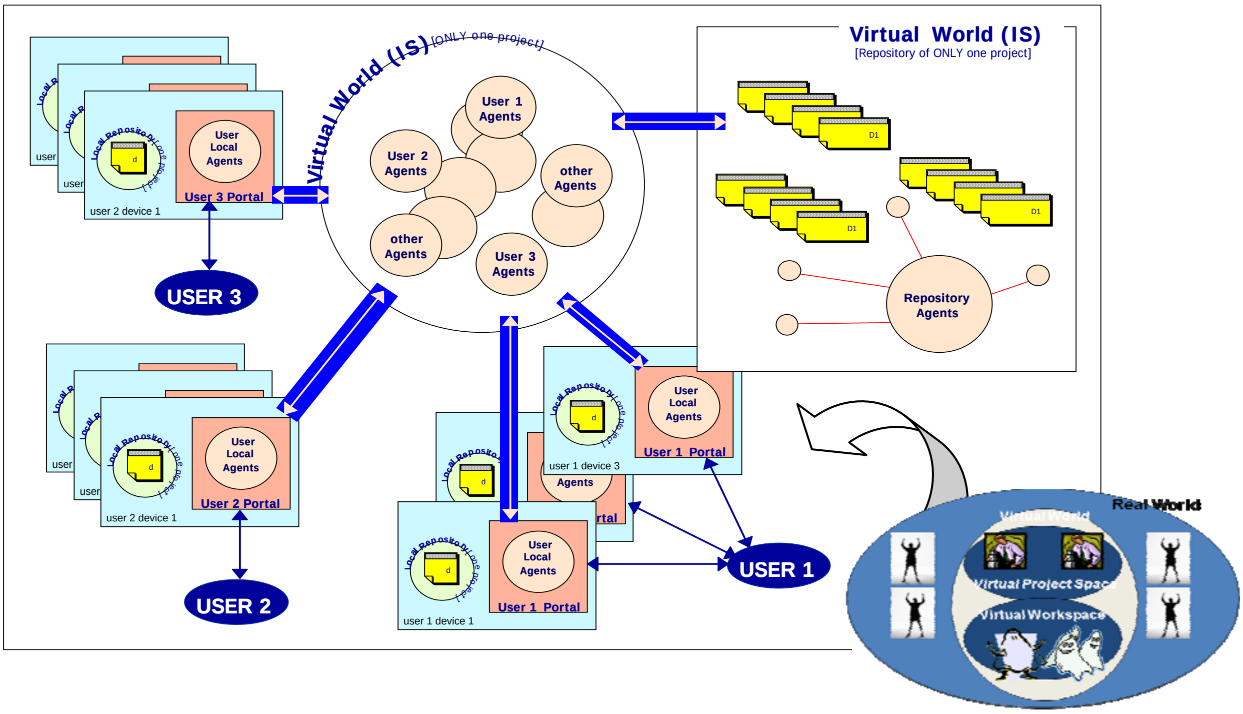


Figure 7 The characteristics of the virtual environment in which LTAgents reside

LTAgents identify, specify and formulate a new comprehensive, integrated formal model for learning paradigm, its infrastructure and CIE environment. In the field of formal models, the knowledge representation is extended from information in context to information and context. The less focused description of context and knowledge allows for adaptively building knowledge models around the primary content dimensions. Context knowledge (i.e. disciplines, roles and tasks) is initially targeted to enable ambient intelligence in interdisciplinary document-based CIE environments. The coordination and control of information and knowledge are often specified on a document meta-level but remain disconnected from the content. Semantically well-grounded task specifications, defining business processes, are established in order to allow the identification of actors or stakeholders and the analysis of their interrelationships.

LTAgent explores new methods of learning and training. In addition to common methods of analysing the (human) knowledge generation processes or unsupervised clustering methods, LTAgent focuses especially on the domain/background knowledge that is encapsulated in domain-specific concept models of more complexity. LTAgents use this knowledge to guide the learning and training processes. In interdisciplinary learning and training environments, the information models of applications and the corresponding mental models of users (learners and trainers) determine the focus, structure and language of LTAgents. Learning from data and engineering models as well as from operational context information provides a clearer description of users' view of the real world or their particular learning documents, and helps to clarify the corresponding rationales. On a component level, this externally and/or internally generated information on technical, information and knowledge models is used utilized to identify, analyze, process and visualize information, in indexing, browsing, filtering and visualizing services.

The LTAgents as an intelligent information and knowledge provider enables easy interconnection of end-users (learners and trainers). LTAgents also support the re-engineering of new learning processes that especially rely on mobile technology and ubiquitous computing. The following list summarizes the above mentioned discussion regarding the specifications, characteristics and conditions of LTAgents:

- Web-enabled
- Knowledge-aware
- Content and Context aware
- Process aware
    - Content can be process information
    - Context always contains process || Activities
- It should be driven by user and the context
- Communicative (content || context || knowledge)
- Role-based (ambient)
- Self aware and pro-active
- Capability to classify (content || context || knowledge)
- Adaptable and learning

Artificial Characters in Virtual Learning Environments

Virtual agents such as LTAgents have *character*, charisma, and wisdom (Figure 8). The *character* holds the information about the physical properties such as trait, feat, and profile. In addition, the character has a set of *skills* related to the agent's profession. The skills are a set of *languages* it understands and uses, and the capability to learn and *educate* it self. Furthermore, it performs a certain intelligence that knows what *knowledge* it has. As an example, the company Virtual Personalities developed a character available via the Internet. The agent is capable of understanding neural languages. It is capable of making dialogs about certain subjects. In the future, we could expect more applications of agents as virtual partners in BC processes.

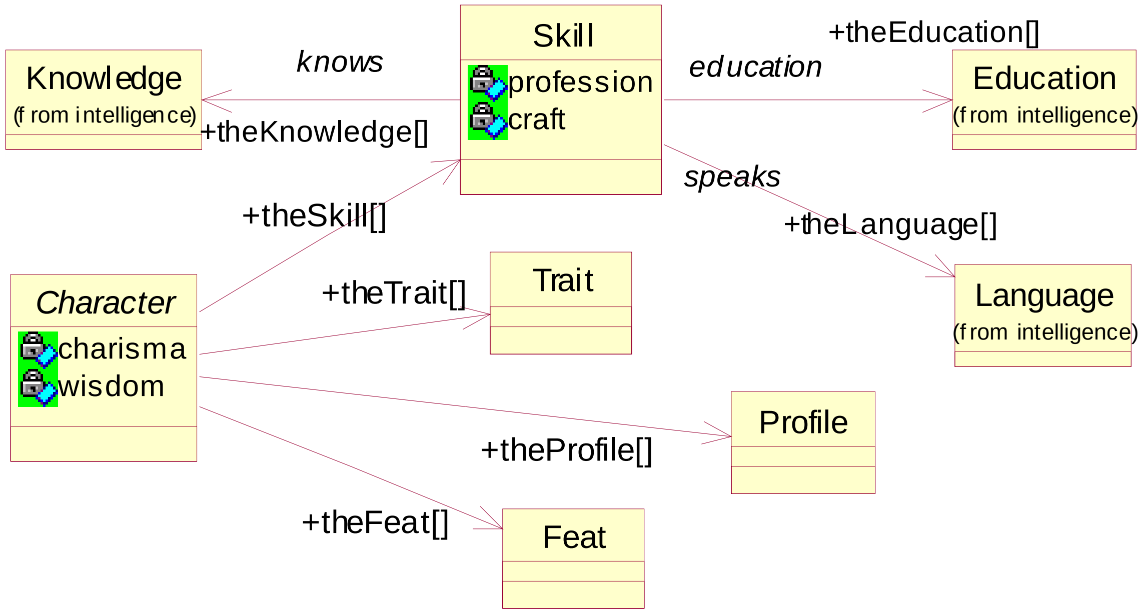


Figure 8 Knowledge and artificial character

Results and Business Impacts

Key Findings

Traditional learning (face to face) and eLearning/eTraining (just-in-time, personalized, continuous, time and location independent) both have their specific benefits and weaknesses. In order to maximize the benefits and to avoid the weaknesses of both a blended mode of learning and training is recommended.

Learning by doing is an efficient way of learning. An active Cognitive Information Environment (CIE) implemented directly into a company's production environment is an excellent way to provide an eLearning or eTraining environment that fits to the specific needs of the BC industry and provide a better return on investment than more traditional approaches.

Business Impacts

The BC industry will benefit from a custom tailored just-in-time learning and training environment that is seamlessly integrated with an employee's personal production environment. Employees will perform better because they will be stimulated to learn and train their newly acquired knowledge directly in their production environment. In this regard it is beneficial for the business as a whole. Products will improve because employees learn much more about production if learning and training materials are tailor made and easily accessible for combined production and learning/training purposes.

The interactive autonomously learning Cognitive Information Environment (CIE) will improve knowledge preservation throughout the business and further reduce the amount of time that employees spend to find relevant information. Integration with the production environment is beneficial for both humans and the CIE itself.

A CIE will be a significant investment, but the return on investment will be high. It also is a way of both preserving a company's knowledge and exchanging knowledge within the company (i.e. knowledge management), which makes the company less vulnerable for problems of the increasing shortage of higher qualified staff as a result of demographic ageing and the increased mobility of labour.

Conclusions

The main motivation for this research lies in the particularities of the current generation of eLearning systems with respect to the current trends in the BC industry. Open Building Manufacturing is one of these trends that fundamentally changes the way we design and construct buildings. It is very difficult to transform the ways of "deciding, doing, acting and responding" in an industry that did not change for decades or even centuries. It poses a true challenge for the traditional institutes in terms of education delivery. Instead of delivering very static (traditional) educational programmes, universities need to adapt their academic programmes dynamically to the demands arising from the new developments within the industry and to the specific needs of individual employees as part of their lifelong educational programmes.

The higher educational institutes are currently transforming themselves from traditional learning institutes into lifelong learning institutes. The application of eLearning/eTraining, i.e. an all-encompassing term generally used to refer to computer-enhanced learning or training, is seen as one of the key enablers for this transformation process. In order to overcome the most important weakness of the current eLearning/eTraining approaches, i.e. the reduction of face-to-face contact to trainers and other learners, higher educational institutes started to embrace the concept of blended modes of learning and training. Blended learning and training, in the strictest sense, are the combination of eLearning/eTraining with traditional face-to-face learning and training. However, this relatively new concept of blended learning/training poses questions whether the current generation of eLearning/eTraining systems are able to support such blended processes. As discussed in this chapter a number of limitations of the current generation of eLearning/eTraining systems could be addressed.

In order to overcome the limitations of the current generation eLearning/eTraining systems and adequately support blended learning/training processes the potentials of a new paradigm of a Cognitive Information Environment (CIE) is discussed in this chapter. This CIE is formed by a community of ‘living’ learning and training agents (LTAgents) that are highly intelligent and self-aware as well as being able to exchange information among themselves and towards their environment. This chapter argued the advantages of a paradigm shift for the BC industry of the future wherein a lifelong learning and training is crucial for the success and survival of the industry in a rapidly changing world. The BC industry needs to embrace new technologies and innovations in an increasingly knowledge driven future. The latter is one of the crucial factors for giving the BC industry a competitive advantage.

Practical Tips

- It is very difficult to transform the ways of “deciding, doing, acting and responding” in an industry that did not change for decades or even centuries.
- Embed lifelong eLearning and eTraining in company policy at all levels using knowledge driven ICKT.
- Apply blended modes of learning and training to prevent the eLearning/eTraining system from becoming impersonal. People appreciate face-to-face contact.
- Let both human and virtual actors participate in the role of teachers (or experts).

References

Agent (2001). http://www.msci.memphis.edu/~franklin/AgentProg.html

Bales, R. F. (2001). Social interaction systems: Theory and measurement, Transaction Publishers

Bartlett-Bragg, A. (2005). Preparing for the Future, International Journal of Design Sciences and Technology, 12:2

Beheshti, R. & Dado, E. (2005). Introducing an eLearning Environment, International Journal of Design Sciences and Technology, 12:2

Beheshti, R. & McKechnie, L. (2005). The Challenge of Virtual Learning Environments, International Journal of Design Sciences and Technology, 12:2

Beheshti, et al (2005). LiveDocs Research Proposal (not carried out).

Collins, A., Neville, P. & Bielaczyc, K. (2006). The Role of Different Media in Designing Learning Environments [www.apc.src.ncu.edu.tw/apc/allanmedia.htm]

Dado, E., Beheshti, R. & Nederveen, S. van (2007). IT education and utilization within the upcoming shared master of science in construction management and engineering in the Netherlands. In: Proceedings of CIB W78 Conference, 26-29 June2007, Maribo

Delhoofen, P. (1991). Learning theories, Universität Wien

EDRS (2000). The power of digital learning, Forum on Education and Technology, Washington DC

Finin, T., McKay, D., Fritzson, R. & McEntire, R. (1994). The KQML information and knowledge exchange protocol. In Third International Conference on Information and Knowledge Management.

Gijselaers, W., & Schmidt, H. (1995). Effects of quantity of education on time spent on learning and achievement. Educational Research and Evaluation, 1, 183-201.

Gutman, P. (2007) http://seclists.org/fulldisclosure/2007/Aug/0520.html

Hebrew (2001). http://www.cs.huji.ac.il/labs/dai/wkshp/index.html

Humair, J.P., & Cornuz, J. (2003). A new curriculum using active learning methods and standardized patients to train residents in smoking cessation. Journal of General Internal Medicine, 18, 1023-27.

Ingraham, B.D. (2000). Schlarly rhetoric in digital media, Journal of Interactive Media in Education (www-jime.open.ac.uk/00/ingraham)

John R. Savery, J.R. and Duffy, T.M. (1995). Problem Based Learning: An instructional model and its constructivist framework. In: Wilson, B. (ed.), Constructivist Learning Environments: Case Studies in Instructional Design, Educational Technology Publications Englewood Cliffs, NJ

Kazi, A.S. et al eds. (2007). Open Building Manufacturing, ManuBuild/VTT, Helsinki, Finland

Kolb, A., and Kolb, D. A. (1999). Bibliography of research on experiential learning theory and the Learning Style Inventory. Department of Organizational Behavior, Weatherhead School of Management, Case Western Reserve University, Cleveland

Kolb, A.Y. & Kolb, D.A. (2005). The Kolb Learning Style Inventory: Technical Specifications. Department of Organizational Behavior, Weatherhead School of Management, Case Western Reserve University, Cleveland

KQML Spec2 ARPA Knowledge Sharing Initiative. (1992). Specification of the KQML agent--communication language. ARPA Knowledge Sharing Initiative, External Interfaces Working Group working paper. Available as http://www.cs.umbc.edu/kqml/.ps.

Laurillard, D. (1993). Rethinking University Teaching, Routledge, London

Lee-Kelley, L., Blackman, D. & Good, B. (2005). The Implications of Strong Mental Models on Innovation in eLearning: A case study, International Journal of Design Sciences and Technology, 12:2

Liu, Y-T. & Lim, C-K. (2006). New Tectonics: A preliminary framework involving classis and digital thinking, Design Studies, 27:3, pp. 267-307

Molen, H. van der et al (2005). Editorial, Journal of Ergonomics in Building and Construction, 36:4 387-389

Montgomery, S.M. (1995). Addressing diverse learning styles through the use of multimedia. Proceedings of the 25th Frontiers in Education Conference. Atlanta

Naur, P. (2007). Computing versus human thinking, ACM, 50:1, pp. 85-94

Negraponte, N. (1995). Being digital, Hodder & Stoughton, London, UK

Nonaka, I., & Takeuchi, H. (1999). The knowledge creating company: How Japanese companies create the dynamics of innovation: Oxford University Press, London

Osguthorpe, R. & Graham, C. (2003). Blended learning environments: definitions and directions. Quarterly Review of Distance Education 4(3): 227-233

Özsariyildiz, S.S., Zreik, K. & Beheshti, R. (2007). Digital learning environments for architects and engineers. In: De Paoli, G., Zreik, K. and Beheshti, R. eds., Digital Thinking, Europia Productions, Paris

Piaget, J. (1977). The development of thought: Equilibrium of cognitive structures. New York: Viking Press

Prochaska, J.O., Di Clemente, C.C., & Norcross, J.C. (1992). In search of how people change: Applications to addictive behaviours. American Psychologist, 47, 1102-14

Rosenberg, M.J. (2001). eLearning: Strategies for delivering knowledge in the digital age, McGraw-Hill, New York, USA

Ruitenbeek, HKM van de & Beheshti, R (2007). Human-Machine Interfaces for Structural Engineers in a Problem Solving Environment. In: BHV Topping (Ed.), Proceedings of the ninth international conference on the application of artificial intelligence to civil, structural and environmental engineering (pp. 1-12). Stirlingshire, UK: Civil-Comp Press

Scott, R. & Bradley, E. (2005). Whither the Virtual Academic? An examination of the implementation of managed learning environments within higher education, International Journal of Design Sciences and Technology, 12:2

Secker, J. (2004). Electronic resources in the virtual learning environments, Chandos, Oxford, UKCarlson, R. and Wilmot, W.W. (2006). Innovation, Crown Business, New York, USA

Sirohi, V. (2007). eLearning : An Overview. Proceedings of the 5th conference on E-governance, India.

SkillSoft (2006). The Future of Learning, Benchmark Study 2007, SkillSoft, London, UK [www.skillsoft.com]

Smit, D., Wall, J., Taylor, C. & Betts, M. (2006). eLearning Modules: increasing knowldege of collaboration tools for construction management. In: Proceedings CRC Construction Innovation Clients Driving Innovation: Moving Ideas into Practice, Gold Coast

Stutt, A. & Motta, E. (2004). Semantic Learning Webs, Journal of Interactive Media in Education, 2004:10 [www-jime.open.ac.uk/2004/10]

Suhonen, J. & Sutinen, E. (2006). FODEM: developing digital learning environments in widely dispersed learning communities, Educational Technology & Society, 9:3, 43-55

Van Der Drift, K. & Vos, P. (1987). Anatomy of a Learning Environment, Swets & Zeitlinger, Lisee

Wall, J., Smit, D. & Betts, M. (2006). A strategy to use eLearning to disseminate the benefits of construction management software to students and industry: An Australian initiative. In: Baldwin, A. et al (eds), Proceedings Bear 2006, Construction Sustainability and Innovation, CIB W89, Hong Kong

Zreik, K. ed (2000). Learners' WWW: Web based learning, wireless based learning, web mining, Europia, Paris, France

Author Biographies

Dr. Reza Beheshti is Associate Professor of Design and Building Informatics at Delft University of Technology, Department of Building Technology. He obtained his PhD from RCA in London in Design Research in 1981. Prior to this PhD research period, he worked for a large Architecture and Engineering Consultancy as the Chief Architect. His specialisations are in Advanced Design Systems, Building Informatics, Parametric Design, Construction IT, Process Innovation, eLearning and Design Methodology. He has authored numerous papers and books in these fields and has participated in a number of national and European research projects.

Dr. Edwin Dado is Associate Professor at the Netherlands Defense Academy. Prior to his current position, Edwin Dado obtained his PhD in Construction IT from Delft University in 2002, where he was appointed as Assistant Professor. Prior to this PhD research period, Edwin worked for a large engineering company in the Netherlands as head of the GIS/Informatics department for five years. His specializations are in Construction IT, process innovation and construction management and authored over forty papers in these fields. He also participated in number of national and European research projects.

H.K.M. van de Ruitenbeek got his MSc in Civil Engineering with special focus on ICKT at Delft University of Technology in 2003. Currently he is a part-time PhD student at Delft University of Technology, Department of Building Technology. The subject of his PhD research is Human Machine Interfaces for Structural Engineers wherein he investigates theoretical and practical applications of HMI for civil engineering discipline. In the remaining time he works for Volker Stevin as a civil engineer, where he implements a BIM (based on the COINS initiative) in a pilot project. In this specific pilot project, the BIM will allow civil engineers to cooperate using systems engineering, object libraries and a variety of drawing and calculation software.

9

Virtual Reality Interactive Learning Environment

Wafaa Nadim, Mustafa Alshawi, Jack Goulding, Panagiotis Petridis, and Mark Sharp

VR Simulation Session Interface

Virtual Reality Interactive Learning Environment

Wafaa Nadim, Salford University, UK, w.nadim@salford.ac.uk

Mustafa Alshawi (Ph.D), Salford University, UK, m.a.alshawi@salford.ac.uk

Jack Goulding (Ph.D), Salford University, UK, j.s.goulding@salford.ac.uk

Panagiotis Petridis (Ph.D), Coventry University, UK, PPetridis@cad.coventry.ac.uk

Mark Sharp (Ph.D), CIRIA, UK, Mark.Sharp@ciria.org

Abstract

Open Building Manufacturing (ManuBuild) aims to promote the European construction industry beyond the state of the art. However, this requires the different stakeholders to be well informed of what 'Open Building Manufacturing' actually entails with respect to understanding the underlying concepts, benefits and risks. This is further challenged by the 'traditional ways of learning' which have been predominantly criticised for being entrenched in theories with little or no emphasis on practical issues.

Experiential learning has long been suggested to overcome the problems associated with the traditional ways of learning. In this respect, it has the dual benefit of appealing to adult learner's experience base, as well as increasing the likelihood of performance change through training. On-the-job-training (OJT) is usually sought to enable 'experiential' learning; and it is argued to be particularly effective in complex tasks, where a great deal of independence is granted to the task performer. However, OJT has been criticised for being expensive, limited, and devoid of the actual training context. Consequently, in order to address the problems encountered with OJT, virtual reality (VR) solutions have been proposed to provide a risk free environment for learning without the 'do-or-die' consequences often faced on real construction projects.

Since ManuBuild aims to promote the EU construction industry beyond the state of the art; training and education therefore needs also to go beyond the state of the art in order to meet future industry needs and expectations. Hence, a VR interactive learning environment was suggested for Open Building Manufacturing training to allow experiential learning to take place in a risk free environment, and consequently overcome the problems associated with OJT. This chapter discusses the development, testing, and validation of this prototype.

Keywords: Construction Industry, Learning, Open Building Manufacturing, Training, Virtual Reality

Background

Industrial Context

The EU construction sector is one of the largest industrial employers in the European Union, encompassing more than 2 million enterprises with about 12 million employed. Hence, this represents a significant importance to the European economy with a Gross Domestic Product (GDP) contribution of 9.8%, and European employment with an overall employment rate of 7.1% of the European workforce (Business Watch, 2005). The EU construction industry is however constantly facing challenges, not least, it has been criticised for its poor performance compared to other sectors/ industries. Moreover, it is argued that construction firms often pass up opportunities in new markets due to lack of relevant skills; which has been attributed to, among others, the reduced attractiveness of construction activities (ECTP, 2005). In this regard, the construction industry tends to lag behind other industries in taking advantage of new technologies and innovative practices; and hence, compromises improvements in safety, cost-effectiveness, quality of life, competitiveness, productivity etc. (DfEE, 2000).

With respect to the uptake of new technologies by the construction industry to improve performance; despite the acknowledged high quality results of EU research projects; dissemination and adoption of results by the construction industry are however, not overtly prominent (Rezugi and Zarli, 2006). This has been attributed to the 'unpreparedness' of the workforce (Gurjao, 2006; Leitch, 2005; Harrison, 2005). In this regard, training is anticipated to help support organisations' expansions and development due to its association with 'greater productivity gains'; implying a 'significant' return on investment (ROI) for employers, as well as the gains it can bring to individuals in terms of greater employability in the labour market (Harrison, 2005; Finegold and Soskice; 1988). In this context, it is postulated that training can help communicate and demonstrate technological solutions/benefits to the construction industry stakeholders through the leverage of aligned and relevant skill sets.

*Manu*Build requires the extensive transfer of knowledge and technology to clients, suppliers, and small to medium enterprises (SME's); and hence, requires change to the whole business process, the organisational structure, roles and responsibilities, information technology, and the creation of shared values and skills. Hence, the implementation of effective training is could be to strengthen and broaden the impact of *Manu*Build to the whole industry by addressing and fulfilling the needs of the different stakeholders in the industry. However, 'typical' learning models are often criticised for providing general instruction, with the anticipation that the prospective employer would be responsible for delivering on-the-job training; i.e. providing experience-based training. In this respect, experience-based or 'experiential' learning has the dual benefit of appealing to the adult learner's experience base, as well as increasing the potential of performance change. In this regard, structured OJT has emerged as a core method of capitalising more 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 has also been criticised for being expensive and somewhat limited in training context (Clarke and Wall, 1998).

Problem

*Manu*Build Training aims to introduce *Manu*Build knowledge, innovative results, and technologies to the EU construction industry by using innovative delivery mechanisms. Hence, a proactive training approach was adopted to satisfy these challenges, as the introduction of new technologies and processes often necessitate the creation of entirely different jobs as well as the acquisition of an extensive range of new skills (Buckley and Caple, 2004; Hackett, 1997). Thus, drawing on the Chinese proverb "*I hear and I forget, I see and I remember, I do and I understand*"; this reinforces the issue that learning can be more effective through 'doing' rather than through 'hearing' or 'watching' (Snee, 1993; Rosenthal, 1995; Koo, 1999; Roussou, 2004; Amthor, 1992). Therefore, the *Manu*Build training approach incorporated an innovative proactive experiential learning approach which links theory with practical experience, using a VR interactive learning environment (Alshawi *et al.*, 2007).

Virtual Reality is argued to have numerous definitions (Bouchlaghem *et al.*, 1996): e.g. '*a computer generated simulation of the real world*', '*the illusion of participation in a synthetic environment rather than external observation of such an environment*', or '*a computer-generated simulation of three-dimensional (3D) environment, in which the user is able to both view and manipulate the contents of that environment*' etc. Hence, VR can be considered a 3D interactive computer-generated environment which represents models of real or imaginary worlds, and hence, provide an opportunity to view problems through more than one symbolic representation for greater understanding (Osberg, 1992). Thus, from a training perspective, using an interactive training simulator can provide means to get the trainee experience the training goals (Magerko and Laird, 2002). Hence, an 'ideal' interactive training simulator, is argued to require a richly defined world, with large amount of actions available to the trainee, just as in the real world. Therefore, each time the trainee starts the system, different interactions would lead to different experiences, thereby maximising the learning experience. In the same context, Agapiou (2006) introduced a simulation game as part of an active learning approach, which encompassed role play in a scenario-driven environment. Therefore, the use of a simulator approach was seen as an important driver for further enhancing the underlying concepts of the subject matter (Spedding, 2003).

In a construction environment, VR has been employed for analysing issues occurring on the construction sites, such as: engineering design, process, logistics concerns, as well as operatives training etc. (Blümel *et al.*, 2004; Bargstädt and Blickling, 2005). In this context, VR training environments have arguably not yet fully reached the potential of reducing training time, providing a greater transfer of expert knowledge; or supporting decision making. This was primarily down to the ways in which this technology was augmented. It is therefore argued that educational training tools need to 'engage' learners by putting them in the role of decision makers and 'pushing' them through challenges; hence, enabling different ways of learning and thinking through frequent interaction and feedback, and connections to the real world context (Anderson, 1983; Brandsford *et al.*, 1999; Becta, 2001; Presnky, 2001; Jayakanthan, 2002, Kirk, 2004; Mitchell and Savill-Smith, 2004; Goulding *et al.*, 2007). Garris *et al.* (2002). Furthermore, it is postulated that paring instructional content with game features, could engage users more fully, hence, help to achieve the desired instructional goals. In this respect, the development team applied an input-process-output model (Garris et al., 2002) of instructional games and learning to design an instructional program which incorporated certain features or characteristics from gaming technology; which trigger a cycle that includes user judgment or reactions, such as enjoyment or interest, user behaviour such as greater persistence or time on task, and full learner feedback.

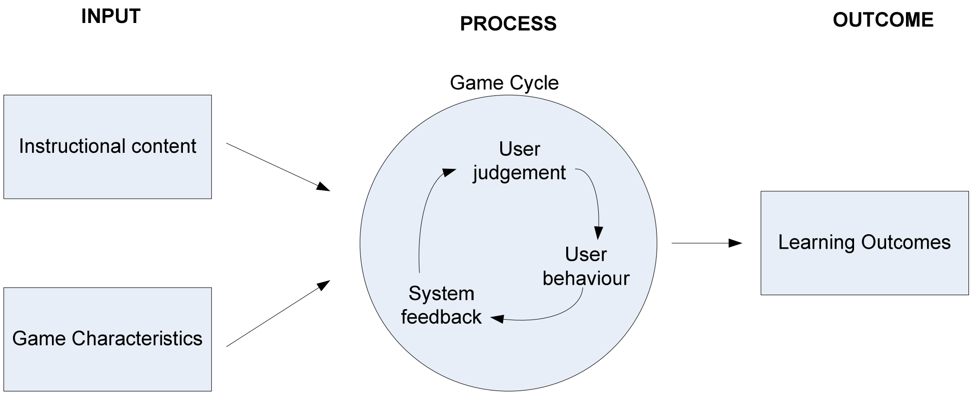


Figure 1: Instructional Game Model Input-Process-Outcome

(Garris et al., 2002)

The use of 3D, 4D, and nD simulation is widely known and used in the construction industry. However, these have been criticised for simulating the construction processes providing all circumstances are optimal; i.e. no external interruptions such as human failures, weather conditions, Health and Safety issues exist (Vries *et al*., 2004). Furthermore, from a construction industry perspective, training using VR applications are somewhat rare (Sawhany and Mund, 1998; Vries *et al*., 2004); and limited to one type of recipient e.g. a construction manager, planner etc. That being said, the Construction Manager Training Simulator (BMSC) in the Netherlands has made a positive inroad into exploitation of this technology (Vries *et al*., 2004); and a similar arrangement has recently been launched in the UK under the project ACT (http://www.act-uk.co.uk/). Both these VR training system were designed to ensure that (potential) construction managers encountered similar situations and problems usually faced on 'real' construction projects using virtual building sites. However, whilst these approaches extol a number of benefits e.g. "challenging, exiting, and rewarding"; the counter to this is that they only really target one beneficiary (construction managers). Furthermore, their environment also limits 'real' virtual interaction as they depend largely on 'real' actor support (which may represent a cost burden in addition to the travelling requirements of learners).

Potential Solution

Key Requirements

*Manu*Build training aims to provide a flexible, interactive, safe learning environment for practicing new working conditions with respect to offsite production (OSP) in general, and Open Building Manufacturing (OBM) in particular; without the do-or-die consequences often faced on real construction projects. Hence, a VR interactive learning environment was sought which builds upon the multi-disciplinary practice-based training concept (Alshawi *et al*., 2007). In this context, the prototype aimed to enable disparate stakeholders, with different professional specialisations, to be exposed to the various aspects of OSP/*Manu*Build concepts. This approach was adopted in order to help overcome the problem of 'compartmentation' of knowledge (Mole, 2003). Furthermore, the prototype had to be flexible enough to allow any-time-any-place learning, so as not to be constrained to a particular place or time for learning to take place.

Approach

The main aim of the *Manu*Build training approach was to embrace 'real life' issues facing OSP construction projects in order to appeal to professionals by engaging and challenging them to find 'real life' solutions to problems often encountered on site. Hence, a real construction project was used to govern the authenticity of the learning environment. In this context, the prototype learning simulator would allow 'things to go wrong', and hence, allow 'learning through experimentation' or 'learning by doing'. In this respect, although the 'scenes' within the simulator take place on a construction site, the target audience is focussed primarily on construction professionals e.g. project managers, construction managers, architects, designers, commercials, suppliers, manufacturers etc. Thus, the construction site was used as the main domain through which all the unforeseen issues and problems (caused through upstream decisions, faulty work etc) could be enacted, so that real implications could be better appreciated in respect of time, cost, resources etc. The real raison d'être was not to solve OSP problems, but rather allow things to 'go wrong' and demonstrate the implications of decisions taken. Furthermore, learning is reinforced through a debriefing session, where learners are able to demonstrate additional understanding, particularly with respect to mitigating such issues in future OSP construction projects. In this context, learning occurs through the following:

- Users have complete autonomy to make all decisions;
- The environment provides feedback on the decisions taken, and their implications on the overall project (cost, time, resources, health and safety, etc);
- Users are able to defend decisions on the feedback provided, and have the ability to identify means to avoid/mitigate potential problems in the future such as:

- OSP strategies e.g. Design for Manufacture Logistics and Assembly (DFMLA);
- Business processes, procurement/contractual arrangements, project management, quality assurance etc;
- Health and Safety procedures;
- Supply chain integration;
- New manufacturing technologies, open system, etc.

VR Simulator Development Concept

The main concept of the simulator is based on its ability to run scenarios through a VR environment to address predefined training objectives. In this respect, learning is driven by problems encountered in this environment, supported by a report critique on learners' choices, rationale, and defence thereof. In this respect, the development encompassed two phases. Phase I embodies the development of the various scenarios, including the generation of reports etc; and Phase II, includes the 'intelligence' components, including the interrogation of learners regarding their understanding, along with the assessment engine – see Figure 2.

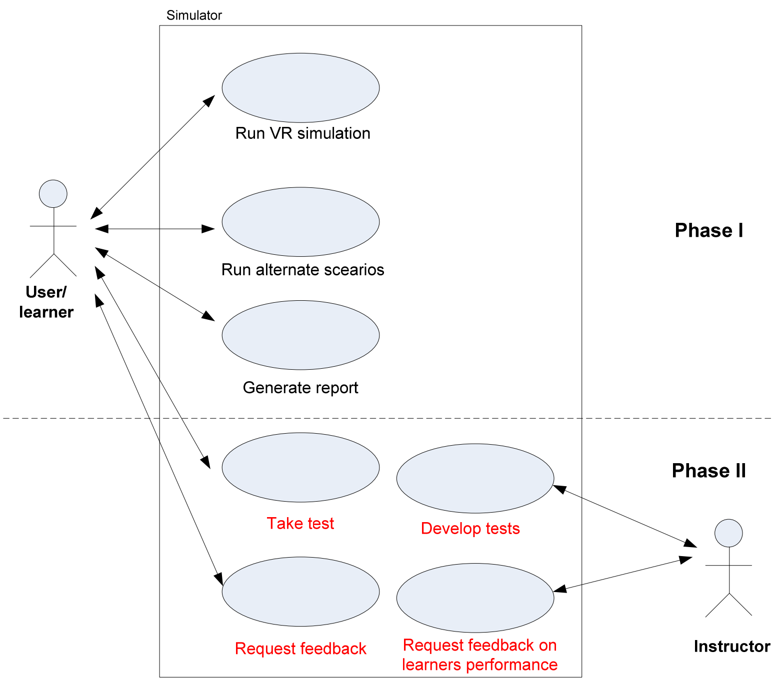


Figure 2: Simulator Development Phases

In light of the *Manu*Build training aim and objectives, this prototype was designed to satisfy the following criteria:

- That all scenarios and scenes should take place on a virtual construction site;
- That learners would predominantly play the role of a construction manager;
- That messages and training objectives would target the different stakeholders involved in a construction project. e.g. project managers, designers, architects, consultants, suppliers, manufacturers, etc;
- That OSP/ ManuBuild working practices would be incorporated;
- That a user-friendly and highly interactive interface would be developed.

VR Simulator Development Framework

The simulator development framework encompasses four main activities: (Identify training objectives; Develop scenario(s); Develop the VR environment; and Validation of the prototype – see Figure 3. This framework required extensive input from the construction industry in order to not only secure relevance, but also help govern authenticity of these stages.

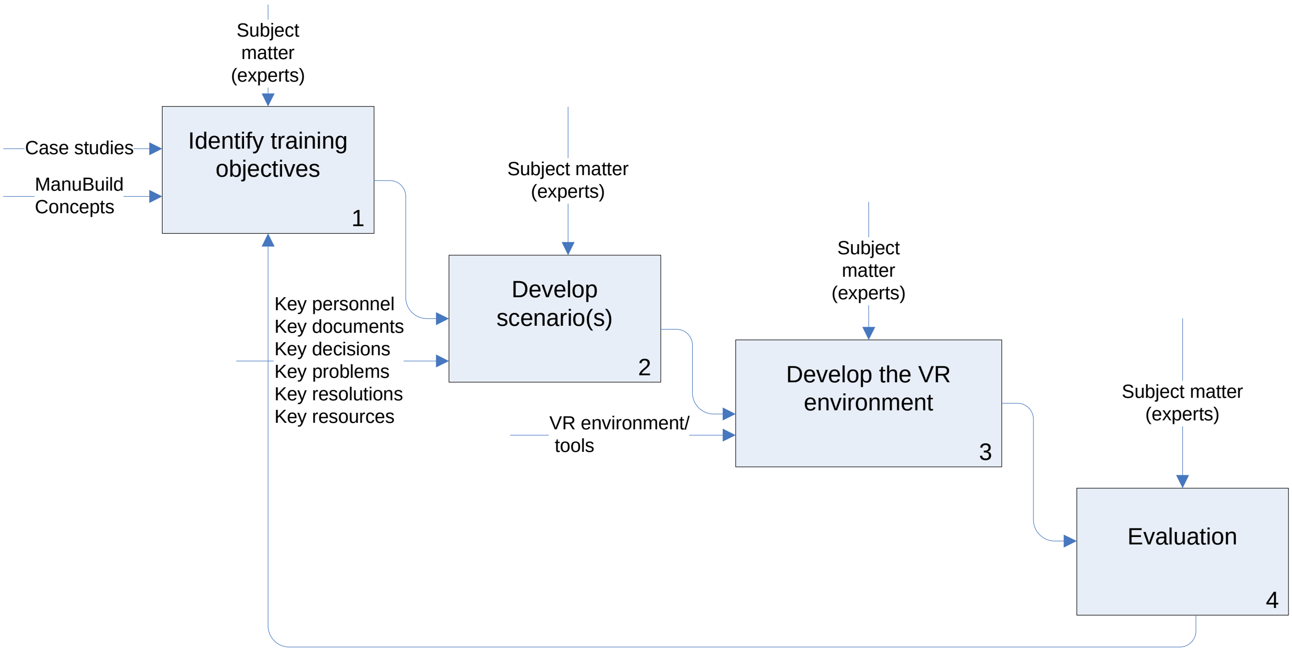


Figure 3: VR Environment Development Framework

Training Objectives

The main training objectives underpinning the simulator were gathered from a synthesis of seminal literature covering the potential risks and threats facing OSP in general, and Open Building in particular. The capture of this knowledge was seen as fundamental for learners to fully appreciate, as it helps form the basis of appreciating how different stakeholders deal with the implications of such problems; and consequently, help learn how these could be mitigated for future practice. In this context, the following risks were identified:

- To encompass late design changes;
- To embrace issues such as the loss of factory production, or production capacity;
- To include unpredictable planning decisions and designs that are not suited to OSM;
- To capture the issues associated with tolerances;
- To include the potential of suppliers' failure to deliver on time;
- To allow for manufacturer bankruptcy.

Thus, in order to mitigate these potential OSP problems and risks, an extensive understanding of the nature of OSP practices would be needed in order to appreciate ‘why’ those problems and risks occur; and hence, appreciate the precise means through which these could be mitigated, i.e. ‘how’. In this respect, mitigation was deemed to include the following issues:

- To involve the manufacturer/supplier of manufactured elements at an early stage;
- To ensure that manufacturers work closely with the design team, architect, client, planners, etc;
- To ensure that effective communication is promoted, especially concerning manufacturers in order for them to prepare for peak production periods;
- To allow for greater standardisation and collaboration between groups, and to allow flexibility in the allocation of production slots;
- To secure early involvement of manufacturers to inspect the site and foundations before delivery;
- To proactively manage the supply chain;
- To identify long-lead items early;
- To promote good management practices and processes;
- To embrace efficient procurement processes to minimise the disruption caused by the search for alternative manufacturers.

Scenario Development

The scenarios were developed in order to expose learners to new working conditions and issues that they were likely to face on real construction projects employing OSP/*Manu*Build concepts. Therefore, it was deemed important to challenge learners to think about the routes of these problems, rather than just reacting to them. This concept was used to provoke learners to think ‘proactively’ about future OSP projects. In this context, the main scenario was based on identifying all possible problems/issues that are traditionally associated with OSP/*Manu*Build practice. These are colloquially referred to as problem 1, problem 2, etc - see Figure 4. For each of these problems, there are a number of possible decisions with associated actions. Depending on the action chosen, the programme schedule, along with corresponding costs, time, and resources are affected.

These scenarios are used to simulate how OSP operates in real-life, in order to provoke learners to think ‘how’ and ‘why’ things may go wrong; and why consequently OSP may end-up being more expensive than the traditional way of working and thinking. As part of the learning process, learners are able to identify ‘why’ things went ‘wrong’, and ‘how’ these problems could have been avoided. Furthermore, a debriefing session is used to allow thorough interrogation of problems and choices selected, whereby learners are able to elaborate on the issues faced during the VR session; which helps to distinguish between ‘being immersed’ within the environment and the process of critical reflection that takes place outside the VR environment (De Freitas and Oliver, 2006).

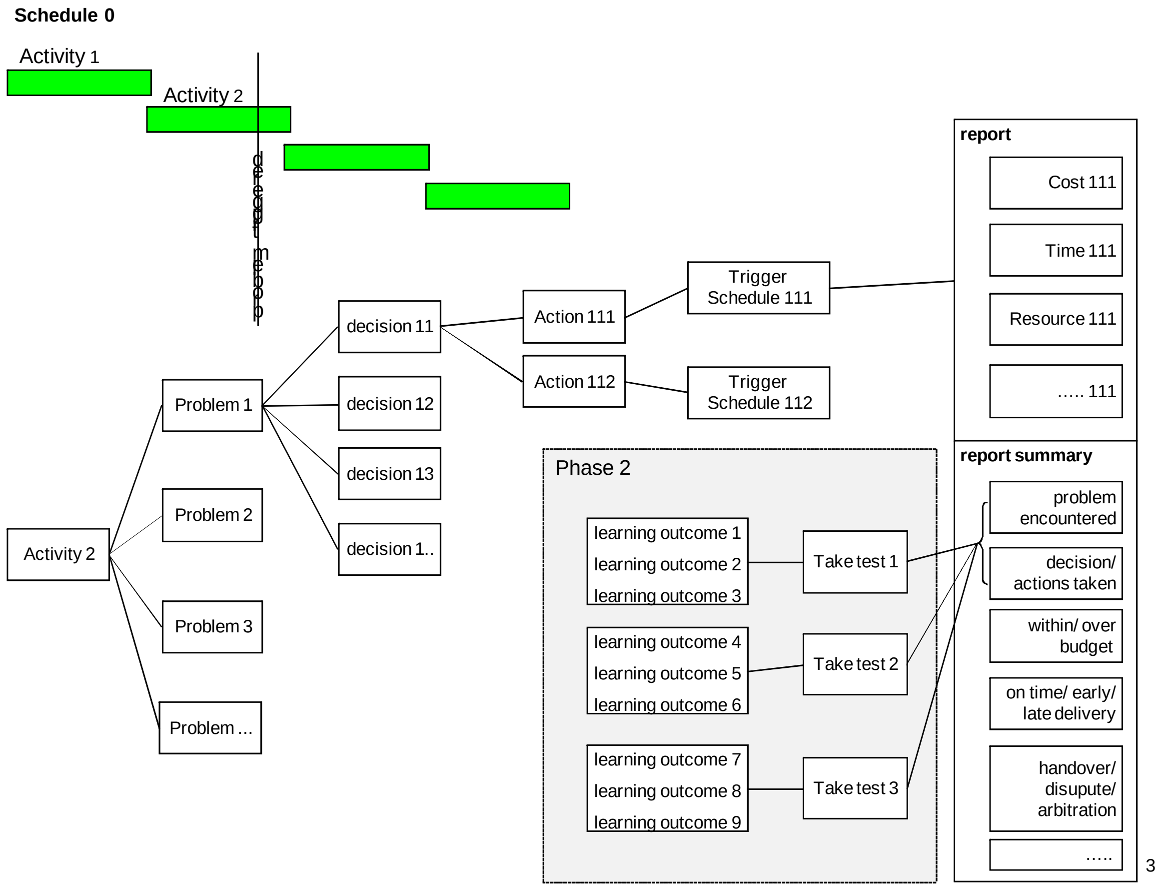


Figure 4: Scenario Implementation Concept

To run a scenario, various information and data has to be input into the system in order to help populate the scenario. This data includes: building structure, site layout, work plan and associated possible interruptions/problems, including manufacturing option – see Figure 5. This information is sourced from a predefined ‘real’ project.

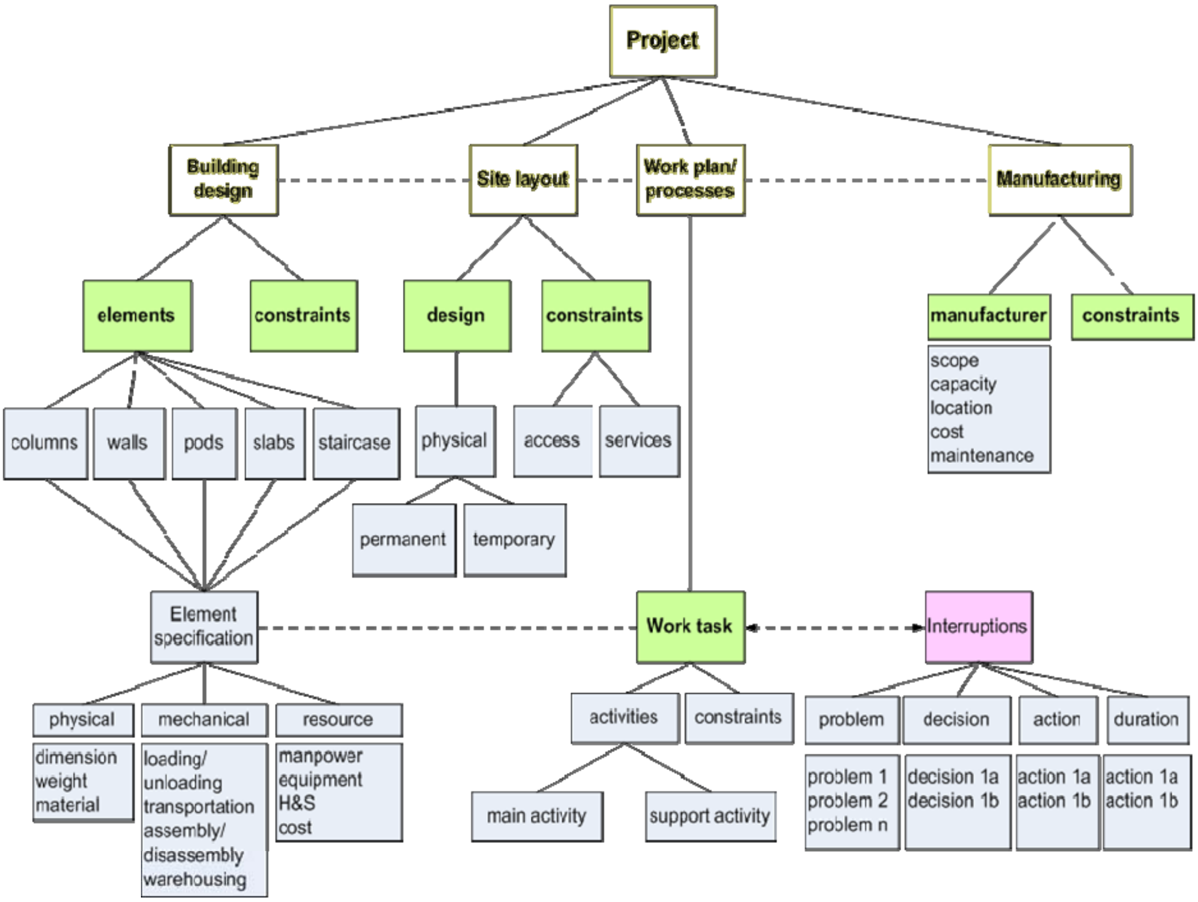


Figure 5: Scenario Information Structure

VR Learning Environment Use Case

The scenes generated by the simulator take place on a virtual construction site based on a real project. From a use case perspective, it was important to impart knowledge and skills relating to OSP/*Manu*Build concepts. Drawing on Fowler (2004), since the learning environment targets various stakeholders with various professional backgrounds; the following use case was developed for the scenario prototype.

Use Case:	**User learns about and experiences OSP/*Manu*Build-related concepts and working conditions**
Design Scope:	Virtual Reality interactive Learning Environment
Context of use:	user learns about OSP/ *Manu*Build concepts
Primary Actor:	Construction Manager
Target Stakeholders:	Project Managers Designers Consultants Suppliers Manufacturers, etc.

Simulator Requirements

- Simulate site operations
- Generate reports
- Save/reload sessions
- Run possible ‘scenario directions/alterations’ randomly
- Interrogate learners knowledge (Phase II)
- Generate feedback to learner

Main Scenario

1. User initiates and saves a session (creating username and password)
2. User selects a site location (urban – rural - suburban)
3. System prompts with the total budget and time frame of the project
4. System simulates site operations (delivery – transportation – assembly) based on decisions/ selections made by user
5. User requests report(s)
6. System generates report (planned/actual)
7. System saves report/simulation

Simulator System Architecture

The VR learning environment system architecture encompasses three main components in order to run the various scenarios virtually; specifically: the content management system, the data framework, and the 3D visualisation engine – see Figure 6. The content management system encompasses a relational database, which stores all the operational data for the scenarios (i.e. scenario content, project data, manufacturer data, equipment data, 3D model etc.). The data framework triggers the relevant scenario, 3D model, and schedule (Microsoft Project) associated with the user selections. Finally, the 3D visualisation engine uses Visual Basic (VB) and C++ programming software; along with a rendering engine based on parallel graphics Cortona VRML client - responsible for the interactive visualisation of the digital representation in real time.

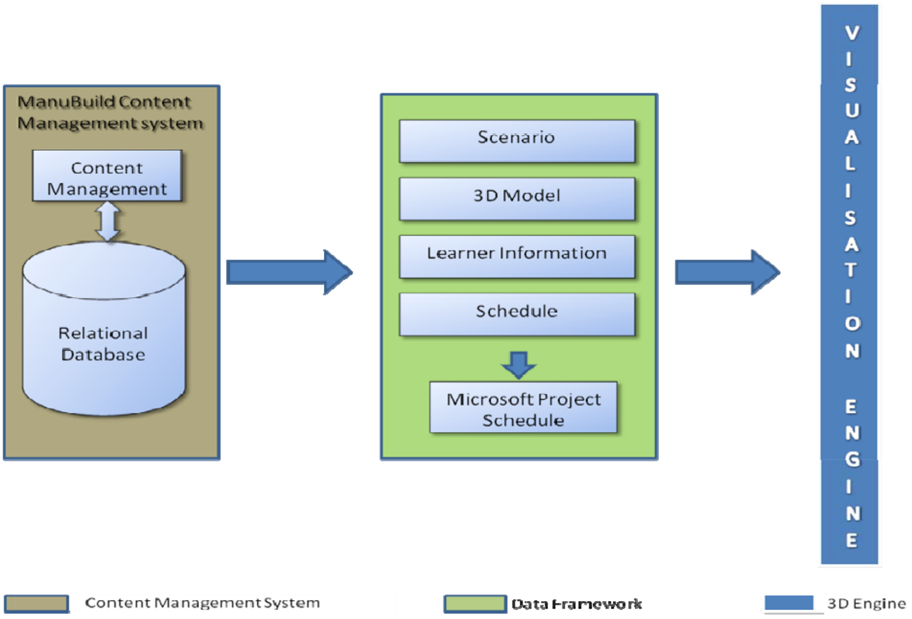


Figure 6: ManuBuild Simulator System Architecture

Graphical User Interface

The Graphical User Interface (GUI) was designed to be as simple and straightforward as possible with respect to data input. Hence a virtual PDA was designed as the primary interface for learners to input and retrieve information from the simulator. In this respect, prior to running a VR session, learners are required to make preliminary selections and decisions, the results of which are used to trigger relevant events later on. Learners are then able to commence the training session, starting with a 'walkthrough' to experience and appreciate the complexity of the project. At various points in the scenario, learners are able to interact with the different elements of the simulator in order to retrieve further information e.g. technical specifications, videos on selected OSP construction systems/details, project data etc. For example, progress on cost, time, resources etc - see Table 1 and Figure 7.

Table 1: VR Environment Initial Selection Screens:

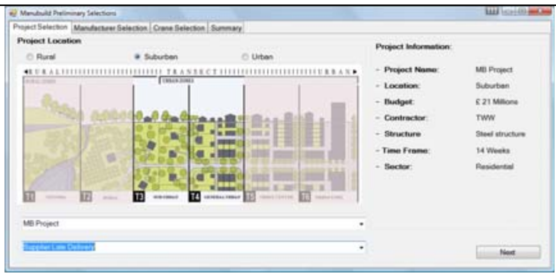
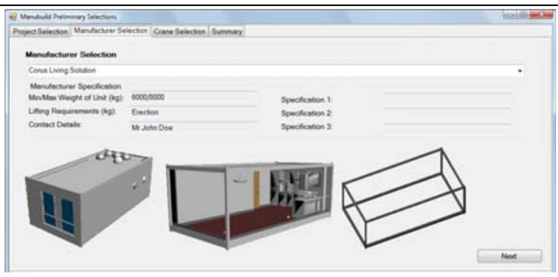
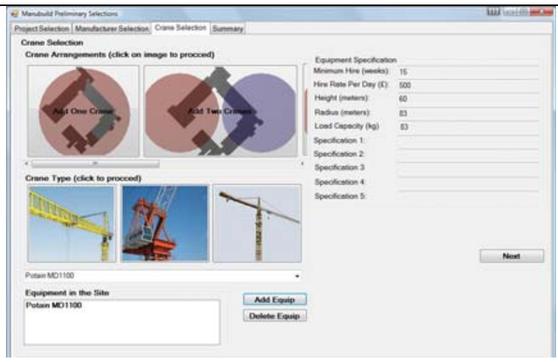
1		**Location Selection:** Users are required to select the location of the project e.g. rural, suburban, or urban. <u>Learning objectives</u> The location of a project has implications on access, equipment, storage etc - thereby affecting the scenarios triggered.
2		**OSP System Selection:** Users are requested to select the type of system/structure to explore, from a repository of stored systems. <u>Learning objectives</u> Different systems have different requirements – some suitable for some locations and not for others.
3		**Site Set up and Equipment Selection:** Users are required to select the site set-up arrangements with respect to the equipment required. <u>Learning objectives</u> Logistics solutions are affected by the type of equipment and site set-up (in addition to equipment constraints).
4		**Launch the VR Simulation Session** After these initial selections, users are able to run the VR simulation to experience how the project progresses based on their initial selections. Different scenarios are triggered to exert 'pressure' on learners to think about options and consequences (as these affect the overall project cost, time, resources etc).

Figure 7: The VR Simulation Session

Validation

The VR simulator was designed, developed, tested and validated with a number of domain experts, ranging from industry, through to research communities, and academia, including:

- Built Environment students (UK)
- Manufacturers (UK)
- Academics/Research (Finland, Germany, Netherlands, Canada, Australia)
- Developers/Industrialists (UK)

These stages not only helped make the simulator more robust, but also helped secure industrial relevance. A synopsis of comments received from these four key stakeholder groups can be seen as follows:

- Built Environment students thought this simulator was "very exciting", and would help them appreciate how things worked in real life (as they currently lacked the opportunity to experience real life examples);
- Manufacturers thought the simulator was an "interesting tool" to interact with; especially as they could 'see' the implications of their decisions in real time (which would help them to 'think' and reflect on 'why' problems occurred, and 'how' issues may be mitigated on real projects).
- Academics/Research perceived the simulator as being "useful" for conveying *Manu*Build/OSP concepts to students/ learners, and noted the potential for further development and exploitation;
- Developers/Industrialists perceived the simulator would help them compare traditional with OSP approaches in order to help identify how cashflow was affected (to help make a decision with respect to the selection of OSP as opposed to the traditional approach). Whilst quantitative tools of this nature were generally readily available, it was noted that these did not factor in qualitative issues.

Key Findings

*Manu*Build training focuses on conveying and delivering *Manu*Build/OSP concepts using highly innovative and pioneering delivery methods. However, the development of the simulator faced a number of challenges at the outset relating to the lack of availability of 'suitable' 'real' case studies addressing Open Building/OSP (along with project data confidentiality). Initial scenario development was based on a late window delivery in order to demonstrate potential. This was then expanded, through a series of workshops, the results of which can be seen under the following two categories of 'general' and 'content' related comments:

General Comments:

- It is useful to have a multi-user environment to gauge different people's perspective;
- The VR environment could be widened to include the inception stage, completion, facilities management, demolition stages;
- It is good to be able to select the project. It would be useful to also categorise projects according to their complexity/sector i.e. commercial, residential, high rise, industrial etc;

- The inclusion of cost implications is welcomed – this gives tangible messages which are easy to understand and comprehend as opposed to ‘soft issues’;
- The use of videos was perceived as being ‘excellent’, and was encouraged to be extended;
- It would be useful to tailor the generated report to reflect the different stakeholders e.g. a client would get a different report to that from a manufacturer, contractor etc;
- The late window scenario was perceived as being “valid”, especially as these such problems do occur in practice;
- It would be good to incorporate different types of contracts within the simulator, along with contract clauses (to appreciate and understand the implications of decisions taken).

Content-Related Comments:

- It was important to use the simulator as a high-level tool and not to go into too much detail;
- That the design/product interface could be an issue if more than one supplier was involved in the project;
- That it would be useful to compare traditional with OSP (cost-benefit-analysis);
- That the environment could be extended to include planning issues, manufacturer issues, designer issues etc;
- That target parameters for cost, time, and other resources could also be included.

Whilst it is acknowledged that all the above identified recommendations are valid viewpoints; from a developmental perspective, these all have a direct correlation with coding and programming time. However, notwithstanding these issues, from an OSP/*Manu*Build training/education perspective, the developed simulator not only openly addresses its original design intent and scope, but has the added flexibility of being able to accommodate a wider context than its originally planned. In this respect, further research is likely to focus on these issues.

Key Business Impact

The scenarios presented in the VR simulator can be used to simulate OSP operations in order to demonstrate ‘how’ and ‘why’ things can go wrong; and ‘why’ consequently OSP may end-up being more expensive than the traditional way of working and thinking. Hence from a business perspective, this tool can help inform the industry to reflect upon their current working practices in order to benefit from new methods of construction. Other business benefits include the simulator’s capacity and capability to incorporate a ‘pool’ of virtual interactive case studies with respect to Open Building Manufacturing/OSP practices. This not only extends the operational business remit, but also increases the capability of embracing peripheral issues – thereby extending its usefulness and overall functionality. In this respect, future exploitation of the VR environment could be extended to include the following four areas:

- Academia – to demonstrate the impact of experiential learning in cognate and non-cognate areas;
- Training institutions - to reinforce the importance of embedding the simulator into their existing training programmes;
- Industry - use the simulator environment as a VR repository of OSP projects (to reflect on lessons learnt);
- Research - to disseminate research findings to peers in order to prioritise the future research agenda.

Conclusions

*Manu*Build's vision is to transform the construction industry from being a rather pragmatic and predominantly 'craft/resource-based' industry, to one which is more 'knowledge-value-driven'. However, this mantra requires the provision of innovative and flexible training approaches to deliver this paradigm. Based on a proactive experiential training concept (Alshawi *et al*., 2007), a VR interactive simulator was designed and developed to address these issues. This chapter introduced the core concepts and strategies associated with the design and development of the VR simulator. In this respect, a VR prototype simulator was discussed as a panacea for providing a flexible, interactive, and safe learning environment for practicing new working conditions associated with OSP/*Manu*Build practices using the incorporation of 'real-life' scenarios. These scenarios were explained, and the benefits were then discussed in relation to the simulator's enhanced features of being able to provide a unique and highly personalised environment tailored to suit a variety of learners' needs. Finally, the 'input-process-outcome' approach (Garris *et al*., 2002) and rubrics adopted throughout the development lifecycle were examined, along with the testing, feedback, and validation stages - which in turn, highlighted the key business benefits extolled by this simulator, along with future suggestions to set and prioritise the future research agenda in this area.

Practical Tips

- *Manu*Build's vision is the transformation of how business is carried out within the construction industry - hence a culture change is needed;
- Traditional on-the-job learning approaches are not always adequate for skill development and transformation;
- Interactive learning environments have the potential to enable experiential learning in a safe and controlled learning environment, with minimal disruption to the working environment, as it can facilitate "any time, any place learning";
- The provision of real-life scenarios are imperative for the success of the simulator (and these are challenging to capture);
- The need for a business decision making tool for OSP is valid - which requires a myriad of parameters to be compared vis-à-vis characteristics/specifications for the different OSP systems (and these do not seem to be readily available within the construction industry).

Acknowledgements

Special thanks go to Taylor Woodrow - Mr. David Leonard, for the provision of real OSP project data and information which helped in the development of the prototype, along with facilitating the capture of knowledge, and for providing further recommendations for future enhancements. Special thanks are also extended to Corus - Mr. David Shaw and Dr Samir Boudjabeur; to the Technical Research Centre of Finland (VTT) - Dr. Kalle Kähkönen; and to the Technische Universität München TUM - Mr. Ron Unser for their feedback and support throughout all stages of this work.

References

Agapiou, A. (2006). "An Evaluation of a Contract Management Simulation Game for Architecture Students." *CEBE Transactions* **3**(2). pp: 38-41.

Alshawi, M., Goulding, J. and Nadim, W. (2007). Training and Education for Open Building Manufacturing: Closing the Skills Gap. In: *Open Building Manufacturing: Core Concepts and Industrial Requirements*. Kazi, A. S., Hannus, M., Boudjabeur, S. and Malon, A. Finland, ManuBuild in collaboration with VTT - Technical Research Centre of Finland.

Amthor, G. R. (1996). "Organisational learning and core capabilities development: the role of IT." Journal of Strategic Information Systems 5. pp: 111-127.

Anderson, J. R. (1983). The Architecture of Cognition. Harvard University Press. London, Cambridge.

Bargstädt, H.-J. and Blicking, A. (2005). Determination of process duration on virtual construction sites. In Proceedings of 2005 Winter Simulation Conference Proceedings of the 37th conference on Winter Simulation, Orlando, Florida, Kuhl, M. E., Steiger, N. M., Armstrong, F. B. and Joines, J. A., pp. 1549-1558 Winter Simulation Conference.

BECTA (2001). Curriculum Software Initiative: Computer Games in Education Project. Becta.http://partners.becta.org.uk/index.php?section=rh&rid=13595

Blümel, E., Straßburger, S., Sturek, R. and Kimura, I. (2004). Pragmatic Approach to Apply Virtual Reality Technology in Accelerating a Product Life Cycle. In Proceedings of International Conference INNOVATION, Slany, Czech Republic pp. 199-207.

Bouchlaghem, N. M., Thorpe, A. and Liyanage, I. G. (1996). Virtual reality applications in the UK's construction industry. In Proceedings of w78:1996 - Construction on the Information Highway, Bled, Slovenia, Turk, Z., pp. University of Ljubljana.

Brandsford, J. D., Brown, A. L. and Cocking, R. C., (1999). How People Learn: Brain, Mind, Experience and Schooleds. Washington DC, National Academic Press.

Buckley, R. and Caple, J. (2004). The Theory and Practice of Training. 5th ed. Biddles Ltd., King's Lynn, UK.

Business Watch (2005). ICT and Electronic Business in the construction Industry, IT adoption and e-business activity in 2005. The European e-Business Market Watch. European Commission, Enterprise and Industry Directorate General.

Clarke, L. and Wall, C. (1998). "UK construction skills in the context of European developments." Construction Management and Economics 16(5). pp: 553-567.

DfEE (2000). An Assessment of Skills Needs in Construction and related Industries. Skills Dialogue: A comprehensive summary from employers of skills required in Construction and related Industries. The Institute for Employment Studies.

ECTP European Construction Technology Platform (2005). Strategic Construction Agenda for the European Construction Sector: Achieving a sustainable and competitive construction sector by 2030.

Finegold, D. and Soskice, D. (1988). "The Failure of Training in Britain: Analysis and Prescription." Oxford Review of economic policy 4(3). pp: 21-53.

Fowler, M. (2004). UML Distilled: A Brief Guide to the Standard Object Modelling Language. 3rd Edition. Addison Wesley, Garris, R., Ahlers, R. and Driskell, J. E. (2002). "Games, Motivation, and Learning: A research and Practice Model." Simulation Gaming 33(4). pp: 441-467.

Goulding, J., Aouad, G. and Nadim, W. (2007). "nD-based computer Game: Engaging School Children in the Construction Design Process." 3(Architectural Engineering and Design Management (AEDM)). pp: 222-237.

Gurjao, S. (2006). Inclusivity: The Changing Role of Women in the Construction Workforce. CIOB, University of Reading.

Hackett, P. (1997). Training Essentials: Introduction to Training. Institute of Personnel and Development. The Cromwell Press, UK.

Harrison, R. (2005). Learning and Development. 4th ed. Chartered Institute of Personnel and Development. London, UK.

Jayakanthan, R. (2002). "Application of computer games in the field of education." The Electronic Library 20(2). pp: 98-102.

Kirk, J. J. (2004). "The making of a gaming-simulation course: A personal tale." Simulation and Gaming 5(1). pp: 85-93.

Koo, L. C. (1999). "Learning Action Learning." Journal of Workplace learning 11(3). pp: 89-94.

Laird, D. (2003). New Perspectives in Organisational Learning, Performance, and Change: approaches to training and development. Sharon S. Naquin and Elwood F. Holton III.3rd. Preseus Books Group, USA.

Leitch, S. (2005). Skills in the UK: A long-term challenge, HSMO. Interim Report.

Magerko, B. and Laird, J. (2002). Towards building and Interactive, Scenario-based Simulator. In Proceedings of Proceedings of the 10th Computer Generated Forces and Behavior Representation Conference, Orlando, FL.

Mitchell, A. and Savill-Smith, C. (2004). The use of Computer and Video Games for Learning: A Review of the Literature, Learning and Skills Development Agency (LSDA). http://www.lsda.org.uk/files/PDF/1529.pdf

Mole, T. (2003). Mind Your Manners. In Proceedings of CIB W89 International Conference on Building and Research Bear 2003, Salford, UK, Newton, R., Bowden, A. and Betts, M., pp. University of Salford, School of Construction and Property Management.

Prensky, M. (2001) Digital Game-based Learning, from http://www.marcprensky.com/writing/Prensky%20-%20Ch1-Digital%20Game-Based%20Learning.pdf. Date accessed: 24July2005

Rezgui, Y., Wilson, I. E., Damodaran, L., Olphert, W. and Shelbourn, M. (2004). ICT Adoption in the Construction Sector: Education and Training Issues. ICCCBE-X: the Xth International Conference on Computing in Civil and Building Engineering, Bauhaus-Universität, Weimer, Germany.

Rosenthal, J. S. (1995). "Active Learning Strategies in Advanced Mathematics" Studies in Higher Education 20(2). pp: 223-228.

Rossou, M. (2004). "Learning by Doing and Learning Through Play: An Exploration of Interactivity in Virtual Environments for Children." ACM Computers in Entertainment 2(1). pp: 1-23.

Sawhney, A. and Mund, A. (1998). Simulation Based Construction Management Learning System. In Proceedings of Proceedings of the 1998 Winter Simulation Conference, Medeiros, D. J., Watson, E. F., Carson, J. S. and Manuvannan, M. S., 2, pp. 1319-1324 WSC98.

Snee, R. D. (1993). "What's missing in statistical education." The American Statistician 47(2). pp: 149-154

Spedding, T. (2003). "Teaching Simulator for Industrial Statistics." MSOR Connections 3(3). pp: 41-43.

Vries, B. d., Verhagen, S. and Jessurun, A. J. (2004). "Building Management Simulation Centre." Automation in Construction 13(5). pp: 679-687.

Author Biographies

Wafaa Nadim is a Research Assistant at the University of Salford. She holds a Masters Degree in IT Management in Construction and a BSc. in Architecture. She has extensive experience in construction project management, and has worked on several international construction projects ranging from £100m - £170m. Her current research interests embrace: Open Manufacturing, Organisational Learning, and Pedagogy.

Mustafa Alshawi is a Professor of Management and IT in Construction and the Director of BuHu at the University of Salford. He holds many international advisory posts in various countries and is a consultant to UN Habitat and the World Bank. He is also the Editor in Chief of the international journal of “Construction Innovation: Information, Process, Management”.

Dr Jack Goulding is the Deputy Director of BuHu at the University of Salford. He is also a Charted Construction Manager by profession and advisor to several high profile bodies and committees within the UK. He has worked on numerous national and international projects in the areas of IT, VR, strategy development, and Open Manufacturing; and has authored over 70 publications in these areas.

Dr Panagiotis Petridis is Senior Research Assistant of the Serious Games Institute at Coventry University, and holds the position of Research Fellow in Sussex University. His research interests include Serious Games, Immersive Learning, Augmented Reality, 3D Interfaces and interaction devices.

Mark is an Associate Director at CIRIA, the largest independent research organisation in the UK, and also the Director of the Scottish Construction Centre. His research interests are in Built Asset Management, Process Modelling and Innovative MMC. Mark is involved with various research organisations and professional institutions, and sits on various sector boards, including board membership of the CIB. He also holds Professorship at the University of Salford.

Open Building Manufacturing

Key Technologies, Applications, and Industrial Cases

Edited by:
Abdul Samad Kazi, Matti Hannus and Samir Boudjabeur

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.

The first ManuBuild book, “Open Building Manufacturing: Core Concepts and Industrial Requirements” reported on some of the key findings from the ManuBuild project and invited contributions covering key concepts, industrial requirements, and a set of solutions and applications for open building manufacturing. This book, “Open Building Manufacturing: Key Technologies, Applications, and Industrial Cases” is the second book launched by the ManuBuild project consortium. As a natural follow-up to the first book, this book primarily focuses on key technologies, application of concepts, and most importantly, industrial cases in open building manufacturing.

The portfolio of chapters in this book present new ways of industrialised building design, value-oriented industrial building concepts, future-proof infrastructure design, learning environments, and a set of industrial cases studies covering: innovation and new construction practices; flexible and innovative manufacturing; industrial management approaches for improving building service works; and industrialised low-cost housing.

ISBN 978-951-38-7144-4 (Print)
ISBN 978-951-38-7146-8 (Electronic)

ManuBuild
www.manubuild.org