

# Virtual reality interactive learning environment

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# Open Building Manufacturing

Key Technologies, Applications, and Industrial Cases



Abdul Samad Kazi, Matti Hannus, and Samir Boudjabeur







# Open Building Manufacturing

## Key Technologies, Applications, and Industrial Cases

Edited by:

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

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# Preface

## Background and Introduction

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

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

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

## The ManuBuild Project

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

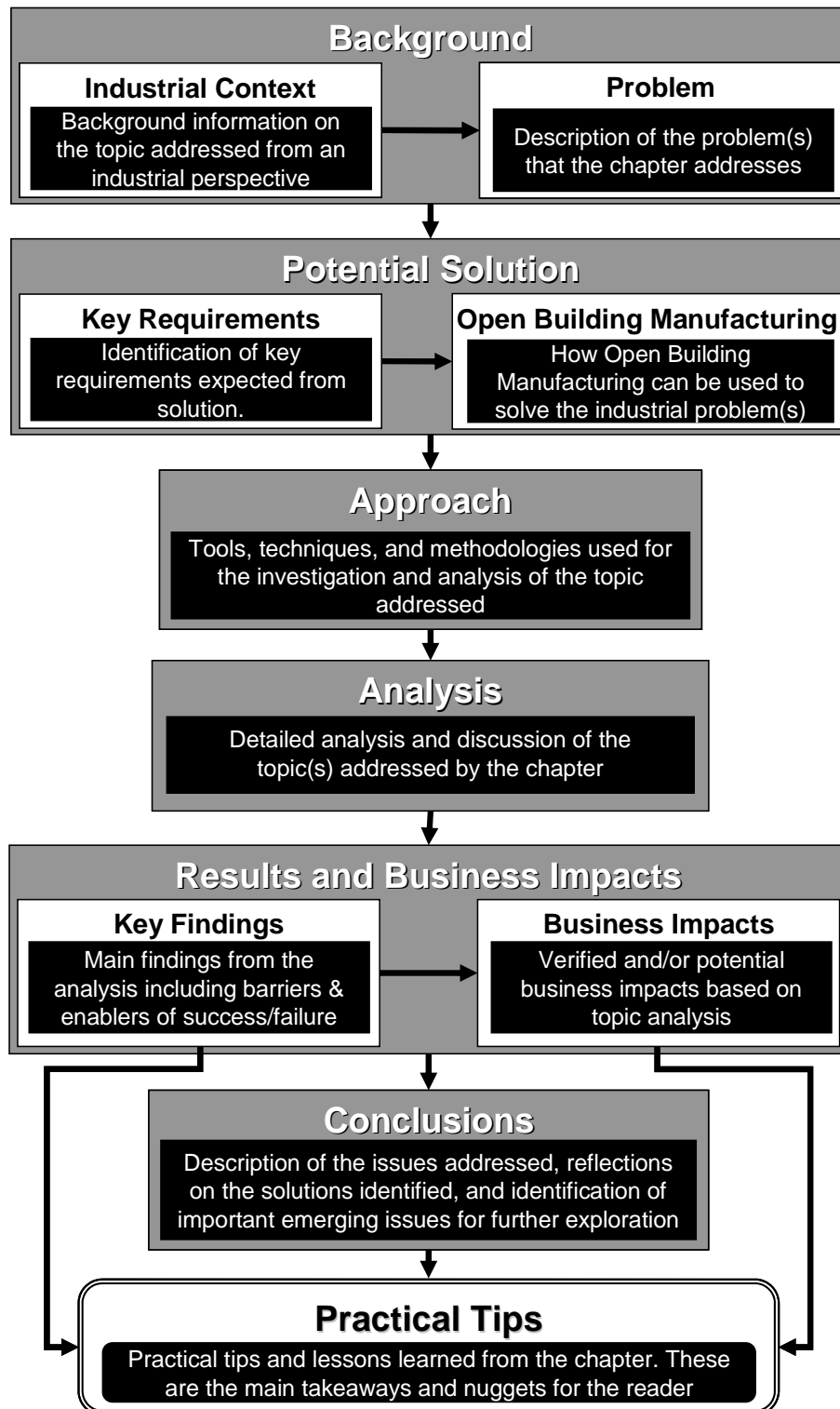
This book, "Open Building Manufacturing: Key Technologies, Applications, and Industrial Cases" is the second book launched by the ManuBuild project consortium to follow-up its first book entitled, "Open Building Manufacturing: Core Concepts and Industrial Requirements". The aim of this book, "Open Building 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*

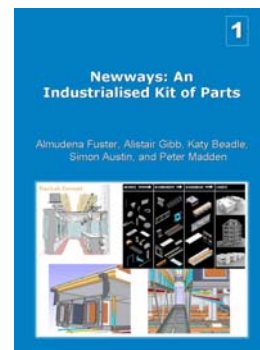


# Portfolio of Book Chapters

## 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*

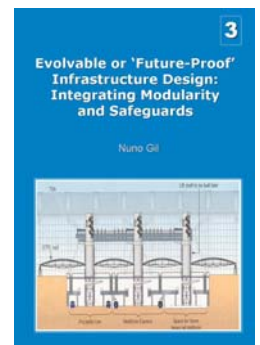
This chapter explores three main themes: value orientation, industrialisation and open building manufacturing, and, life cycle orientation and open building manufacturing. It advises on exploring opportunities for remanufacturing of building components in other building facilities when the host building 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*

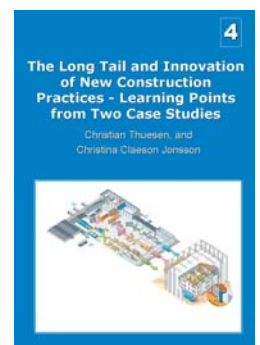
This chapter advocates understanding the importance of modularity as a strategic approach to building in flexibility in infrastructure design. It argues that modularity and safeguarding are at the heart of efforts to design future-proof infrastructures, i.e., design affordable infrastructures that can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

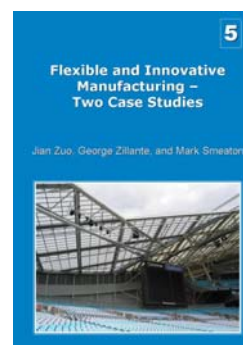
This chapter presents two different development initiatives aimed at delivering customisable residential buildings in a standardised way. While one was trying to implement a huge flexibility through industrialised manufacturing processes, the other was aiming to constrain the flexibility in traditional 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*

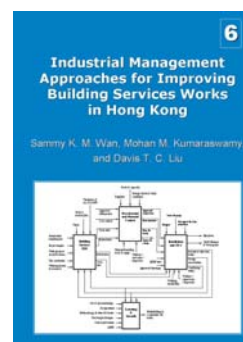
This chapter reports on the application of the principles of open building manufacturing to small scale projects. In particular, it focuses on the systems used for prefabrication, transportation and on-site assembly. It reports on how open building manufacturing was used to make substantial savings in 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*

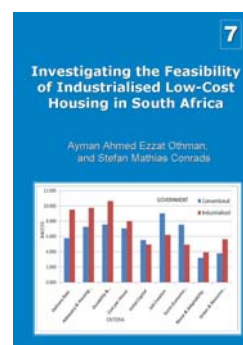
This chapter reports on the use of different industrial management approaches for improving building services in Hong Kong. It advocates adoption of a 'material tracking system', 'dynamic coordination buffering' and 'self-governing' multi-skilled work teams with reference to a 'dynamic production cell', 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*

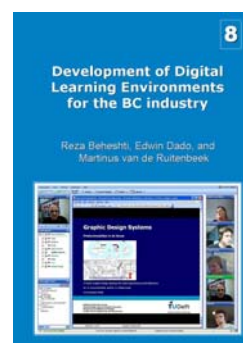
This chapter explores the feasibility of industrialised building systems as a means to solve housing problems in South Africa. Some of the key benefits of industrialised building systems over conventional building systems for social housing include delivery rate, production control, quality control,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



## Development of Digital Learning Environments for the BC industry

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

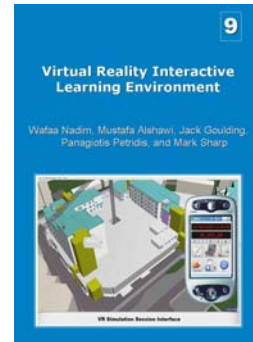
This chapter lays the foundation for next generation learning environments in the construction industry by illustrating how both human and virtual actors may participate in the role of teachers (or experts) within digital learning environments. It advocates the application blended modes of learning and 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*

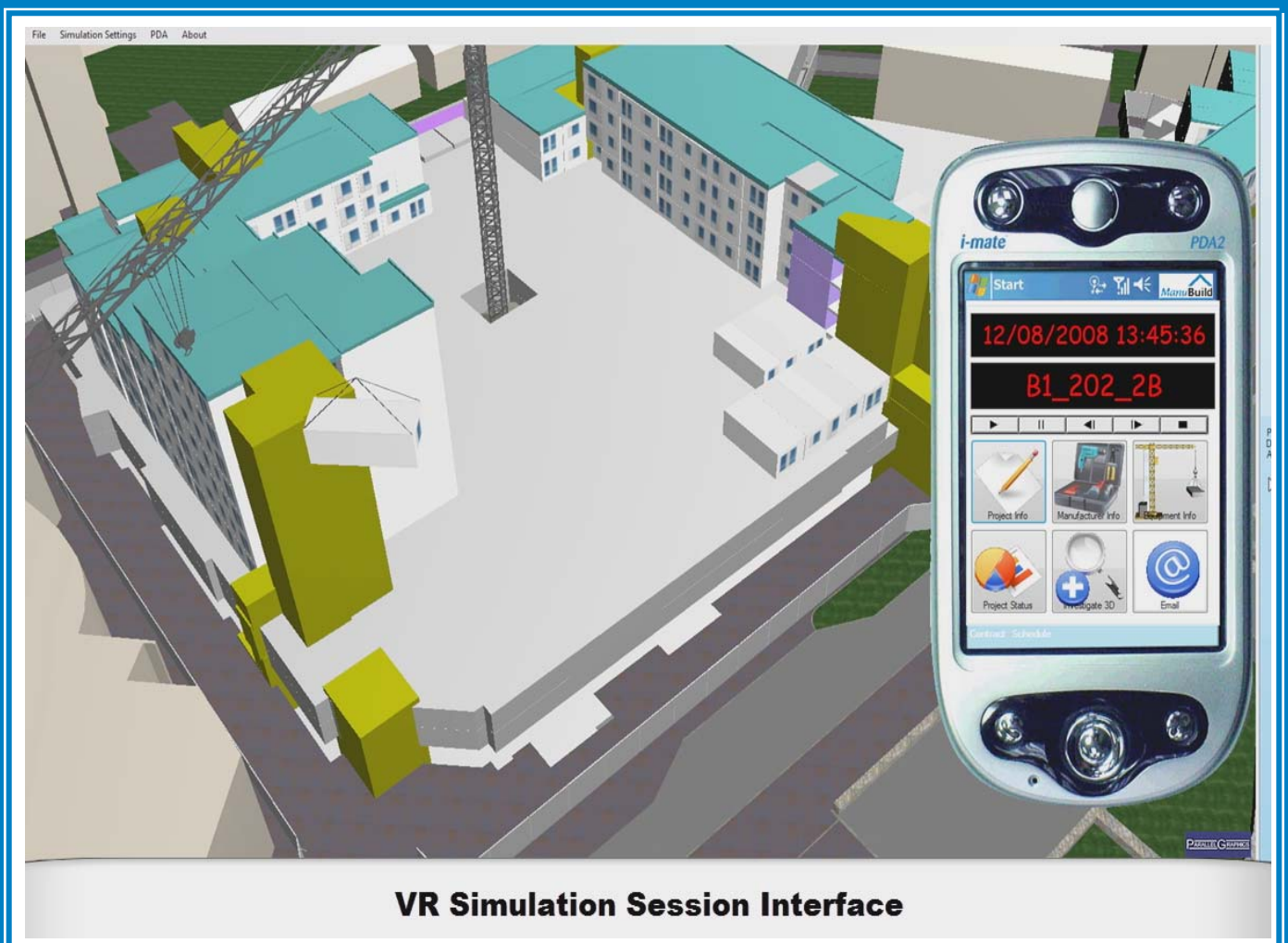
*Matti Hannus, VTT – Technical Research Centre of Finland*

*Dr. Samir Boudjabeur, Corus, UK*

ManuBuild, March 2009.

# Virtual Reality Interactive Learning Environment

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





# Virtual Reality Interactive Learning Environment

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## 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.

*ManuBuild* 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 *ManuBuild* 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

*ManuBuild* Training aims to introduce *ManuBuild* 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 *ManuBuild* training approach incorporated an innovative proactive experiential learning approach which links theory with practical experience, using a VR interactive learning environment (Alshawhi *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.

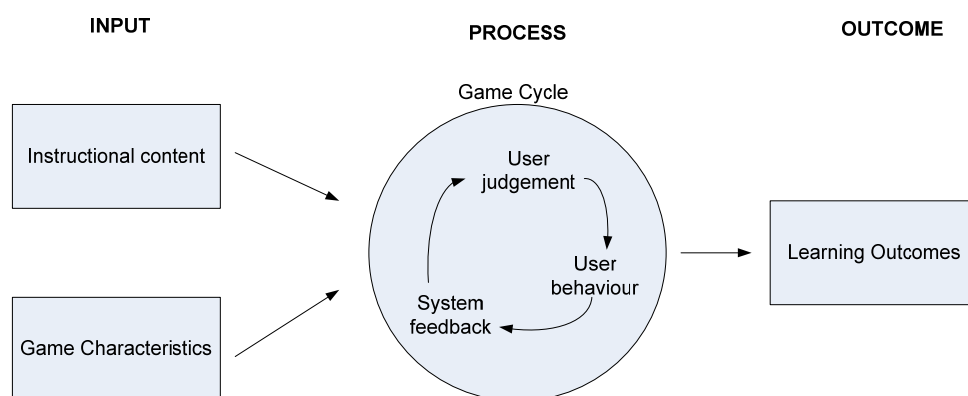


Figure 1: Instructional Game Model Input-Process-Outcome

(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

*ManuBuild* 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 (Alshaw *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/*ManuBuild* 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 *ManuBuild* 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.

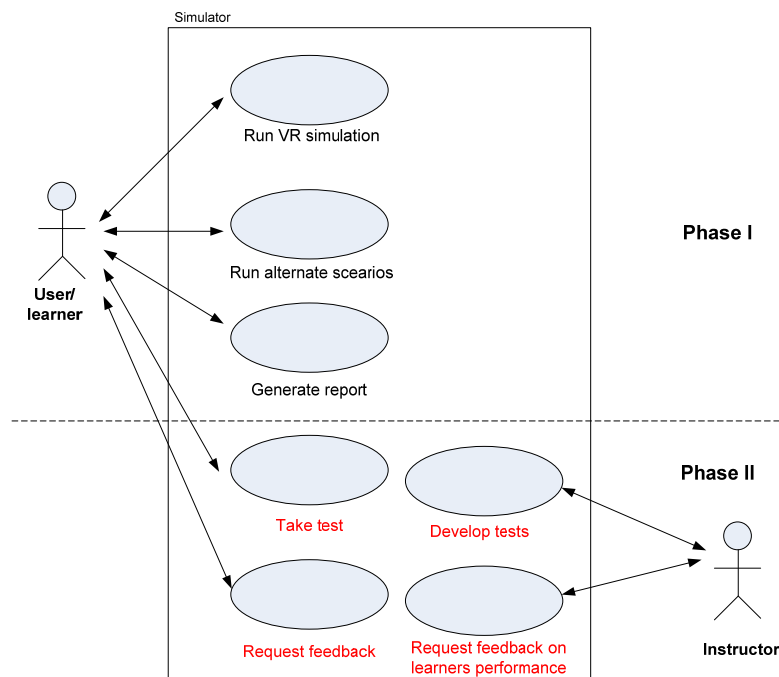


Figure 2: Simulator Development Phases

In light of the *ManuBuild* 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.

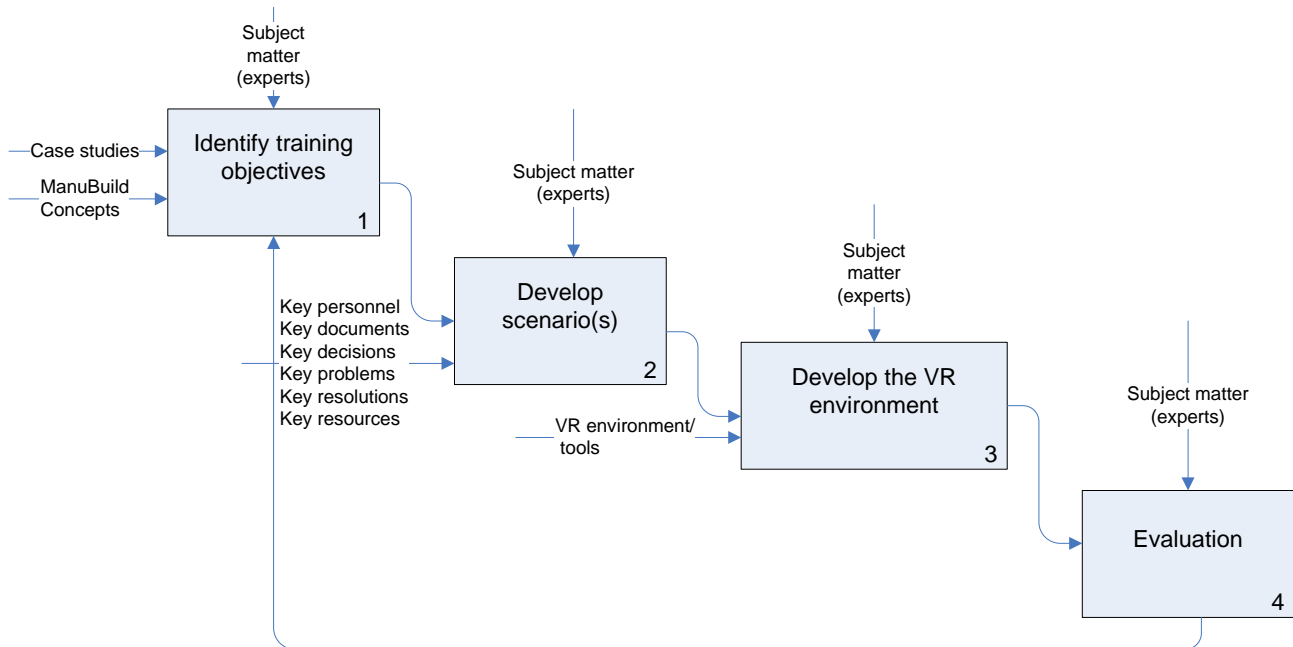


Figure 3: VR Environment Development Framework

### 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.

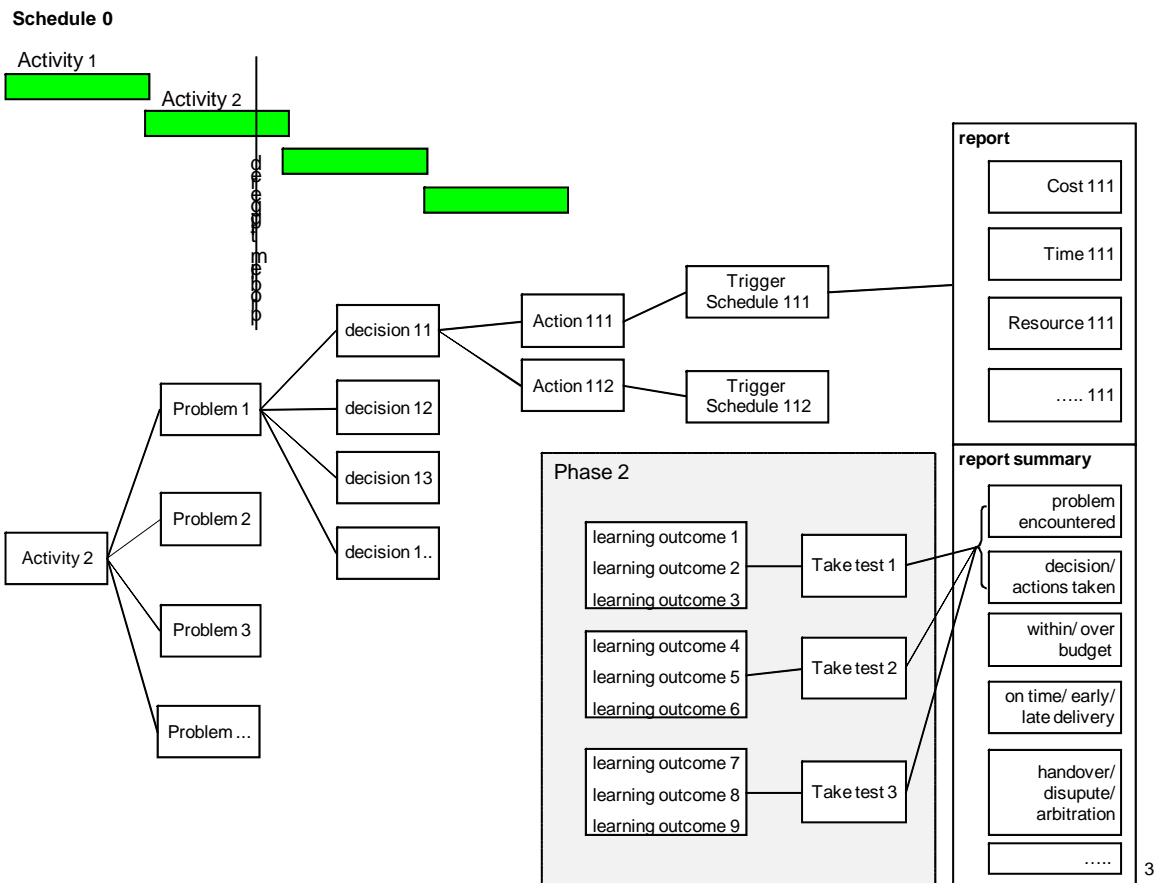
Thus, in order to mitigate these potential OSP problems and risks, an extensive understanding of the nature of OSP practices would be needed in order to appreciate ‘why’ those problems and risks occur; and hence, appreciate the precise means through which these could be mitigated, i.e. ‘how’. In this 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/*ManuBuild* 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/*ManuBuild* 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.

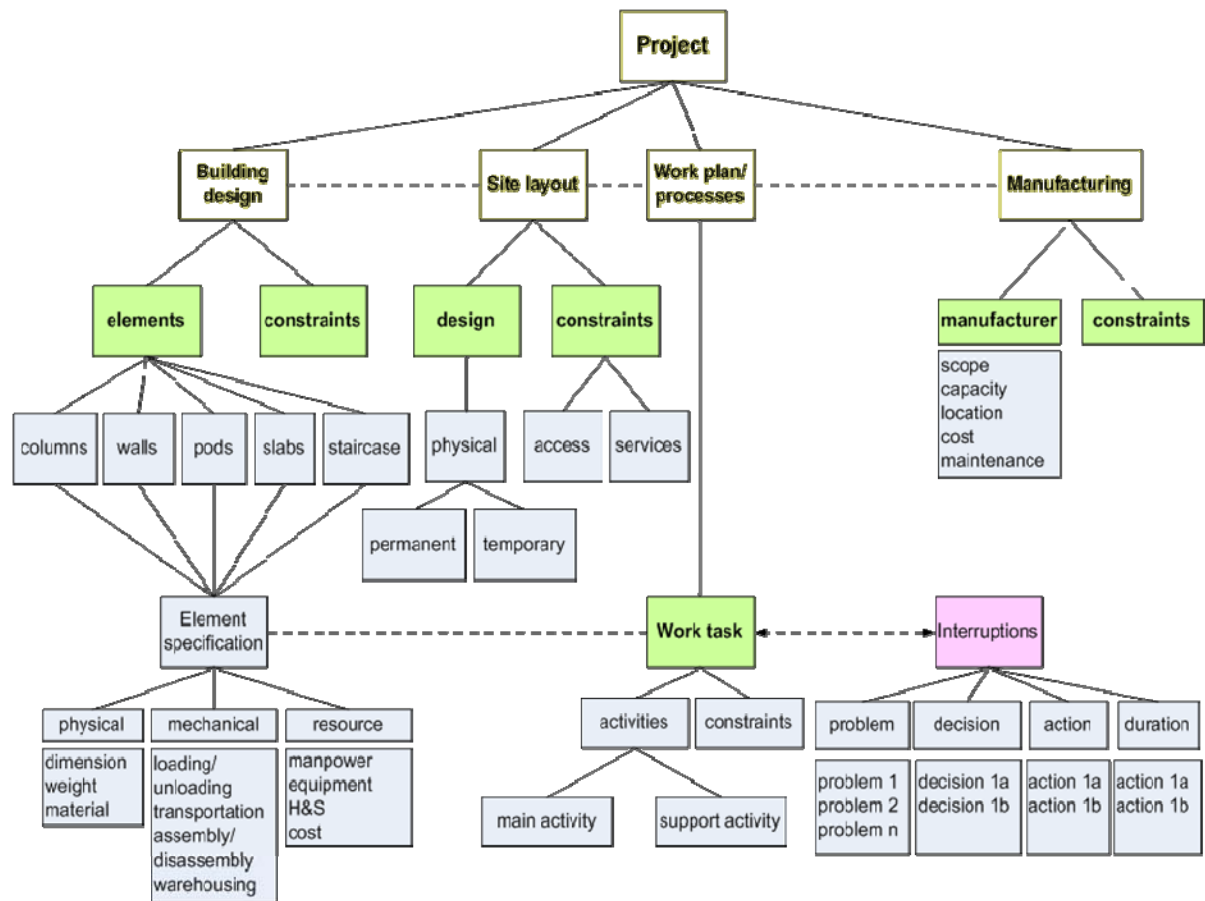


Figure 5: Scenario Information Structure

### 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/*ManuBuild* 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/*ManuBuild*-related concepts and working conditions

**Design Scope:** Virtual Reality interactive Learning Environment

**Context of use:** user learns about OSP/ *ManuBuild* concepts

**Primary Actor:** Construction Manager

**Target Stakeholders:** Project Managers  
Designers  
Consultants  
Suppliers  
Manufacturers, etc.



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### 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.

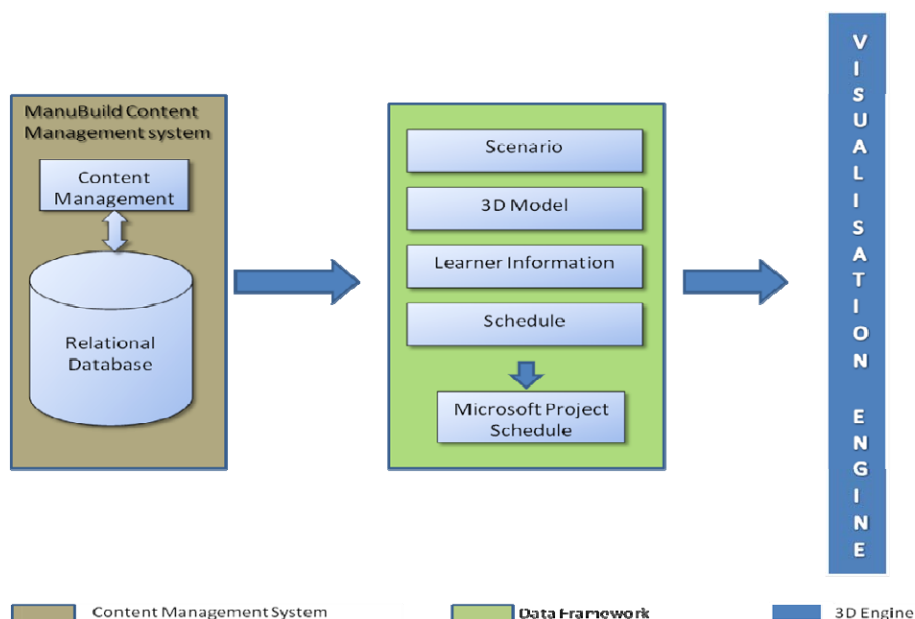
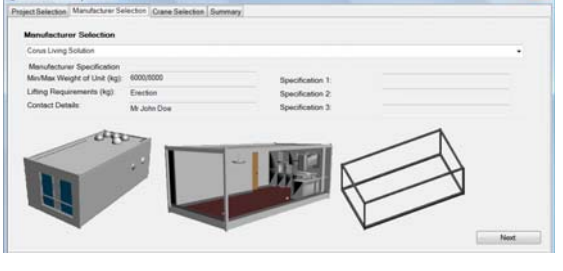


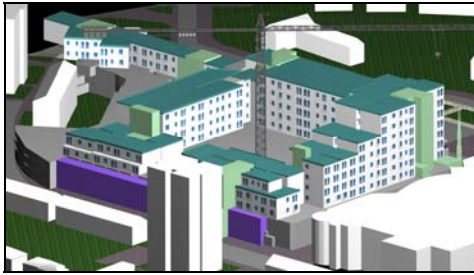
Figure 6: ManuBuild Simulator System Architecture

## 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		<p><b>Location Selection:</b> Users are required to select the location of the project e.g. rural, suburban, or urban.</p> <p><u>Learning objectives</u> The location of a project has implications on access, equipment, storage etc - thereby affecting the scenarios triggered.</p>
2		<p><b>OSP System Selection:</b> Users are requested to select the type of system/structure to explore, from a repository of stored systems.</p> <p><u>Learning objectives</u> Different systems have different requirements – some suitable for some locations and not for others.</p>
3		<p><b>Site Set up and Equipment Selection:</b> Users are required to select the site set-up arrangements with respect to the equipment required.</p> <p><u>Learning objectives</u> Logistics solutions are affected by the type of equipment and site set-up (in addition to equipment constraints).</p>
4		<p><b>Launch the VR Simulation Session</b> After these initial selections, users are able to run the VR simulation to experience how the project progresses based on their initial selections.</p> <p>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).</p>



*Navigate the environment and walkthrough to appreciate the complexity and size of project*

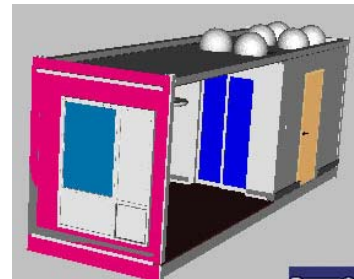


*Ability to retrieve videos on setting up specific systems/ details for better conveying messages.*

© Corus Bi-steel (corefast)



Virtual PDA



*Interrogate the different elements/ components for technical, logistic information etc.*

To: **Me**  
From: **The Manufacturer**  
Subj: .....

☒ Send an email to the manufacturer taking up the offer of storing the modules at the factory.

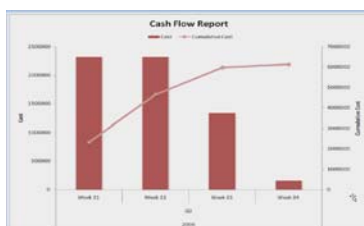
☐ Send an email to your Technical Manager, asking if he has any other suggestions if we wait.

*Scenarios are triggered in a form of e-mails for user to reflect on and decide on actions.*

Total Number of Units: [ ]  
Number of Units in Production: 175  
Number of Units Delivered: 42  
Number of Units in Stock: - 1  
Number of Units in Assembly: 41

☒ Plot Cost Graph ☐ Plot Delay Graph ☐ Plot Extra Graphs

**Back**



*Retrieve project progress/ production and cost data etc.*

**Decisions Taken:**

- Responded directly to the manufacturer asking to store the units at the factory
- Accepted storage cost quote from manufacturer
- Responded directly to Crane Supplier confirming disassembly
- Responded to the Crane Supplier, delaying the scheduled crane disassembly
- Accepted the Crane Suppliers quote of £8,400
- Accepted the Crane Suppliers quote of £8,400, after consultation with Technical Manager
- Decided to increase shifts to 8 hrs

**Time Impact**

- 3 days for units Assembly
- 7 days for facade assembly
- Total of 10 days delay

**Cost Impact**

- Storing Modules in factory: £ 13446
- Labourers pay day for 3 days: £ 5640
- Crane Hire: £ 8400
- Labourers pay for 7 days: £ 4704
- Liquidated Damage: £ 100000
- Total Cost Impact: £ 1023190

*Report is generated based on user actions*

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 *ManuBuild*/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

*ManuBuild* training focuses on conveying and delivering *ManuBuild*/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/*ManuBuild* 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

*ManuBuild*'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 (Alshawhi *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/*ManuBuild* 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

- *ManuBuild*'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).

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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.



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# 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.

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