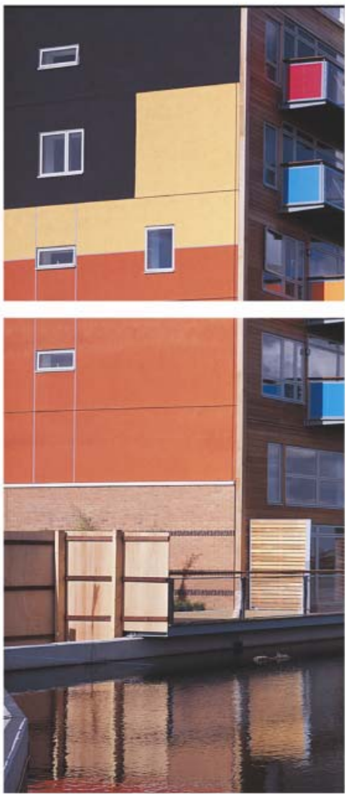
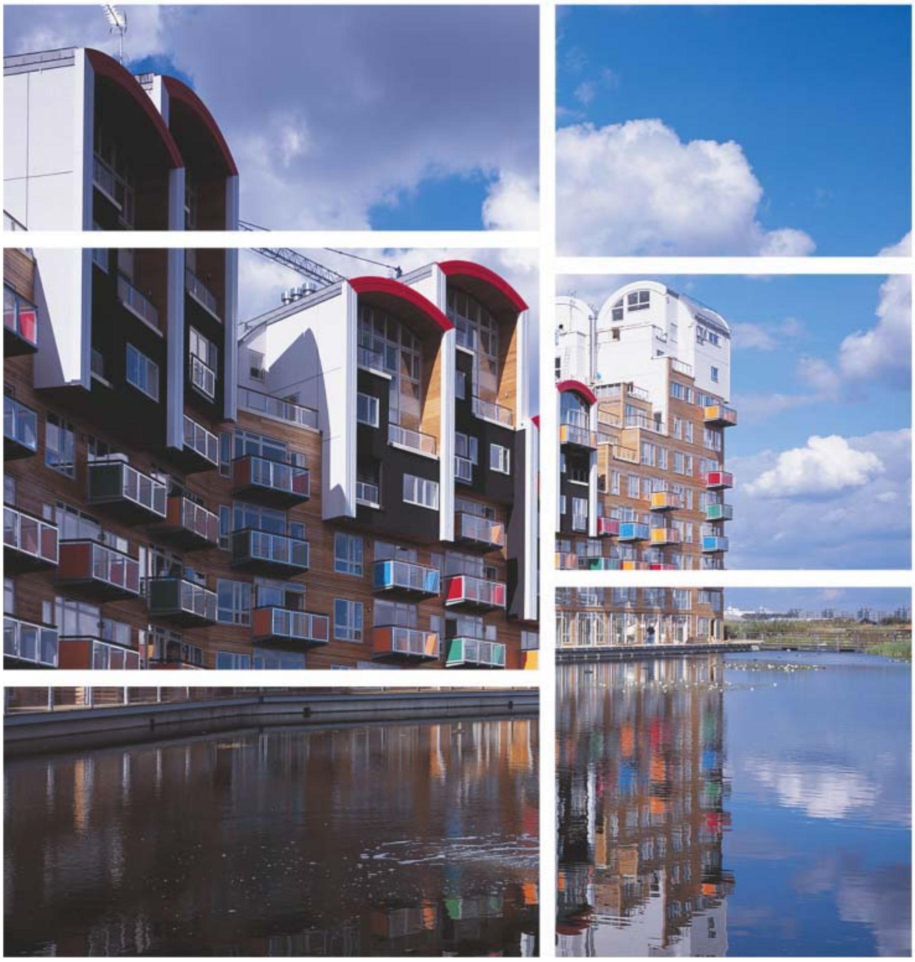
ManuBuild

Open Building Manufacturing





System Handbook

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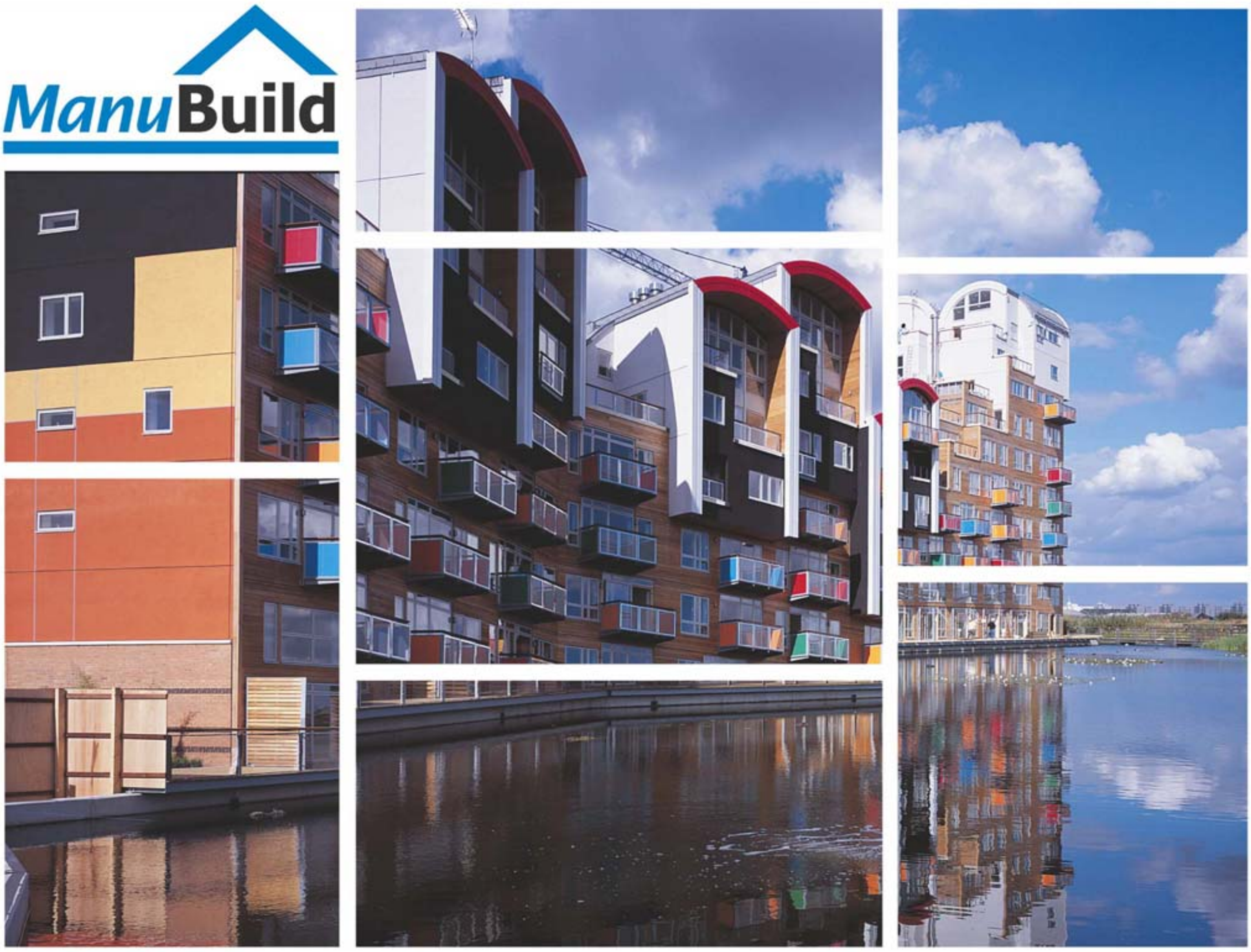

System Handbook

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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.

ManuBuild: Open Building Manufacturing – System Handbook

This open building manufacturing – system handbook showcases some of the key findings from ManuBuild in an easy to read and digest format. Its contents are structured to answer one or both of the following questions:

1. What is …?
2. How to …?

Each of the topics covered includes a section on "industrial context", "key results", relevant "references" and information on "key ManuBuild contacts" to contact for additional information on the topic.

The Content of this System Handbook

This book starts with a short introduction to the vision and strategy of ManuBuild to set the scene for the main content that is structured under seven sections. Each of these sections then provides answers to the "what is ..?" and/or "how to ..?" for relevant topics covered within ManuBuild. The seven sections and covered topics are listed below:

- **Section I: Methods for the Design and Specification of Open Building Manufacturing**
  - Methodology for Product Development
  - ManuBuild System Framework
  - Architectural Typology
- **Section II: Products for Open Building Manufacturing**
  - New Multi-functional Materials
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  - Smart Components
  - Partition Wall Systems
  - Building Acoustics Classification
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- **Section III: Business Models and Processes for Open Building Manufacturing**
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  - Medium Rise Apartments in the UK
  - High Rise Apartments in Madrid
  - Medium Rise Apartments in Sweden

Acknowledgements

The results presented in this system handbook would not have been possible without the hard work and enthusiasm of the ManuBuild consortium in carrying out the work and in then helping showcase and compile it in a simple and digestible form. This handbook is but a summary of the extensive work carried out by the consortium in ManuBuild.

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 some of the key results of ManuBuild as summarised in this handbook. It is our sincere belief that this handbook will guide you on your journey in Open Building Manufacturing.

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ManuBuild, March 2009.

Introduction

Vision and Strategy of ManuBuild

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

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

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

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

Vision and Strategy of ManuBuild – Open Building Manufacturing

Background

Industrial Context

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

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

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

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

Problem

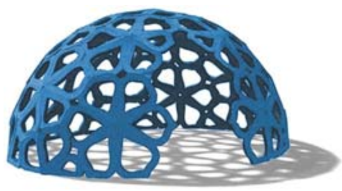
The construction sector is characterised by collaboration between many stakeholders who work together in projects for limited periods of time. Other key characteristics include the complexity and long life cycle of products. Therefore it is only natural that the current use of ICT is fragmented serving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

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

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

Vision

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



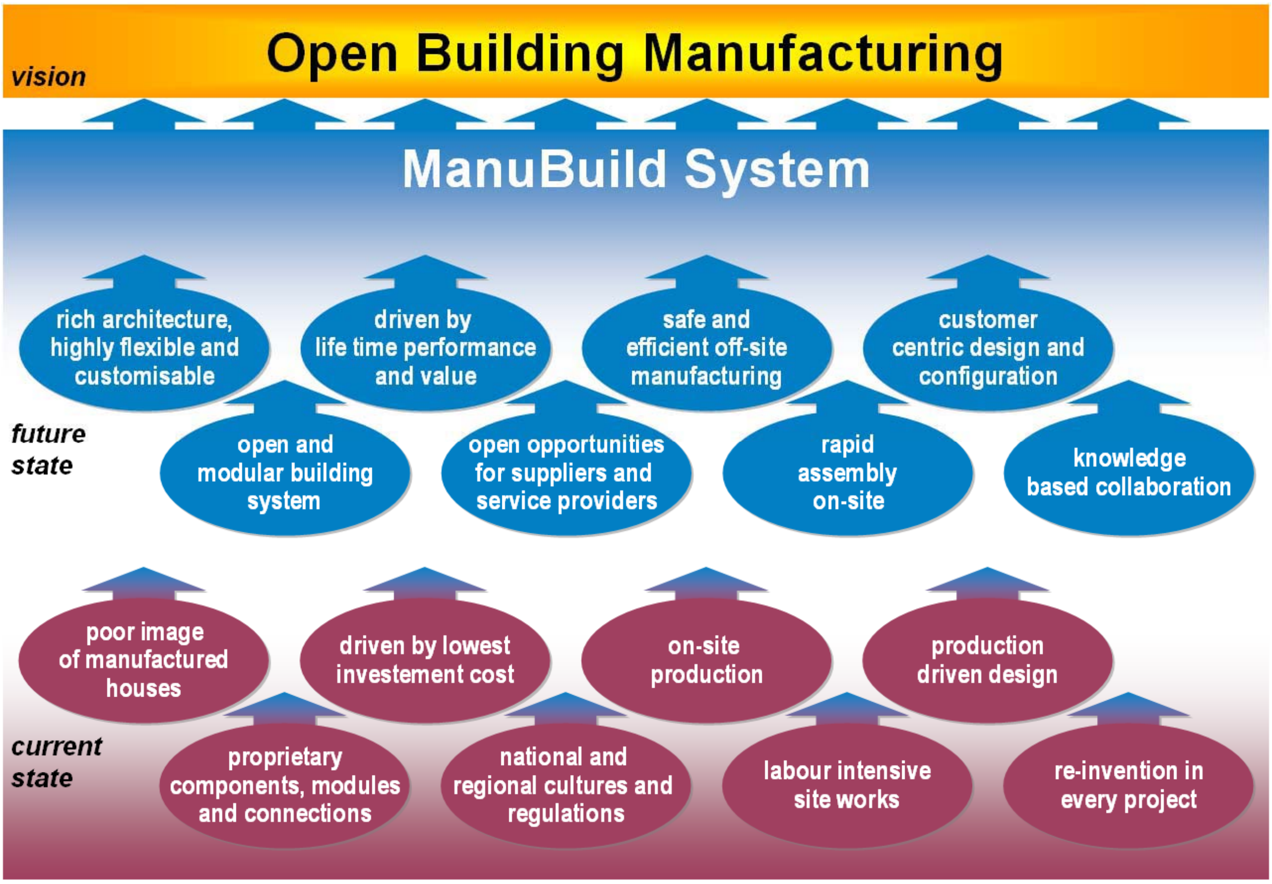
In a first step for guiding the construction sector into this future centred around open building manufacturing, and in order to initiate the visionary paradigm shift from construction's current state being mainly "craft and resource based" towards its future state characterised as "agile, value-driven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

Strategy

Objectives and Targets

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

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



From Current State to Future State – Via ManuBuild System towards Vision

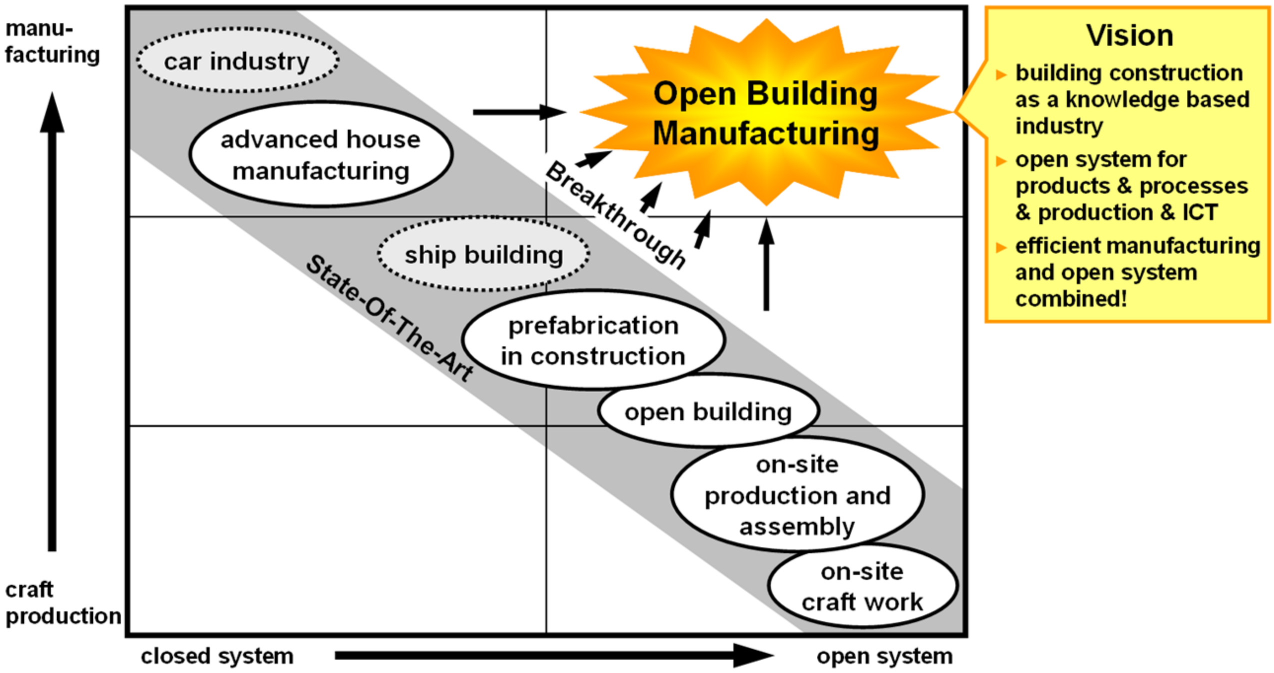
To achieve these goals (from current state to future state) ManuBuild has to define the appropriate principles and rules for developing concepts, methods, tools, technologies and products as well as for working in an open building manufacturing world. Based on these principles and rules, ManuBuild establishes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

- transformation of design from "re-invention in every project" to standardised custom-configuration before the project as well as on the fly re-configuration during the project
- shift from unique results of handcraft to pre-manufactured ready to be assembled products with high architectural and aesthetic quality
- development of new system concepts for flexible architectural and spatial typology
- implementation of on-site manufacturing and pre-assembly with mobile factories
- implementation of efficient off-site manufacturing methods, concepts and technologies
- application of new materials, integrated multifunction modules and smart components
- community and customer driven building configuration, production and fully integrated urban planning, supplying clients with a new quality of life as a service of society
- implementation of new concepts for networked and distributed organisations for design, manufacturing and assembly
- development of future concepts for intelligent maintenance services in the sense of product service co-design

Openness and Manufacturing

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

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



Current State in Relation to Open Building Manufacturing

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

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

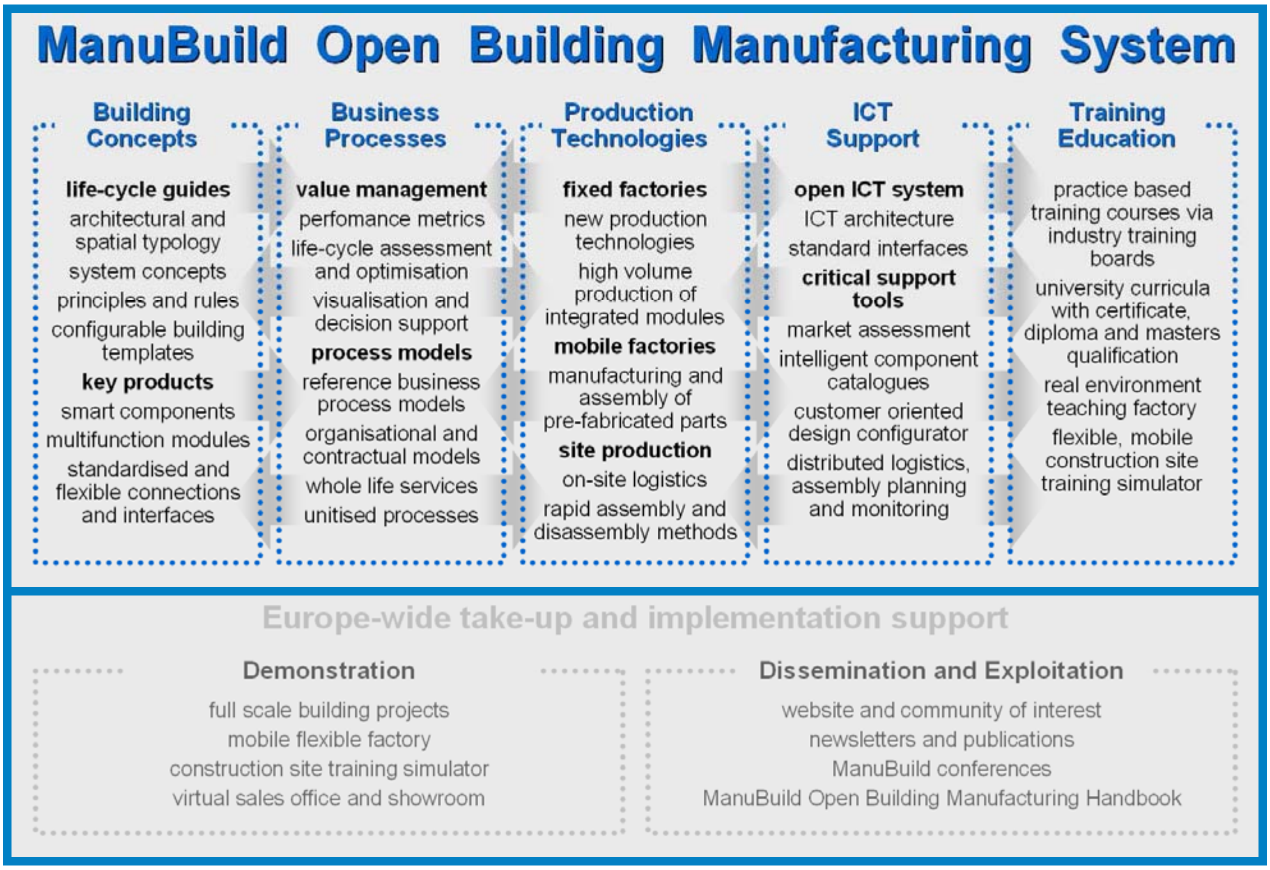
As a summary of the current examples from the figure and as outlined above, for ManuBuild it is essential to avoid the pitfalls that each approach bears in itself when being examined separately and to completely eliminate the compromise solutions or even disadvantages obviously accepted in current attempts.

The ManuBuild Open Building Manufacturing System

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

The **ManuBuild Open Building Manufacturing System** is ***an integrated system that holistically incorporates*** **Building Concepts**, **Business Processes**, **Production Technologies** and **ICT Support** as well as **Training**.

This enables future construction to act as a flexible, agile, value-driven, and knowledge based industry, and most of all, to be highly customer-centric, efficient and competitive.



Key Priorities of ManuBuild

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

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

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

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

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

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

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

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

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

Demonstration to validate the ManuBuild results and prove usefulness in daily business:
- full scale building projects
- mobile flexible factory
- construction site training simulator
- virtual sales office and showroom

Dissemination and Exploitation for raising awareness and informing the European Community:
- stakeholder involvement and concertation
- website and community of interest
- newsletters and publications
- ManuBuild conferences
- ManuBuild Open Building Manufacturing Handbook

Key Results

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

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

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Key ManuBuild Contacts

UST, VTT, DRA, COR, NCC, TWC

Section I

Methods for the Design and Specification of Open Building Manufacturing

- Methodology for Product Development
- ManuBuild System Framework
- Architectural Typology

Methodology for Product Development

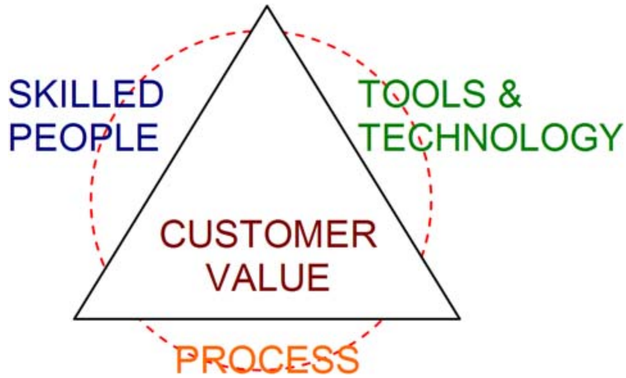
Industrial Context

As a direct cost factor, the product development is itself a relatively minor component of the entire production cost of a product. However, it can exert a very large influence on the other cost factors. Furthermore, just as with costs, the European Union estimates that 80% of all product related environmental impacts are determined at the design phase.

A holistic, systems approach to product development

While product development is clearly a unique environment, the work performed across projects is similar and can benefit from some of the same optimization tools and methods applied to manufacturing. This is especially true for tasks further downstream in the product development process where manufacturing capability becomes an essential competitive advantage. It is possible to manage, standardize and continuously improve the product development process as long as there is a solid understanding of, and allowances are made for, those characteristics of the product development environment that are indeed unique.

The basic elements of the product development system (people, processes, and technology) are fully integrated, aligned and designed to be mutually supportive. Highly skilled, intelligently organized people are the heart of the product development system. Processes are designed to minimize waste and maximize the capability of the people who use them. Finally, technology must be right sized, solution focused and selected to enhance the performance of the people and the process. When these fundamental system elements are coherent by design, they combine to create a truly synergistic system effect. Clearly, in order to achieve this result, other functions within the organization must also be aligned. Without question, this is the most difficult challenge in the transformation of the company or the whole construction sector!



An integrated system for product development

The necessary steps

Processes

1. Define the customer
2. Work up-streams and study different alternatives
3. Create a balanced development process
4. Standardize to reduce variation

People and culture (skilled people)
5. Develop a system with senior engineers
6. Create an organization to achieve balance between functional competence and interfunctional integration
7. Develop engineers with a deep technical understanding and competence
8. Integrate suppliers in the development process
9. Built-in learning and continuous improvement
10. Build a culture that supports success

Tools and technologies
11. Adapt the technologies to suit your people and processes
12. Direct your organization through simple and visual communication
13. Use powerful tools for standardization and organized learning

The development phase

How well defined the product, i.e. the system, is may differ from one product to another. A well-defined product makes the development process more convenient and straightforward. On the other hand, an overly defined product may hinder creativity and innovative thinking and good ideas may be left out. This is a matter of vital importance and it possibly decides the success or failure of the product.

Once the product is defined, the development phase starts: the definition is evaluated and translated into certain proposals about what the product should contain; what is possible to do within the frames of the definition, resulting in concept solutions. Further on, the longer the development process progresses, the possible concept solutions become more and more detailed. For each concept proposal, scenarios are studied and solutions are evaluated. Thus, the number of suitable concept solutions is reduced as the development process proceeds. It should be emphasised that each step or phase should be accompanied by a clear go/no go decision (the gate).

One area that often needs early attention is the connections. The connections may be designed using the same overall approach. This approach is further elaborated in Connections and Interfaces factsheet and its referenced documents. Here it becomes clear how a detail can have a large impact on the overall quality of the final solution.

Key Results

The proposed methodology treats the above mentioned elements and provides a smorgasbord of available tools and technologies. Furthermore, the deliverable in itself illustrates different parts using a prototype development work as examples.

Know-how for all actors involved at the early stage design. If used properly, the cost regarding construction as well as environmental costs can decrease radically.

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Claeson–Jonsson C et al (2008) ManuBuild WP2 Deliverable 2.1-3 (m44) Product Development Process, ManuBuild site.

Key ManuBuild Contacts

COR, NCC, MOW, DRA, CON, TNO, TWC

ManuBuild System Framework

Industrial Context

The ManuBuild building concept can be described as an industrialised open building system with extensive customer choice and flexible high quality architecture with multifunction integrated modules, materials, smart modules, connections and interfaces. The actual building is the final product and should fulfil not only the expectations and requirements of the customer, but also those from the manufacturing and assembly processes. Contrary to traditional building, all decisions must be made before production can start.

Client/Customer value

Some of our aims in ManuBuild are:

- Cost reductions in excess of 50%;
- Time reductions in excess of 70%; and
- Reduction in accidents of 90%.

Clearly, these are indeed very much related to productivity[1]. Productivity could be defined as:

Productivity = Value / Resources

Looking at the definition of productivity, it must be the client/customer/society that defines the value. Usually it is the buyer, and not the participants of the delivery team (architects, engineer, constructor etc.), who decides what is most valuable and likely to yield highest payback. Clearly the delivery team members have values as well but one would hope that they are concerned with delivering the best value to their client. This means we can divide the value of the interests into:

- External values – client/customer value
- Internal values – by and between the participants of the team.

In this work we focused on the external values while the internal values are dealt with elsewhere.
The external values can be separated into (i) process value and (ii) product value. Process value would then be about giving our customers the best experience during the design and construction of the project. It comprises: soft values (ethics, communication, conflict solving), hard values (keeping deadlines, cost estimates, quality and safety) and values that comes from the design and construction process (learning from participating, secondary effects). Then, soft and hard values can be understood as partnering values for the project.

[1] which in turn could be related to lean thinking as the maximising of value adding activities

The 6 Design Values

Product values can be summarised into six design values, the first three being derived from Vitruvian values combined with the surroundings, sustainability issues and buildability.

- Beauty: differentiation in two levels of decision making on beauty, a high (professionals) level and a personal (end-user) level.
- Functionality: Design for maintenance with well defined interfaces and connection compatibility and special attention towards health and comfort
- Durability: Design for durability and European standardisation of regulations, standards and codes in residential buildings.
- Suitability: a building concept in harmony with its surroundings and compatible with changes in family structures and perceptions of the build environment.
- Sustainability: environmental, social and economic sustainability
- Buildability: open system, dimensional coordination and well defined tolerances.

Naturally these can be further broken down in a value tree to make sure the client is guided through the entire value spectrum. The process and the product values do of course interact.

Key Results

The 6 Design Values have been utilized throughout the remaining work including the prototype work. This framework makes sure that the different areas are taken into account and thus providing an integrated concept with the customer's values in focus.

References

Claeson–Jonsson C et al (2006) ManuBuild WP2 Deliverable 2.1-1 (m12) ManuBuild System Framework , ManuBuild Website

Key ManuBuild Contacts

COR, CON, NCC, ITB, MOW, TWC, TNO

Architectural Typology

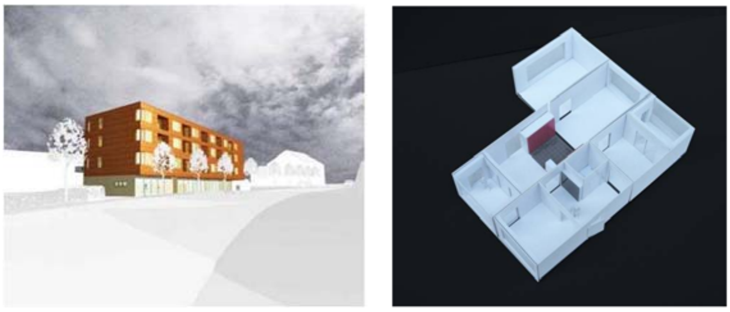
Industrial Context

Standardization and industrialisation allow for important improvements in quality, affordability and sustainability of housing. In the past standardized housing has often been scrutinized for alienating people. There seemed to be no more room for regional differences. Building style and its use were forced in the malls of a global format, the International Style or plain pragmatism. With progress of technology towards mass customization this differentiation becomes possible. In ManuBuild Architectural typology was therefore seen as an essential ingredient in order to safeguard the typical regional differences in the appearance of buildings and the way buildings are used as an important European asset. Architectural Typology is therefore used as an essential ingredient in ManuBuild to connect industrialized housing to specific locations.

Different European regions

In order to get a grip on the differences in European building styles, the typology for regions were studied:

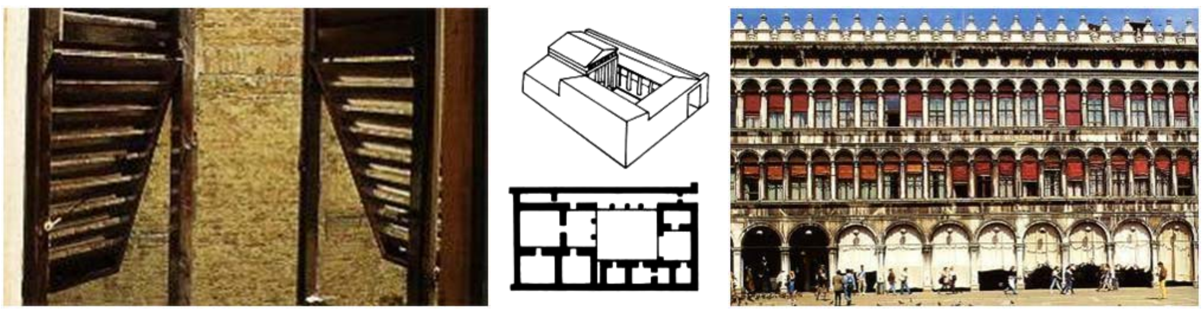
- Sweden as representative of the Nordic region
- The Central European region with examples from the UK, France, Switzerland and the Netherlands.
- The Mediterranean region with examples from Italia, Spain, Greece etc



Examples of the Nordic typology, images by Marie-Louise Greger

Focus and scope

The study focused on the implications for conceptual design process in building manufacturing. Investigation was carried out from the point of view of the architect although the study also addresses the issues which are of interest to readers involved in urban planning, technical design, production and construction. Design cases of medium-rise residential buildings were examined.



Examples of the Mediterranean typology

Key results

The following aspects were the centre of the analysis:

- **Social and cultural features**. References are made to habits and ways of life, which could affect the space configuration and characterization, however, there is a tendency that they become more and more uniform. On the other hand, the ManuBuild project pursues a house that is flexible and adaptable to different situations and cultures. The social and cultural features link to two principal design values of beauty and functionality. Whilst the concept of beauty have been around since Vitruvian times and before, our notion of beauty has changed significantly over time. Functionality, on the other hand, relates to that aspect of design that makes a product or building 'work well' for its intended purpose.
- **Materials and constructive systems**. The local materials or the implementation systems should not be considered in a ManuBuild Open Building System as elements which characterize the different typologies. This includes the principal design values of buildability and durability. Buildability considers factors such as dimensional coordination, tolerances and interfaces, logistics and flexibility of construction type, suitability of components, future maintenance and guarantees, as well as the skill sets and training required by certain construction technologies. Durability relates to the ability of the resultant building and its components to survive and perform as designed through an extended period of time, providing the required level of functionality to future occupants over the lifecycle of the building.
- **Climate**. An element that distinguishes and characterises the different typologies is climate. The three different typologies definition may be tackled according to the answer of the local architecture to the climate conditions in each area. This includes the principal design values of suitability and sustainability. Suitability includes such considerations as local identity, cost, and the ability to meet a client's aspirations beyond mere functional requirements, along with suitability of construction for a given site or project. Suitability as a value is arguably more variable when dealing with regional differences than the other design values suggested in this section. The three key aspects of sustainability are social, economic and environmental.

Examples of the Central typology

References

Engström, Dan (2008) Deliverable 2.2-2 Architectural typology

Thompson, Steve (2007) Dwellings for today and tomorrow – Central European Typologies, ManuBuild website.

Fúster, Almudena (2005) WP2 T2.2 Mediterranean Typology, ManuBuild website.

Greger, Marie-Louise (2007) BOVO. Dwellings based on moduls; A study of architectonical benefits from factory production, ManuBuild website.

Sebastian, Rizal (2008) Cross-case analysis and conclusions, ManuBuild website.

Key ManuBuild Contacts

NCC, EMVS, COR, TWC & TNO

Section II

Products for Open Building Manufacturing

- New Multi-functional Materials
- Connections and Interfaces
- Smart Components
- Partition Wall Systems
- Building Acoustics Classification
- Multi-function and Integration

New Multifunctional Materials

Industrial Context

For any type of construction, building materials are required. The total amount of materials needed for construction purposes in Europe exceeds two billion tonnes per year, making it the largest raw material consuming industry. This is equivalent to 10 tons of aggregates per capita per year being used for construction. The materials form an essential part of the buildings we live and work in, and of the roads, bridges and tunnels we use for transport, networks of drinking and waste water, etc. Materials, and their different combinations, create the aesthetic expression and provide structural strength and durability for buildings and structures. In the coming years, building materials will not merely be selected on their ability to do the job, but on the impact of their whole lifecycle. With between 50 and 60 thousand different materials found in the average house, there is a lot of scope for innovation and improvement.

Sustainability

Building materials have an important role to play in sustainable development through their energy performance and durability, as this determines the energy demand of buildings throughout their lifetime. By developing the use of materials and their combinations, significant improvements of the environment and quality of life can be achieved. Together with the energy and the raw materials used during their manufacturing, it becomes obvious that the production of building materials has a significant environmental impact due to the sheer quantities involved. On the other hand, just small improvements will have a major beneficial impact on the environment. Over the long-term, knowledge generation and better use of building materials can impact beneficially on many areas of our daily life. Other important challenges in the construction industry to which the building materials industry can contribute are the improvement of productivity, a better working environment and the creation of architectural added value.

Concept House – the building with no electricity bill

Tailored material

In the future, new functional and reduced-scale materials that are currently in the forefront of technology will be hybridized into designer materials that can perform dramatic “tailorable” functions in large engineered systems. These performance-tailored structures will have the ability to change or adapt the performance or style of a structure on demand. Today, engineers can imagine designing adaptive flight profiles from morphing aircraft-wing structures; comfort tailored performance, such as active structural vibration and noise suppression or temperature compensation, from louvered or pore-based “smart skins”; energy-efficient structures, such as tropical-plant-inspired solar structures; adaptive structures that can compensate for distortion or heal themselves; and structures reconfigured to satisfy style preferences. Imagine, for example, being able to commute to work in a stately professional car that can be reconfigured into a sportier car for the weekend.

Smart materials

Smart materials and systems are now being used in virtually all areas of technology, and in many high and low-tech applications and products. This course will focus in the basic principles and mechanisms of smart materials and structures, and provide a spring board for further study. What is a smart material? The term “smart material” means a lot of things to a lot of people. The basic definition is: a “smart material” is a general term for a broad category of multifunctional materials for which a specific property (optical, mechanical, electronic, etc.) can sense the environment and can be controllably modified. Many of these materials and structures emulate biological systems that can adapt to changes in their environment, and development of these materials involves combining several technological disciplines, including materials science, chemistry, solid state physics, biotechnology, nanotechnology, and robotics

Examples

- **Biomimetics** - looks at the extraction of engineering design concepts from biological materials and structures, and, has much to teach us on the design of future manmade materials
- **Mechatronics** - essentially hybrid mechanical/electronic systems, approach having been used for vibration control of high rise Japanese buildings
- **Ken materials** - the Chinese characters meaning wisdom, structure, monitoring, integration and benignity
- **At the atomic level** - functionality occurs at the microstructural or atomic and molecular scale

Buzz of burdocks inspiring the development of Velcro

Key Results

Traditionally in construction, we have basically used one material for one purpose. In order to be able to fulfil the aims of ManuBuild it is essential that the material in question is a multi-performing material. This means that we must be able to reduce part counts through the introduction of the new multifunctional material. A simple example is a composite concrete-steel column which eliminates the need of formwork, fire protection, and reduces the number of required columns and maintenance costs just to mention a few effects. Another example is the FRP wall system proposed by Mostostal.

References

Claeson–Jonsson C., Engström D., (2008) ManuBuild WP2 Deliverable 2.7-4 (m36) New Multifunctional Materials, ManuBuild Website

Key ManuBuild Contacts

NCC, MOW and COR

Connections and Interfaces

Industrial Context

Connections and interfaces are crucial for the success of an open building manufacturing system. However, the aim has not been to develop the ManuBuild connection, the interface to solve all interfaces. The aim is to develop a useful method of communicating the properties of an interface between building parts, in order to avoid misunderstandings. In fact, we are looking for a common languag, applicable to all levels of the building system (element, component and system), and independent of materials. Only with such language can successful connection be developed.

Design for Openness

An open building system has a number of specifications and ground rules for the designs but are otherwise open for variations and choices, it is for example open for all suppliers that meet the specifications. We argue that the specifications should not be technical in their nature, for example connections and interfaces common for several systems. For a system with technical specifications, the system owner must provide suppliers with designs to offer tenders on. On the other hand, a system that is developed in collaboration builds on openness within the working group. With such systems, all involved have the opportunity to develop and agree the technical content together.

We move away from technically inspired image of openness and consider the reasons to have open options. Such reasons include, for example, *varying products* (the perspective of the client and society, respectively), an *open market for both suppliers and system owners* (the perspective of the sector and of society, respectively) and *future changes of the building* (the perspective of the user). We believe that the possibilities to reach such goals are more dependent on what *working principles* we have in common than what *products* we have in common.

Openness then means that options and choices are open. Every time openness is used to describe a system, the perspective being used needs to be specified. Is the system open from the perspective of future changes or new suppliers? A comprehensive definition of the concept of openness in building manufacturing systems is lacking. Our suggestion is qualitative in its nature:

> *A system that is open from a certain perspective offers a number of choices and variations relevant to the perspective in question.*

From this it follows that a system that is *closed* from a certain perspective offers no or only a very limited number of choices and variations relevant to the perspective in question.

Openness for choice of supplier is necessarily not easy to be combined with openness for varying forms. Openness in the value chain is facilitated by standards, for example, how modules and interfaces should be handled. Research and development of standards must find possibilities for positive effects both for the company and society in general. From the perspective new industrialised architecture, it is a priority to develop shared knowledge that supports freedom of choices for the architects and for the living environment in particular. Form a perspective of a common building market, the shared knowledge shall encourage openness in the value chain.

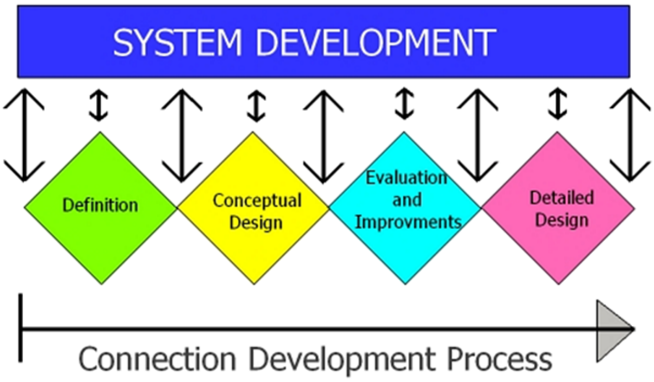
The work has generated a method for evaluating the level of openness that an element, component or system exhibit. Furthermore, areas of potential improvement for openness can also be identified. The method has been illustrated through the use of the partners' prototypes.

Design for easy assembly

With the knowledge from the studies, a four step design method for structural connections in industrial construction was developed. The method starts with guidelines aimed to help the designer develop connections which are easy to assemble. Next, design proposals, which should be investigated with the help of the method, has to be described with comments and figures. Then absolute demands, depending on the design situation, are controlled using a checklist. A connection must, for example, withstand applied loads. The next step is an evaluation regarding the connections' assemblability, consisting of criteria divided into three statements. A grade is calculated for each criterion depending on the connection's performance and the criterion's importance. The result of the evaluation is a mean grade and an assembly index for each connection. A case study has been performed in order to improve the method and it has shown that the method works satisfactorily.

Developing connections for a building manufacturing system

The connection development method uses ideas from traditional product development, used in manufacturing industry. The method suggests four clearly defined activities that should be included in a connection development process, *Definition, Conceptual design, Evaluation and improvements* and finally *Detailed design*. The *Definition* activity should give the structure of the development process, stating how information should be treated by suggesting standard document formats, etc. The *Conceptual design* activity should result in a few connection concepts that should be evaluated in the *Evaluation and improvement* activity, which should deliver one connection concept to the *Detailed design* activity. The *Detailed design* should make the connection ready for manufacturing. The activities should be iterative. The process is however not iterative between the activities, the activities end with a clearly articulated breakpoint. The activity's aim should be confirmed before the next activity is initiated. To a high degree, the new knowledge in this work consist of that the intuitive and creative activities are explicitly defined. The method was confirmed with help of a case stud which simulated an existing building system's connections.



Connection development process: activities illustrated as rhombuses and arrows illustrated the information flow between the connection development and the system development

Key Results

The aim was to develop a range of standardised connections and interfaces for joining/combining pre-fabricated elements and components based upon performance requirements and manufacturing efficiency. This included the aims to identify and structure performance requirements and manufacturing efficiency parameters and to prototype connections and interfaces at element, component and system level. Some issues must be addressed to be able to design such connections and interfaces. Once these issues are addressed and applied, actual products can be developed.

References

Engström D et al (2007) ManuBuild WP2 Deliverable 2.6-2 (m30) Connections and Interfaces , ManuBuild Website

Claeson–Jonsson C et al (2008) ManuBuild WP2 Deliverable 2.6-2 (m42) Connections and Interfaces , ManuBuild Website

Key ManuBuild Contacts

COR, NCC, MOW, LAB, CON

Smart Components

Industrial Context

The ManuBuild building (product) concept can be described as an industrialized open building system with extensive customer choice and flexible high quality architecture. In order to fulfil customers' individual requirements, this product (building) can be built/assembled in various ways with multifunction integrated modules, standard smart components and flexible connections and interfaces. The actual building is the final product and should fulfil not only the expectations and requirements of the customer, but also those from the manufacturing and assembly processes.

Smart Component requirements

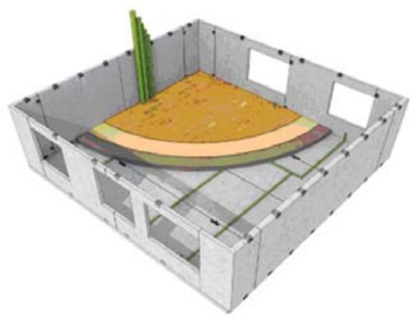
Focus on the smartness – ***the added values to the user, the facility manager, the contractor and so on***.

- Fulfil regulated functions
- Think *smart development* of components, not only development of *smart components*.
- Decide on a level of smartness. Balance between the level of prefabrication and the level of skill needed in the workers on site – how complex should the component be?
- The same basic component should be possible for different uses, different variants of codes etc. Changed features should be possible during the life-time and removal and replacement depending on the requirements
- Risk assessment
- Added values
- Ease of manufacture and assembly
- Cost

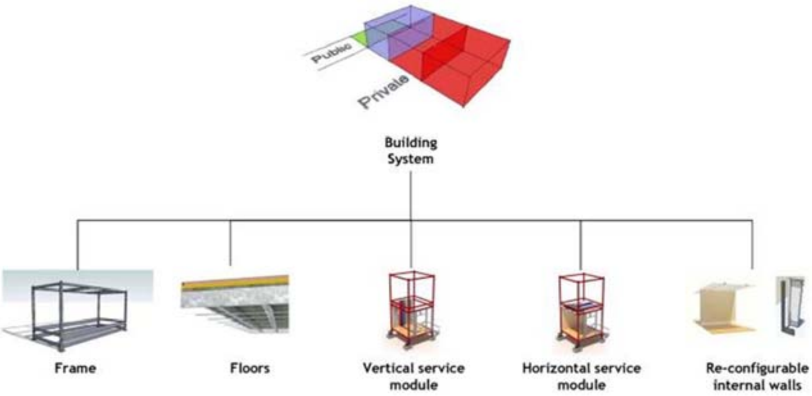
Case Studies

The **Dragados Service Core** - The Service Core is a step forward towards its industrialization by prefabricating the vertical service nucleus which gives service to the "humid rooms" (bathrooms, kitchens, etc.). The idea is to industrialize the construction of the module assuring a higher quality of the final result and an easier on site work and future repairs.

The **Consolis ConBolt System** – A prefabricated concrete system which is very quick and easy to erect at the site. The system does not require any wet phases and it gives a great flexibility for room positioning during the design phase and also in the future. It also makes standardized, and effective production at the factory possible.



The **Corus ManuBuild Building System** - Significant changes are occurring in the required flexibility and performance of buildings, and in particular dwellings. The aim of this prototype system is to explore how these changing criteria can be met. Concentrating first on what is needed by legislation and the market at a building level, and then designing a system and its components to support and achieve these requirements. This employed a market-focused approach rather than a product-focused approach.



The **Mostostal FRP partition walls** - Fibre Reinforced Polymers (FRPs) combine light weight and high corrosion and good mechanical resistance, making life cycle costs lower than conventional materials. The FRP partition wall system will be open for the end-user perspective. The system will offer flexibility of different wall dimensions, shapes and colour. During the life-cycle it will be easy to remove the wall, change the surface or extend it.

Impact of prototypes in the construction industry

The work also included an analysis of:

- Construction cost
- Construction time
- Workers safety
- Market share impact

All prototypes showed promising steps in fulfilling the overall ManuBuild goals regarding these topics. Moreover, a general discussion was carried out regarding sustainability.

Key Results

ManuBuild has developed and illustrated a methodology for the development of smart components, putting the main focus on customer's values. By applying these principles a reduction in construction time and cost are possible as well as increasing the health of the construction workers.

References

Engström D et al (2007) ManuBuild WP2 Deliverable 2.4-2 (m30) Smart Components, ManuBuild Website

Claeson–Jonsson C et al (2008) ManuBuild WP2 Deliverable 2.4-3 (m42) Smart Components, ManuBuild Website

Key ManuBuild Contacts

COR, NCC, MOW, ITB, DRA

Partition Wall Systems

Industrial Context

Traditional systems of building partition walls are heavy (~165 kg/m^2), difficult and unsafe to assembly, and require skilled (expensive) personnel. A fundamental disadvantage of traditional partition wall systems is the lack of flexibility. Once a traditional partition wall is built, it cannot be moved. Locations of partition walls are planned in an early phase of building design and after this time it is almost impossible to change their positions without destroying them. Furthermore, problems like cracking, corrosion, low acoustic properties are common in traditional partitions systems. The above consideration shows a real need for new, simple, and smart partition wall construction solution using new advanced materials. One such solution is a new innovative dividing wall system designed in fibre reinforced plastic composites (FRP).

Composite materials

A composite is a mixture of two or more distinct constituents or phases. When the phases consist of a fibrous material dispersed in a continuous matrix phase, the resulting composite material is commonly known as Fibre Reinforced Polymer (FRP). Composites offer the designer a combination of properties not possessed by traditional materials (concrete, steel and wood). Components used for new partition wall system are glass fibre, epoxy matrix and closed cell foam with an excellent temperature resistance which perform a function of sandwich core.

Sandwich structure

Sandwich panel construction is a technique in which two high modulus, high strength, facing sheets (called skins) are bonded to a low density material (called core). The skins are subject to tension/compression and are largely responsible for the strength of the sandwich. The function of the core is to support the thin skins so that they do not buckle and stay fixed relative to each other. The core experiences mostly shear stresses as well as some degree of vertical tension and compression. Sandwich structure constructed in FRP offers very high ratios of stiffness and strength to weight.

FRP Partition Wall System

The partition wall consists of a double-sandwich system with an air chamber between both laminates. Each sandwich is made of two glass fibre skins and a core. A surface treatment is applied on the partition face to achieve the desired texture and colour (panels are painted in the factory). The electrical installations are integrated in the partition system. The partitions fulfil the standards in force on the application place, in terms of mechanical, thermal, acoustic and fire properties. The final tolerance is less than 1mm.

FRP Partition Wall system developed by Mostostal during the ManuBuild WP2 is based on sandwich panel manufactured in innovative material – GFRP (Glass Fibre Reinforced Polymer).
The main idea of the partition wall system designed and manufactured in FRP is to reduce as much as possible, the weight of elements and part counts. The system consists of very simple panels or partition wall elements (including modular panels, corner elements, and result panels), and different types of connections between the systems and building structure.
Final surface of the wall will be made from alumino-silicate fibres. Significant advantage is a resistance for high temperature up to 1400°C. This factor is especially important in houses and apartments. External layer will ensure resistance to corrosion and offer low thermal conductivity. Other types of surfaces are equally compatible: regular paintings, ceramic tiles, wallpapers, gelcoat etc.

Openness

The FRP partition wall system is open in an end-user perspective. It is highly recommended that the client has influence on the final features of the product. The system will offer flexibility of different wall dimensions, shapes and colour (this features depend on the end-user). During the life-cycle it will be easy to remove the wall, change the surface or extend it.
System is open for the material suppliers. This will allow introducing new materials to the system in the future. Both design process and manufacturing will be simplified. Therefore, the assembly and installation will not require highly skilled workers.

Potential use of the product

The main advantage of Mostostal ManuBuild partition is that it is a partition wall which can be easy moved from one place to another. This product could be used both in residential flats and office buildings. In a flat it helps people to reconfigure their space as desired. It could be a particularly good solution for open-plan offices where there is a need to reconfigure and adapt the work place.
It has been proven that by application of the FRP system, lifecycle construction cost can be reduced by up to 50% and price per square meter of usable floor space in building can be lowered. This product can also improves safety by cutting accidents by up to 95%.

Key Results

Within ManuBuild project partition wall system has been developed and demonstrated within MB building demonstrators. FRP panel based on glass fibre, epoxy matrix and closed cell foam was developed. Furthermore manufacturing techniques were proposed, tested and elaborated. Various partition wall connections and surface solutions were presented. The design of the system has been integrated with ICT tools developed within MB WP5.

References

ManuBuild m42 deliverable, D2.6-3 Connection and interface prototypes at element, component and system levels.

ManuBuild m42 deliverable, D2.4-3 Smart Component prototypes.

Poneta P., Gilun A., “FRP Manufacturing Process”, Warsaw, Poland 2007.

Key ManuBuild Contacts

MOW, NCC

Building Acoustic and Classification

Industrial Context

The vision of an open system for manufactured building is focused on the needs and requirements of all stakeholders. Clear and uniform assessment criteria and coherent indicators which are easily all-understandable regardless of the building location play pivotal role in a proper and precise definition of these requirements. Actual situation in building acoustic around Europe is rather confusing. There are dozens of indicators, local classifications and different requirements. Proposed uniform classification scheme gives the possibility of choice within the performance range covering all European limits and assures that the building of a certain class meets legal requirements in a defined group of countries.

Actual situation in building acoustics

From a perspective of an open building system functioning on the open market, the legal situation in building acoustics is really complicated. Several different indicators are in use in different countries and the level of minimum standard of performance differs substantially. Airborne and impact sound insulation are considered separately, as well as the level of noise penetrating from outside and from the technical equipment.

Airborne and impact sound insulation, single number indicators presently used in Europe

Indicator	Countries
R'_w	Czech Republic, Denmark, Estonia, Finland, Germany, Hungary, Iceland, Italy, Lithuania, Latvia, Norway, Slovenia, Slovakia,
$R'_w + C$	Poland
$R'_w + C_{50-3150}$	Sweden
$D_{nT,w}$	Austria, Belgium,
$D_{nT,w} + C$	France, Holland, Switzerland
$D_{nT,w} + C_{100-5000}$	Spain
$D_{nT,w} + C_{tr}$	UK
$D_{n,w}$	Portugal

Indicator	Countries
$L'_{n,w}$	Czech Republic, Denmark, Estonia, Finland, Germany, Hungary, Iceland, Italy, Lithuania, Latvia, Norway, Poland, Portugal, Slovakia, Slovenia,
$L'_{n,w} + C_{I,50-2500}$	Sweden
$L'_{nT,w}$	Austria, Belgium, France, Spain, UK
$L'_{nT,w} + C_I$	Holland, Switzerland

Beside legal requirements for minimum standard, several countries have adopted local classification schemes defining higher acoustic quality of a building which is not mandatory but if achieved it assures higher level of comfort and quality. Such local schemes are in use in Nordic countries, France, Holland and Germany.

Actually the final user, and also architect, developer, contractor, etc., is rather interested in the acoustic quality of a building and price related to it than directly in values of different sophisticated acoustic indicators which may be misleading even for professionals e.g. the value of airborne sound reduction index is better if higher while impact sound insulation indicator is the opposite. Building acoustic is not very well represented in building performance rating systems. The probable reason for this is the lack of coherent acoustic indicator for the whole building.

The concept of uniform classification

The uniform acoustic classification scheme within open manufacturing system should give a simple and clear assessment criterion in a similar way as the number of stars describes the category of a hotel.

There is a lack of any extensive research in the area of building acoustics on user expectations and individual requirements taking into consideration diversity around Europe, different habits, cultures, sensitivity to noise, local possibilities, sense of comfort and quality etc.. However, it may be assumed that the local legal regulations and local classification schemes are based on a local research and studies thus reflecting local expectations, possibilities and cultural habits. Hence, the limit values and local classification schemes existing in different European countries are used for constructing the frame of uniform classification scheme and the span for a single class. The proposed scheme embraces all values of sound insulation indicators used in Europe, when particular classes reflect different level of requirements in a reasonable way.

Structure of the classification scheme

The frame proposed for airborne sound insulation categorization is shown beneath. The range of part A embraces all minimum requirements, while part B contains higher (not mandatory) limit values defined by local classification schemes. Analogous arrangement was worked out for impact sound insulation then both frames were combined into one scheme.

Airborne sound insulation, frame values for classification scheme

Group	Range of national requirements	Class, R'_w
A	R'_w = 50 dB (Italy) $D_{nT,w} + C_{tr}$ = 45 dB (UK)	50 dB
	...	53 dB
	R'_w = 55 dB (Denmark, Estonia, Finland, Island Lithuania, Norway) $D_{nT,w}$ = 55 dB (Austia) $D_{nT,w} + C$ = 54 dB (Switzerland)	56 dB
B	R'_w = 57 dB (Germany SStII) $D_{nT,w} + C_{tr}$ = 57 dB (Holland k=2)	59 dB
	…	62 dB
	$D_{nT,w} + C$ = 62 dB (Holland k=1) $R'_w + C_{50\text{-}3150}$ = 63 dB (Denmark A, Finland A, Island A, Norway A)	65 dB

Key Results

The concept of acoustic classification scheme within open building system gives simple and coherent assessment tool similar to the number of stars for a hotel quality. It takes into consideration actual requirements in all European countries and general relationship between values of different acoustic indicators in use. Acoustic class clearly define the quality of a building, influence the price, and guarantee chosen level of comfort thus allowing for tailor-made buildings for different users. Adopting uniform classification scheme as an assessment tool in an open building system can be a step towards harmonization of acoustic criteria and requirements around Europe.

References

Nurzyński J. (2007) Evaluation of acoustic performance of multifamily buildings, open building manufacturing approach. Proceedings of Inter-Noise 2007, Istanbul 28-31 August 2007.

Key ManuBuild Contacts

ITB, COR, DRA, IVF, FCC, CA3, TWC, NCC, CON, MOW

Multi-function and Integration

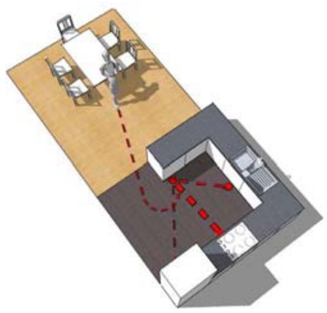
Industrial Context

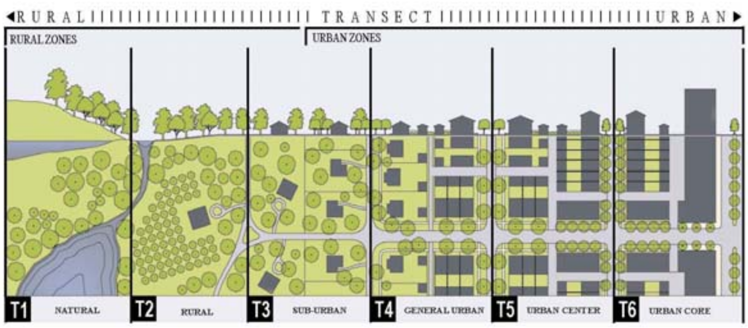
Today there is a greater awareness of the need to reduce carbon emissions than ever before. It is clear that this is a global issue; both in terms of the reductions in emissions needed and the impact climate change will have on our lives.

The main focus of ManuBuild has been the residential sector, which has a significant impact on global emissions, and one of the largest contributors to residential emissions is the impact of changing demographics. The issues go far beyond a simple increase in overall population; they include considerations of household numbers and the size of those households, the age of individuals, how much space they occupy and where they are located. To develop open manufactured components and building systems that facilitate great quality architecture that is suitable for its occupants, we need to clearly understand the people that occupy the buildings we create, what they need and aspire to, what is common or different between households, and how systems can be optimised to meet these changing needs.

Design for Living

Parker Morris (Ministry of Housing and Local Government, 1961) developed an activity-based approach, which he described as being indirect. The arrangement of rooms and spaces should be the results, not the starting point of a design. The layout needs to grow from the inter-relations of activities: an appreciation of which activities can be carried out simultaneously or together, and which need to be separated. In this way, spaces develop from the needs of the occupants and evolve as a consequence of thought, not from bringing out the same standard (and often inappropriate) solutions used before. ManuBuild has used existing consumer marketing tools and end-user surveys, combined with urban planning and analysis tools to create a greater understanding of the needs of different household types, to enable designers to understand more clearly who they are designing dwellings for.





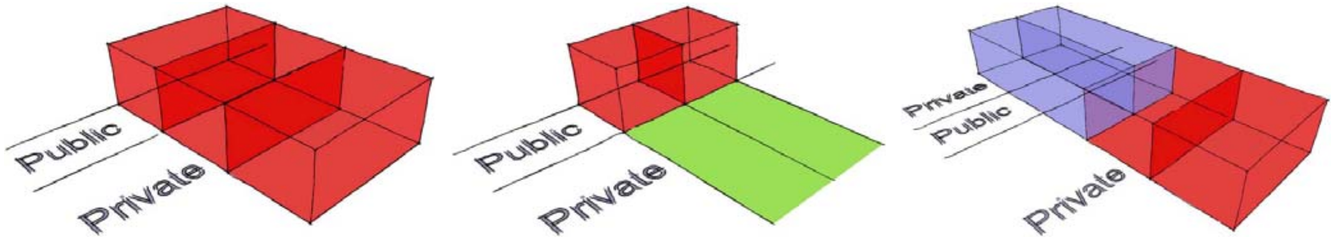
Componentisation & Whole Building Thinking

In developing manufactured building components and systems, it is important to understand how each component contributes to meeting the desired objectives at a building level, throughout the lifecycle of the building. By componentisation, we mean to divide a building into its constituent parts, and also in terms of open building manufacturing, we are looking at parts manufactured and potentially pre-assembled before reaching the final construction site.

We also need to look at the interfaces between components and how they work together to form quality architecture and dwellings that are suitable for their occupants but also work for those that deliver the buildings. In ManuBuild we have looked into key issues such as dimensional co-ordination and management of tolerances between different systems, and the key players that are involved in delivering buildings using open building manufacturing, and how products can be optimised to create value to all players in the process.

Construction Flexibility

ManuBuild works on the principle of creating building systems that can facilitate great architecture, not define it. By this we mean that manufactured components should not restrict the architect's vision of building design, and a number of building types and styles can be created using the same basic components. This also means that a system can be regionally refined to suit the needs of the specific project.



In-use Adaptability

Through careful consideration of the design of homes based on the needs of the occupants at both individual and community level we can, to a large extent, future-proof our homes; allowing them to adapt to their changing requirements over time and cope with external as well as internal contextual differences. We can allow for future upgrades or replacements whilst also providing flexibility to develop an unlimited range of typologies to suit different requirements using the same or similar components and methodologies.
Achieving this will reduce some of the need for future housing across Europe and improve the sustainability of neighbourhoods, cities and housing in general.

Key Results

ManuBuild has developed a methodology of using geodemographic information, such as consumer marketing tools, end-user surveys and real geographical and cultural contexts to inform the design process for quality, sustainable speculative dwellings. Combining this with work on architectural typologies has provided guidance on how dwellings change over time, and how open building manufacturing can provide dwellings that can be adapted and upgraded in the future to minimise obsolescence and maximise quality in the future. A new Corus ManuBuild Building System has been developed to illustrate the potential for these systems, along with guidance on dimensional co-ordination and tolerances that need to be considered to create deliverable solutions.

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Key ManuBuild Contacts

COR, TUM, NCC and CIRIA

Section III

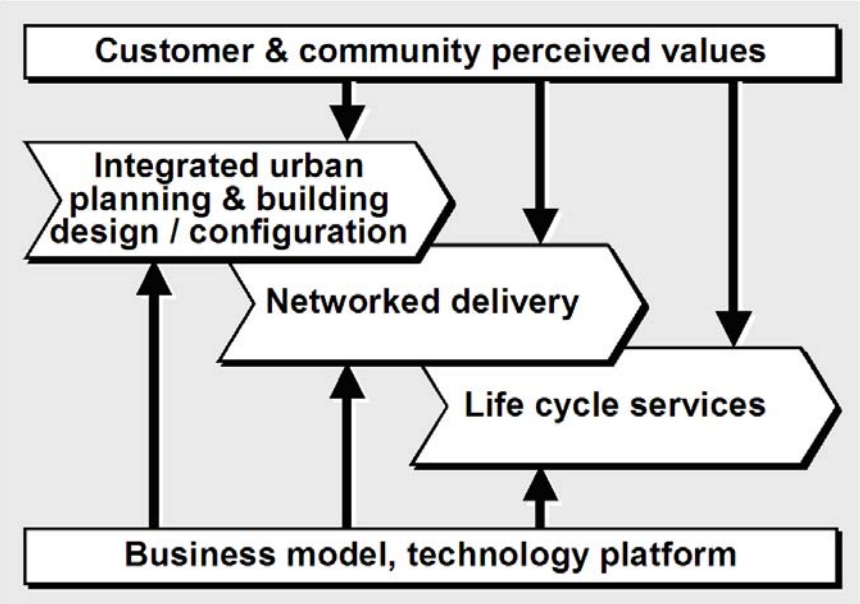
Business Models and Processes for Open Building Manufacturing

- ManuBuild Business Model
- Reference Business Process
- Organisational Models
- Service Models
- Business Models
- Performance Metrics
- Market Analysis Methodology

ManuBuild Business Model

In the context of the ManuBuild project the relevant business processes for the construction of buildings, not only the actual construction but also the different necessary procedures for ensuring the product building and its operation, like design, development, manufacturing or after-sales services were investigated and re-designed to suit the approach of open building manufacturing.
The current construction business has got some peculiar habits compared to other industries, and that makes construction very particular and problematic. Below, some of these traditions and their consequences are shortly outlined with regard to:

- **end users** (customers) are typically involved at the end of the constructive process, only in the sale of the building and during the building's operation, without very much consideration of their preferences and needs. They are known indirectly through sales experiences of the developer. Besides, these preferences and needs, and even the end users themselves, can change, however the constructive systems are not flexible enough and do not enable consequent building transformation. This results in additional costs for building modifications even before the first use of the dwellings.
- **stakeholders** (architects, designers, developers, administrations, builders, manufacturers etc.) only participate in some phases of the whole building's life-cycle, and they are interested in optimising their own phases only, ignoring the interrelation to the other phases. This fact creates a system based on conflict, not on cooperation. Each stakeholder only looks for benefit through minimisation of the own costs. With that the processes are not integrated through the whole life-cycle of the building, which makes it impossible to optimise the overall process.
- **designs** (architectural) do not sufficiently take into account industrialisation issues, so the construction industry is often viewed as underdeveloped by society. Not considering industrialisation complicates the ability to use different components from different suppliers as well as their interchangeability and interoperability.
- **construction systems** also show little industrialisation, in practice we can find mostly "wet construction systems", which are not suitable for transforming on-site work to factory-style assembly work. This results in the need of great manpower, with the directly related risks of safety, control and efficiency. There is also the general lack of specialised and qualified manpower, which intensifies these problems even more.

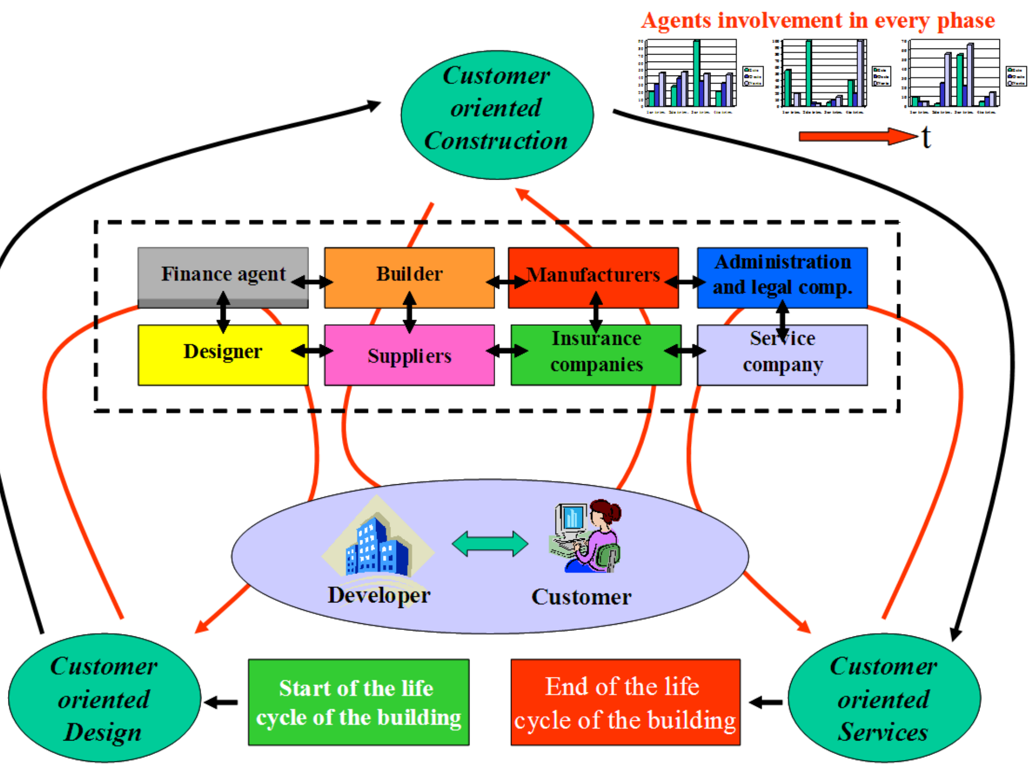


Accordingly, one of the main objectives of ManuBuild was to develop a new business model which enables the transformation of current practices to allow for high customer orientation and added value for everyone involved in the construction process.

The main foci of this new business model can be expressed as:

- **placing the end user in the core of the whole building process** throughout the different phases: customer oriented design, customer oriented construction and customer oriented services. As the end user is involved since the start of the process, the needs, requirements and preferences will be fully satisfied, obtaining an individualised product with a high added value for the end user.
- **integrated processes** for the whole life-cycle of a building. This new model must include pre-design, design, construction, operation, maintenance and after-sale services where all of the stakeholders have a different intensity of involvement. Thus all the stakeholders will have responsibilities for the overall building process and not only for the (sub-)processes where they traditionally participate.
- **maximised value for all stakeholders** by replacing the focus on minimisation of partial costs through targeting a values of quality-cost-ratio, for all the processes of the building business and for all the stakeholders (including the end user)
- **highly flexible constructive systems** to be able to react to the rapidly changing conditions of the inhabitants, surroundings, environments and markets allowing faster fulfilment of the preferences needs and requirements of the end-users and society.

The figure below summarises the customer-oriented concept of the ManuBuild Business Model:



Customer-oriented ManuBuild Business Model

Elements of the ManuBuild Business Model include

- Performance Metrics
- Reference Business Process
- Organisational Model
- Service Models
- Business Model
- Market analysis methodology

Key ManuBuild Contacts

DRA, VTT, FHG, YIT, EMV, CA3, FCC, TWC, COR, TNO

Reference Business Process

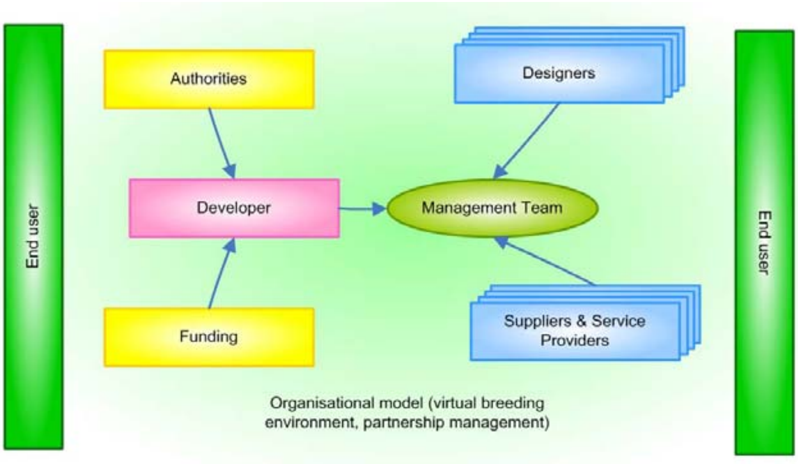
Industrial Context

Concepts such as customer active involvement, activities integration, value driven processes and sub processes, multifunctional building teams etc., which are strongly enhanced in the Open Building Manufacturing environment which ManuBuild promotes, only make sense within the framework of a New Business Process for this sector.

High Level Approach

Main Roles:

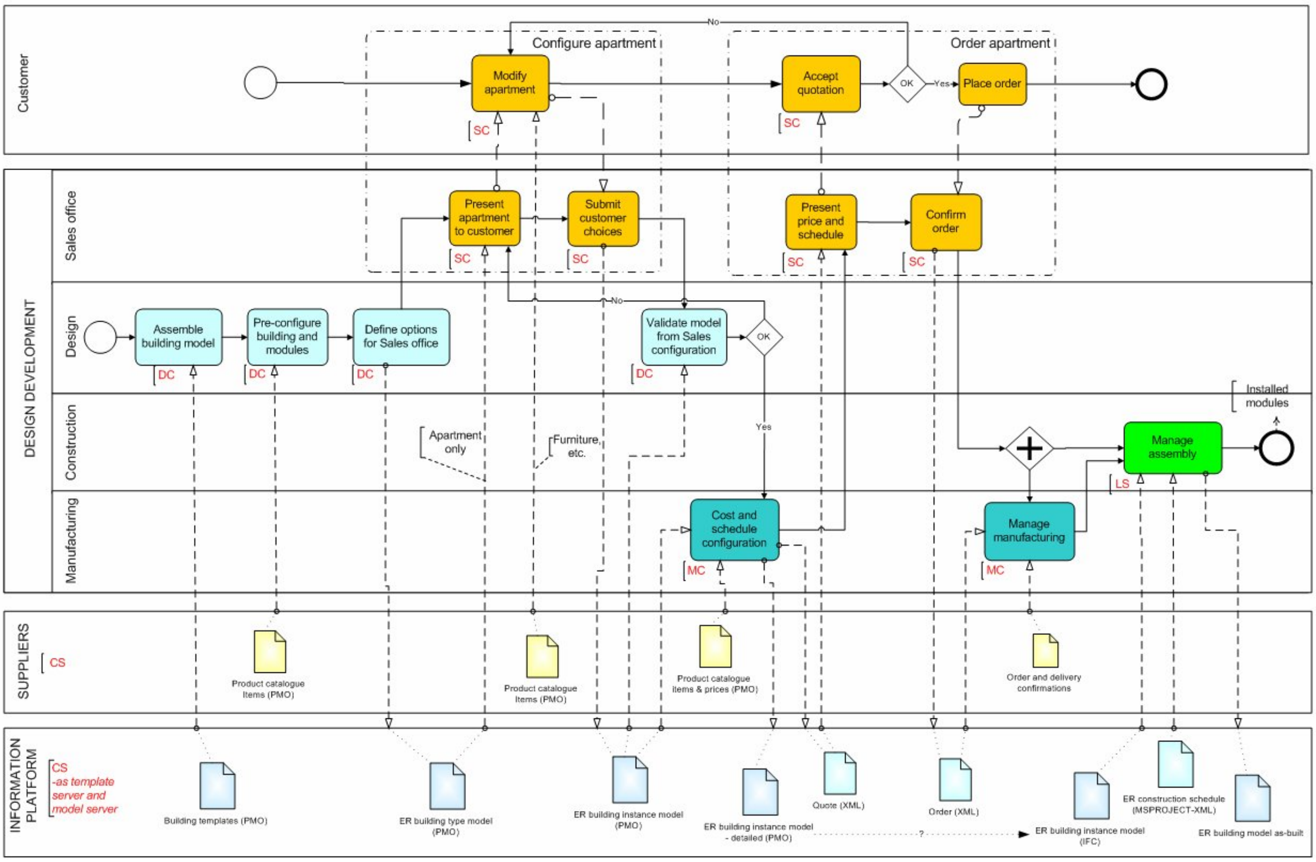
- **End user**: the whole process is oriented towards him. For this, his involvement is promoted from the early stages up until the operation phase.
- **Designers**: Multidisciplinary team (building team) including architects, general contractors, engineers, services companies representatives, environmental and sustainability experts, etc. A nexus with the end user must always be present so his requirements can be "translated" into design concepts.
- **Developer**: important involvement during the whole process, from customer needs detection to life cycle services engaging. This agent (or entity) would act as well as nexus between design team and end user.
- **Authorities & Funding**
- **Suppliers & Service Providers**: Their input is important during the design phase and, as service providers, will also play an important role during the operation phase, delivering value-adding services to the end users, but might have also some play during different phases where outsourcing services might be required.
- **Management Team**: not a stakeholder but an actor, playing the role of fostering efficient communication and information flow among stakeholders. Some of the challenges handled by this actor are: target setting and conformity management (sustainability), communication platform (building information models) and validation (life cycle commissioning), in the frame of the value driven process.



High level diagram of Business Process

Main Phases

- **Pre-activities** (requirements setting) including size and location study, customer profile/segment identification, cost/profit ratio and funding, sustainability and environmental studies, building performance analysis (energy efficiency, flexibility, etc.)
- **Design** including building team requirements gathering, building team design, dwelling template selection, end user interaction, dwelling configuration, final production design and production orders



Generic process diagram (relations between functions, actors, information platform)

- **Off-site Manufacturing** comprehending manufacturing and assembly planning, procurement, storage and shipment, real time performance monitoring, off-site vs. on-site production planning, addition of features and customizations, etc.
- **On-site Assembly** counting work-site facilities set up, components reception and storage, support structure assembly, components and modules assembly, services installation and control, real time performance monitoring, safety and health control, etc.
- **Operation & Services** including customer satisfaction evaluation, project evaluation and continuous improvement, after-sales services deployment, operation performance monitoring, building dismantlement and recycling, etc.

Key Results

A new concept of a generic construction process has been developed including novel concepts that can still be considered realistic enough for the construction industry. New roles and activities have been identified in order to integrate stakeholders, enable customer centric approaches, improving communication, performance and added value for all agents involved.

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Key ManuBuild Contacts

DRA, YIT, VTT, COR, TWC, EMV

Organisational Models

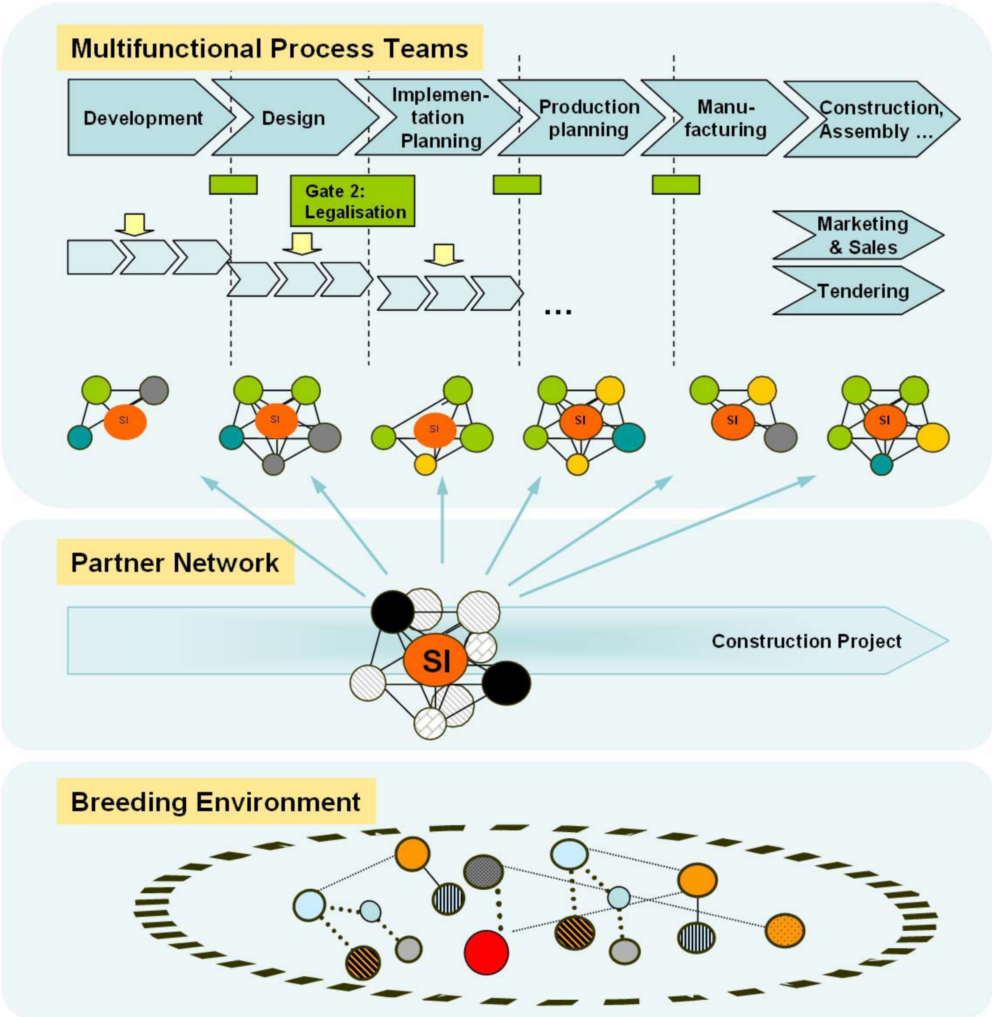
Industrial Context

An approach like Open Building Manufacturing with strong emphasise on customer orientation, freedom of choice, flexibility and agility also implies an appropriate organisational model that enables these targets at the organisational level of the stakeholders involved in the building process.

Organisational Model and Corresponding Roles

The developed organisational model for ManuBuild is a combination of virtual organisation, building team and partnering approach. The generic ManuBuild Organisational Model consists of three core components:

- Breeding Environment: a persistent network of partners which constitutes common working standards and guidelines and which also provides supporting services
- Partner Network: a temporary consortium of partners for a specific construction project
- Multifunctional Process Teams: specific implementation teams for each process step



ManuBuild Organisational Model

The generic approach ensures that the model has a high adaptability to the requirements of the specific regions, network partners and projects as well the ability to be further developed over time.
For each level of the organisational model, different supporting roles have been identified. These roles are performed by various stakeholders and are reassigned for every new project. In other words, each

stakeholder can have (several) different roles in different projects or even different roles in different phases within the same project. This aims to facilitate consortium set-up and partner change, decision making and change management as well as documentation standards and information flow. The roles and corresponding responsibilities for the Breeding Environment, Partner Network and Multifunctional Process Teams are shortly outlined below.

Breeding Environment roles:

- Network Broker / Curator: continuous partner evaluation and certification, support for partner search and acquisition
- Marketing Specialist: conduction of market analyses and brand marketing
- Open Tender Researcher: project initiation and search for open tenders
- Training Provider: analysis of training requirements, management of training offers, development and provision of training
- IT Manager: technical administration of e.g. project portal, maintenance, secure data transfer etc. of the common IT parts of the consortium

Partner Network roles:

- System Integrator: coordination and control of the whole construction project, customer integration, team building
- Change Agent: tracking of all changes, identification of implications and reporting to partners
- Documentation Agent: collection and provision of all relevant documents and information on the information platform
- Controller: tracking of time and cost schedules, quantity surveying, reporting to the system integrator (in case of clearance service also responsible for billing and accounting)
- Logistic Manager: coordination of partner logistics and material flow, reporting to system integrator and controller
- Legal Consultant: elaboration of contracts based on OBM model contracts, legal consultancy.

Multifunctional Process Team roles:

- each team consists of a set of roles resp. partner companies that is composed in order to implement a specific phase of a construction project. Each process team has a defined team leader who is not necessarily the system integrator but directly reports to him/her. Generally the four generic basic roles Process Team Leader (or even System Integrator), Planning or Implementing Partner, Consulting Partner and Associated Partner can be distinguished in each process teams. As mentioned, the specific roles within each Multifunctional Process Team are reassigned according to the roles described above for each process step in every new project.

Key Results

A flexible and highly adaptable ManuBuild Organisational Model which supports and ensures customer orientation, freedom of choice, flexibility, openness and industrialisation at the organisational level of the stakeholders involved in the construction process.

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Camarinha-Matos, L.M.; Afsarmanesh, H. (Eds.): Processes and Foundations for Virtual Organizations; Springer, 2003. - ISBN 978-1-4020-7638-1

Camarinha-Matos, L.M.; Afsarmanesh, H.; Ollus, M. (Eds.): Virtual Organizations. Systems and Practices; Springer, 2005. - ISBN 978-0-387-23755-8

Key ManuBuild Contacts

FHG, EMV, YIT

Service Models

Industrial Context

An approach like Open Building Manufacturing with strong emphasise on customer orientation, freedom of choice, flexibility and agility also creates the necessity to shift from only selling a product (like the building itself) to supplying complete solutions which satisfy the actual needs and wishes of the customers (e.g. a building with appropriate life-cycle services like re-configurability fitting to the different ages of the customer etc.). In this context an approach to create new company specific service concepts has been developed.

Development Procedure

The ManuBuild project uses an integrative approach, considering the building process and its supporting functions as well as the building product. The development of "Service Models" follows this comprehensive approach. Therefore the user requirements on building services have been identified and clustered in respect to several thematic areas of innovative living accompanying services. In addition, the stakeholder requirements (of the participants in a reference construction process such as architects, public administration, construction companies etc.) on life cycle services for the construction process have been investigated and implemented in an integrative target system.

Service Engineering Approach

The conception of new business fields and services is based on the identified user requirements to building services (living accompanying services) as well as on the stakeholder requirements and experiences concerning life-cycle services for a construction project.
By grouping existing and new service ideas according to the pre-requisites and skills needed, the following business fields have been identified: "information and communication", "finance and insurance", "maintenance, refurbishment and supervision", "convenience and assistance for individual persons" and "infrastructure (e.g. for leisure time, culture, sports etc.)".
As a framework for the ManuBuild project, four customer profiles with specific needs have been defined: aged people (good indoor conditions, safety, maintenance-free), young couples (low cost, semi-finished), ubicom (home theatre, wireless services and control), ecologists (less energy, recycling, service life). Additionally the services ideas have been allocated to the three groups of services: "living accompanying services", "pre-construction services" and "after sales services".
The specific features of those services have been analysed in comparison to physical products and a service engineering method was elaborated. The respective phase model for service development provides systematic innovation and development processes for the generation of new life-cycle oriented services, which were described according to four service dimensions. Each of these dimensions has to be considered for service development. In detail they are:

- Potential dimension resulting in resource concepts: assists the planning of the resource assignment, which is required for the subsequent provision of the service, i.e. employees, current assets, information infrastructure and communication environment

- Process dimension resulting in process models: describes how the results of a service are accomplished. In this phase the process steps are determined and the interfaces between the respective steps are defined

- Result dimension yielding product models: describes the achievement of the service before the service can be offered to the customers. This phase includes the description of a service (the expected achievements of the services), the determination of master data and the definition of modules (if a module concept is applicable to the service in mind)

- Market dimension resulting in marketing models: comprises the marketing strategy (determination of target groups, strategic positioning and marketing system), the marketing mix and the so-called 4R of service marketing (Referrals, Retention, Related sales and Recovery)

Service engineering does not only deal with the development of single services. Therefore, a holistic service development system for providing integrated solutions is necessary. Similar to traditional product engineering, which contains a fixed sequence of processes, a service engineering phase model consists of the following generally defined phases: "Situation Analysis", "Service Creation", "Service Design" and "Service Management". This supplies systematic innovation and development processes for generation of new life-cycle oriented services. The respective phase model provides assistance in the systematic realisation of innovative services for the complete life-cycle of components, products and buildings.

Following the service engineering approach, the ManuBuild partners developed two prototypical service concepts for refurbishment and for life-cycle cost assessment. Both the new service concepts and the service engineering approach were thoroughly evaluated by the project partners involved and did prove their applicability, flexibility and future potentials.

Key Results

A service engineering approach and two prototypical service concepts (refurbishment and life-cycle cost assessment), which have been developed following the service engineering approach

References

Ganz, W.; Meiren, T. (Eds.): Service Research Today and Tomorrow; Fraunhofer IRB-Verlag, 2002. - ISBN 3-8167-6226-3

Spath, D.; Ganz, W. (Eds.): The Future of Services; Hanser, 2008. - ISBN 978-3-446-41546-1

Key ManuBuild Contacts

FHG, EMV, YIT, VTT

Business Models

Industrial Context

ManuBuild has an ambitious Vision: open manufacturing in construction, ambient manufacturing methods, and value driven business processes appropriately supported by ICT provide affordable, customized and flexible (configurable on demand) buildings improving the quality of life and providing better value to the customer through a diverse range of “plug-and fix” modules and components and related services offered by knowledge-driven SMEs. Progressing towards that direction requires, not only new building, process and production concepts together with an appropriate ICT platform, but also new ways of understanding customer needs, collaboration, learning and value creation - a new business model.

Approach

ManuBuild process models, organisational models and service models were analyzed and promising systematic methodologies and approaches (lean construction, open building, performance based building, system supply, virtual organizations etc.) studied to form the framework and to help selecting appropriate tools for future business models supporting value creation.
A fictitious story of a challenging value driven housing development case is described to show how the new business model exploiting a broker based business ecosystem could successfully function. Industrial partners are given means to position themselves and their company vision in five years time and applicable support is given to them to progress development in that direction.

Content

The report describes a value creation cycle and related business processes. The framework provides maps to position the target using different axes and explains how a customer satisfaction path could be successfully followed. The need for new actors, and/or new role(s) for present actors are discussed. The supply chain, networking and brokerage concepts are presented together with related methods and tools. The new business model supports sustainable and cost-effective customer-oriented housing through radical integration and industrialisation of the design, production and delivery processes.

Key Results

The ManuBuild business model consists of a conceptual frame covering the corresponding processes, technologies, tool support and products as well as services over all life cycle. In addition, examples of applications by a Developer, Contractor and Supplier are presented and an approach for business model development given.

Key ManuBuild Contacts

VTT, DRA, COR, TNO, TWC

Performance Metrics

Industrial Context

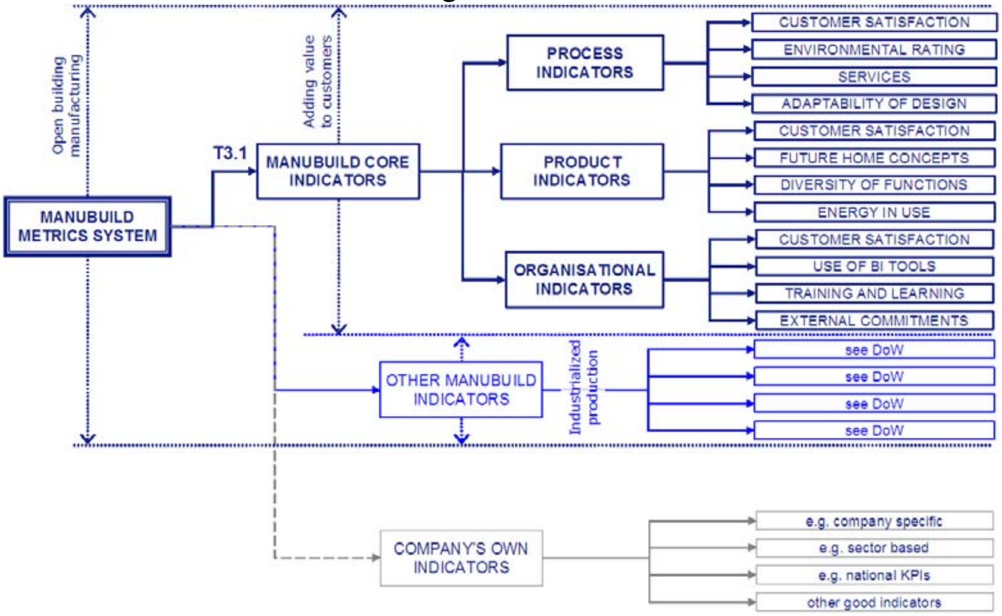
End users of buildings are mainly concerned about how buildings perform in use, instead of how they are constructed. Key Performance Indicators that are currently utilized focus primarily on production phase and don't cover well client satisfaction during the operation of buildings. ManuBuild Performance Metrics focuses on value creation as perceived by inhabitants of dwellings and owners of buildings. The metrics covers process, product and organisational aspects.

Approach

First 53 potential performance indicators were collected to meet ManuBuild objectives and the ECTP Vision and Strategic Research Agenda (to meet client requirements, to become sustainable and to transform the sector). They were classified into process (30), product (13) and organisational (10) categories. Then a small number of core indicators representing those main categories were selected together with the industrial partners and some external experts, focusing on value creation. This metrics was given to ManuBuild partners for demonstration, and second validation was planned to meet the future requirements a new ManuBuild Business Model.

Key Results

ManuBuild performance metrics is an indicator system consisting of twelve core variables reflecting process, product and organisational performance that adds value to end users. The system, still under validation, is shown in a wider context in the figure below.



ManuBuild Metrics System

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Huovila, P. (2007): Measuring Performance and Value in Manufactured Housing. Invited Presentation @ Revaluing Construction Conference. Copenhagen-Malmö, 9-10 October 2007.

Huovila, P., Kähkönen, K., Navarro Suñer, J. M., (2006): Performance Metrics for Residential Building Business. Joint CIB W65/W565/W86 Symposium in Rome, 18-20 October, 2006.

Key ManuBuild Contacts

VTT, DRA, NCC, TWC, YIT

Market Analysis Methodology

Industrial Context

The chapter demonstrates the key elements that affect the housing market and its development. These elements are incorporated into the model of the housing market that is used in the process. The objective is to define the methodology for the housing market to better understand the relationships between the macroeconomic forces interacting on the market.

Aspects Related to Housing

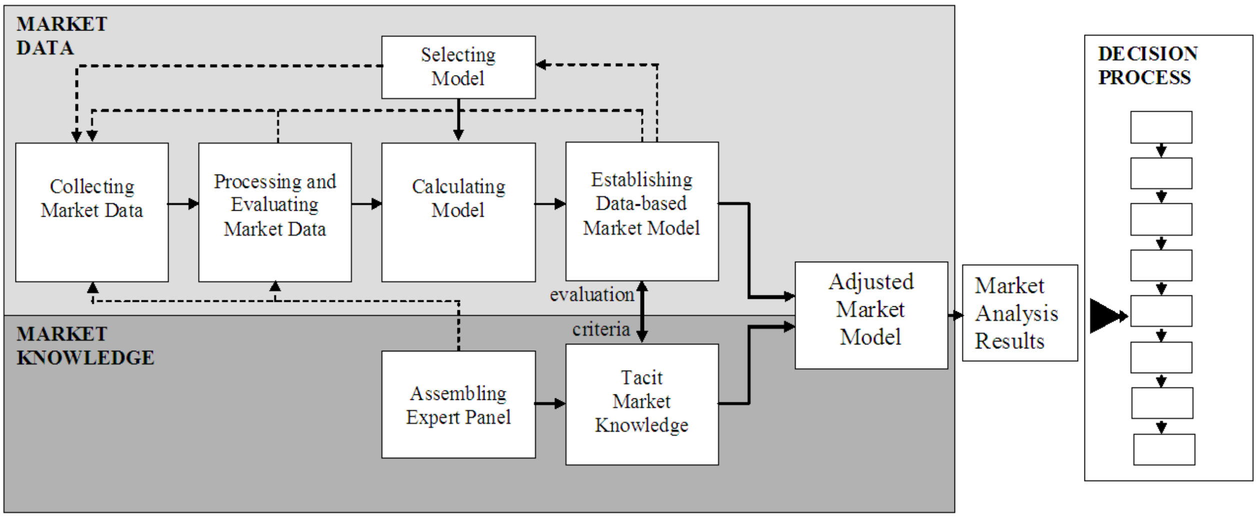
Housing as a commodity possesses many idiosyncrasies: Housing satisfies a basic human need for shelter and housing has few substitutes. It is exceptionally long-lived and durable commodity that has a great number of heterogeneous characteristics, such as size, number of rooms, layout and location. No unit is identical to another in every respect. Another important housing characteristic is its spatial fixity. Even though the housing markets are basically regional, there is a close relation between them and the national and international economic development. The national and international economies interact with regional housing markets through general economic conditions and especially through financial markets. The reason for housing's close link to the general economic development is the housing unit's dual role as a commodity. At the same time, the housing unit functions both as the provider for housing services satisfying the basic need for shelter, and as a capital investment reacting to the different changes in the general economic situation through price adjustments. The housing research is challenged and complicated by the existence of these special characteristics of the commodity and the market.

Macroeconomic Factors

The housing market forms a network of major interrelated forces that operate on the market. These forces are housing demand and supply, national and international economic development and the policies adapted by the authorities. The forces are again influenced by the macroeconomic factors. The demand for housing is determined by such factors as demographic factors of households, current housing price level, rent levels and user cost of housing ownership, housing subsidy levels and tax treatment of owner-occupied housing. The supply of housing is influenced by such factors as the current stock of housing that is deteriorating at a given rate, the current price level, construction costs and availability of the construction elements. An important factor affecting the supply and the demand on the housing markets is both households' and the housing suppliers' expectations of the future market, especially price, development. Public policies can be divided into those that are oriented at the supply or demand or interfere with the housing market directly. Households' incomes, employment rates, inflation and the development of the financial system, especially interest rates, are the key factors of the economic development affecting the housing market. These forces jointly affect the price, rent and construction levels of housing that ultimately determine the housing market outcome.

The Method for the Housing Market Analysis

ManuBuild market analysis methodology presents a review of aggregate housing market models. In the aggregate models the analysis of the housing market focuses on the adjustment processes where housing is seen as part of the macroeconomy, and it excludes the aspects related to the qualitative nature and locational attributes of housing. The most commonly used approach to model the macroeconomic housing market development is the stock-flow approach. The stock-flow approach is usable in this case as it demonstrates the basic relationships of the fundamental factors of the housing market. The adjusted stock-flow model is selected as the model whose suitability to analyse the housing market is tested. Though having explanatory power, the dynamic housing market model forms only a part of the whole market analysis process. An important part of the market analysis is the market knowledge of the business entity that must be included in the analysis process. In the method for market analysis is illustrated as an integrated market modelling process.



Integrated Market Modelling Process

In this approach the two elements of analysis – the market data and market knowledge – are constantly interacting on every stage of the process. It is also important to notice that the process forms a cyclical system, so that it is possible to restart the analysis at any stage of the process in case new information presents itself or selected approach proves to be unsuitable.

Key Results

Method is applicable by companies in the markets of interest. It allows for specification of point of interest in accordance with the company's needs. The results of the market analysis have three main functions. They act as a supporting component of the operative decision making system as they offer a means for assessing the prevailing market situation and the changes in the operating environment. Another significant function of these results is their role in the strategic business forecasting. With the help of the developed analytical model the business entity is able to make a forecast of the future market state on the basis of presumed development in the model components. This information will help the entity to plan its future operations in the desired direction. The third function, complementary to the second function, is the validation of made presumptions in the development of the macroeconomic indicators. The forecasted development is compared dynamically with the realised development on a regular basis, and the needed adjustments to the forecast scenario are made.

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Key ManuBuild Contacts

YIT

Section IV

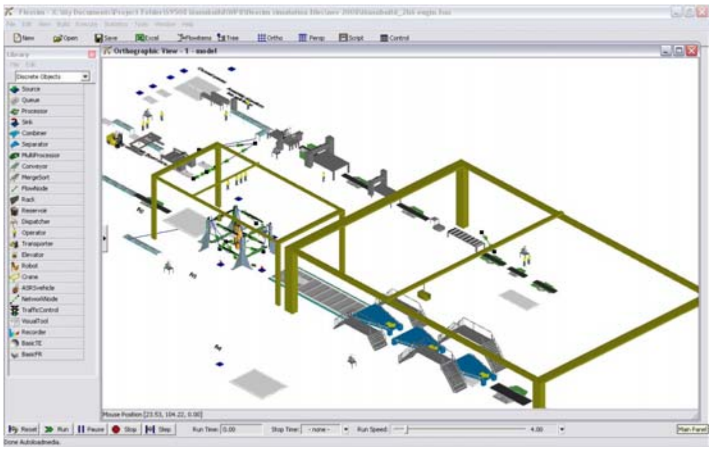
Manufacturing Methods and Techniques for Open Building Manufacturing

- Manufacturing Methodologies and Principles
- Process Technologies
- High Volume Fixed Factory Manufacturing
- Mobile Factory Concept
- Logistic Solutions
- Rapid Connection and Assembly Methods

Manufacturing Methodologies and Principles

Industrial Context

Off site Manufacturing (OSM) is related to the processing, manufacture and assembling of components and systems for installation on the construction site. Examples of offsite systems are essentially pre-engineered solutions which have high tolerance, high quality and has a high level of confidence that each product is made in the same repeatable manner. This is done in a controlled, efficient and safe environment, hence not driven by site conditions. Examples of OSM systems could be Modules, Roof systems, floor systems, wall systems, envelope systems. These could be used in many market sectors such as residential, health care, commercial and education.



Software Simulation of Fixed Factory

OSM can be undertaken in both a fixed factory and or mobile factory environments. These factories can be automated, semi automated or manually intensive, depending upon the product that is being manufactured and the volumes being produced.

Value Argument

In order to create an off site manufacturing environment (fixed or mobile factory) there are a number of drivers which are deemed important in order to deliver a product to site successfully and effectively. Large capital investment in the most sophisticated and latest technology available is not always necessary when considering the benefits of OSM. On the contrary there is a place for low tech, low budget solutions that will adequately meet the needs of the product that is to be manufactured. The driver is to create environments that are efficient, flexible to demand, improve time/costs and health and safety for construction workers.

Principles

In order to design and specify an OSM facility, key known principles can be used. Principles such as Lean manufacturing and Design for manufacture and assemble (DFMA) should be central to the decision making process. Only by integrating the design team at an early stage can the right level of automation, process technology, manning levels, logistics, product and process flexibility and assembly considerations be understood.

Methodologies

To define a single methodology for OSM is difficult, however, if the process of what needs to be considered and the steps that are required to be undertaken are known then the design and specification of the OSM facility would be more robust. The results of this project would suggest that the following points could be used to outline the requirements of an OSM facility:

- Understand the product to be manufactured
    - Understand holistic view of that product
    - Understand holistic view of that product in a subassembly and assembly
    - Understand holistic view of that product in a building

- Integrate design and production teams
  - Consider the impact of connection interface to the manufactured product
  - Tolerances required
- Consider process maps for manufacturing route
  - Define critical manufacturing processes
  - Consider right levels of automation and innovative processes
    - Assess against volumes and cost
- Consider process maps for logistic route
  - Define critical logistic issues
  - Multi tier supply chain
    - Appropriate ICT solutions
- Review process maps iteratively
- Introduce process simulation as a manufacturing aid
- Produce process simulation models of key process and assembly areas
- Understand bottle necks, machine utilisation, and comparison of one process technology with another.
- Consider how OSM facility would be sustainable
- Detail final process flow map for manufacturing and logistic solution

Key Results

Key results from this work include:

- Repository of innovative process technologies and manufacturing methods
- Understanding of offsite fixed factory environments
- Understanding of mobile factory concepts
- Guidelines and methods for logistics solutions
  - Identified requirements for identification and traceability of components for complete supply chain
- Shown benefits to rapid connection and assembly methods

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Key ManuBuild Contacts

COR, DRA, IVF, FCC, CA3, TWC, NCC, CON, MOW

Process Technologies

Industrial Context

In order to determine which methods and processes can be usefully employed to create a cost effective manufacturing environment using efficient technologies, it is important to collate new and available knowledge, methods and technologies to support the product creation process and the people involved. An Internet based Manufacturing Guide has been created which begins to do this.

The Manufacturing Guide

The Manufacturing Guide can be found at http://extra.ivf.se/manubuildpilot/template.asp
The contents of the Guide are:

- ManuBuild Goals
- Lean Production
- Benchmarking with Learning
- Product Development
- Production Processes
- Rightomation
- Logistics
- Work Environment, safety
- Transformation Roadmap
- Case Studies
- External Links

Lean Thinking

Lean Thinking is about the creation of value and elimination of waste. Using Lean Principles waste within a factory can be classified under a number of areas.

Over Production

Movement (of operator or machine)

Waiting (of operator or machine)

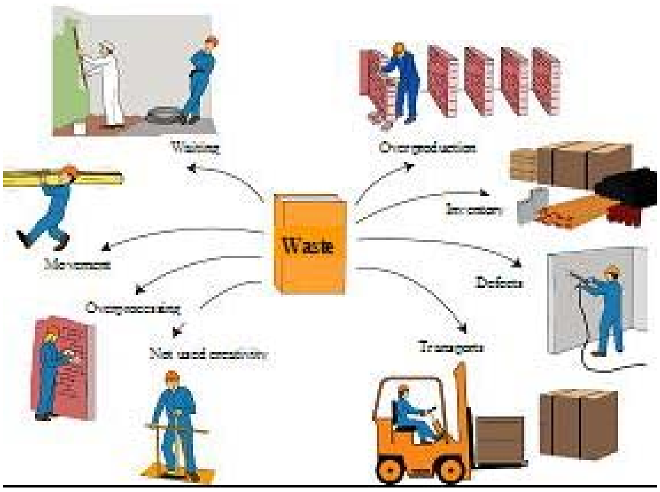
Over Processing

Not using creativity

Transports (movement of material)

Correction (rework and scrap)

Inventory (Raw material)



There are many learning resources relating to Lean Thinking principles which can be found on the website.

Links include:

- The Toyota 14 management principles
- A presentation on “The Lean Approach towards high performance and safe production”
- Lean web education "Lean across Europe"
- Lean Game demonstrator
- International Group for Lean Construction – which includes abstracts and white papers from conferences
- Lean Construction Institute
- Case studies applying Lean principles

Benchmarking with learning

Benchmarking is founded on the insight that there is always another one doing something better than us …and the ability to take advantage of that. Bengt Karlöf

Benchmarking is a tool to initiate improvements. Working with others, maybe even competitors helps to share learning, mistakes and improvement opportunities. By examining a partner that is considered to be excellent in some aspect, you may be inspired to set new level of performance of your own organization.
The stages of benchmarking of interest to ManuBuild are:

- **Benchmarking** - standardized KPI's accompanied by explanations about causality i.e. why and how
- **Benchmarking with learning** - adds significant understanding about the context in which the model has emerged

The Process of Benchmarking

- The BM process starts with the definition of the challenge and the team to carry out the benchmarking exercise. A subject is chosen, a problem identified and a tentative formulation of the problem is developed.
- The second phase is about mapping the flow in detail. Relevant tools are used to create an image of the improvement area in focus (the process, the structure etc.)
- The third phase is finding a partner, make a comparison and develop understanding.
- The last phase is the improving activity that makes progress of the business as a result of the partner analysis.

The Manufacturing Guide website gives links to reports which have resulted from numerous factory visits. An example is Acrivia/Volvo in Sweden who builds and manufactures bus frames in a radically different way than previously. This specific visit can be seen as inspiration to part of the ManuBuild case studies and innovations.

Automation and Rightomation

One of the biggest challenges faced in implementing lean production will involve determining how much automation to use. The key is to use the right level of automation which is describes as the level of automation, where "machine loading" is made manually, the "machine cycle" is automated, "unloading" is automated and "transfer part" is made manually.

Key Results

The Manufacturing Guide identifies the importance of understanding efficient production processes and the use of them in a factory environment which has been evaluated using Lean Principles to ensure that waste is eliminated from the process. The Manufacturing Guide contains the results from Lean exercises and case studies, where new products and/or new manufacturing steps are made. Both ManuBuild partners and other relevant industries are represented. There are many links to Manufacturing Solutions provided by companies exploiting the latest technologies with reference to construction methods and processes which can be found on the website.

References

The Manufacturing Guide can be found at http://extra.ivf.se/manubuildpilot/template.asp

Key ManuBuild Contacts

IVF, Corus, DRA, FCC, CA3, TWC, NCC, TNO, YIT, CON, MOW

High Volume Fixed Factory Manufacturing

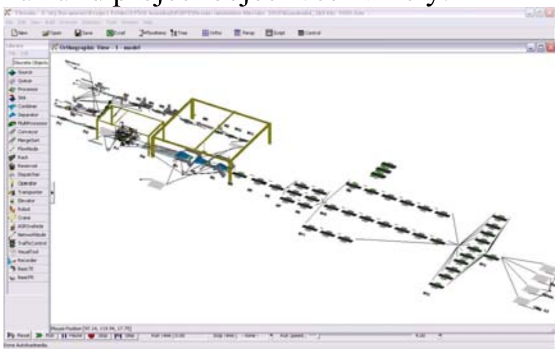
Industrial Context

The use of and creation of a fixed factory for off-site Manufacturing (OSM) has a dependency on many things. Complexity of components to be manufactured, volumes of production required, levels of automation envisaged, market drivers and levels of investment available amongst others. Factory design should be integrated with product design to enable an efficient process and to deal with factory conditions for handling, moving and lifting of components.

Challenges for Manufacturing

The size of the challenge for manufacturing is set by the ManuBuild project objectives namely:

- A 50% reduction in construction costs
- A 70% reduction in construction time
- A 90% reduction in work related accidents
- Improved quality
- Product design flexibility
- Assembly methods



For the system to be successful manufacturing efficiency must play a key role. The fixed factory concepts that are developed must be manufactured quickly, efficiently, sustainably and safely. It is not acceptable to simply move the current site practices into a factory environment. The manufacturing system developed must employ relevant advanced manufacturing systems and methods currently commonplace in long established manufacturing industries such as automotive and aerospace. It is also important that the technology and methods used in the proposed factory are appropriate to the products produced.

The factors that will determine what methods are appropriate include:

- The production volume of the proposed factory.
- The batch size of the productions runs
- The level of customisation required
- The cost of labour
- The materials used

The advantages of a high volume fixed factory

- It can take advantages of advance manufacturing techniques such as automation that would not be viable on site
- It can take advantage of the economies of scale that are not practicable in a mobile factory
- Significantly improved tolerances – CNC controlled cutting etc.
- Improved quality
- Reduces the requirement for skilled on site labour (short supply)
- Provides more stable employment in a factory environment
- Better, safer, more controlled working conditions. The average accident rate in a factory environment is only 20% of the rate on the average construction site.
- Reduced waste - Waste materials can be recycled in a controlled manner with separation of different materials. On many construction sites in Europe site materials are disposed of unsorted in a single skip. Furthermore in a mass production environment material can be order sized, further reducing waste.
- Factory based installation of services. Use of plug and play electrical systems that can use unskilled labour with skilled inspection. Access holes for services and fittings and fixtures cut by machine in the up stream processing rather than by a craftsmen when the fittings are installed

Disadvantages to the high volume factory concept

- High transport costs are often quoted as a disadvantage of modular production. These costs are more significant for low value added modules such as bedrooms but less so on high value more heavily serviced modules such as kitchens, bathrooms and plant rooms in apartments. However transport costs have been estimated to be of the order of 4% for this kind of production. Significant but not prohibitive.
- Transport costs can be reduced by manufacturing serviced panels as several 'rooms' of panels can be transported on a single track.
- In order to gain a return on the substantial investment required to create a manufacturing line, the line must operated at a high level of utilisation. This means large volume markets are required or the factory must be flexible enough to satisfy a number of markets.
- The size of modules is limited by logistic considerations, the maximum size being determined by the maximum length and width permitted on the roads. This size limitation can be overcome by the use of serviced panels as the size is only limited by the length restriction, which is generally greater than the width limitation.

Supporting Functions to the fixed factory

- To optimise the production of elements, components and systems, close cooperation with the product design function will be a requirement. This is to ensure that the concepts and designs developed consider the manufacturing and assembly implications when optimising the final design.
- Simulation Modelling can support the design and layout of the fixed factory by running various production scenarios identifying areas of process bottlenecks and where equipment is left idle.
- Information Communication Technology (ICT) is also crucial to the efficiency of a manufacturing facility. It is essential that the design intent is captured and this geometric data is available in a useable form in the manufacturing methods and processes. This information can be used to control the production machines, provide data for purchasing, stock control and costings.

Key Results

A key result is a high volume factory design for the manufacture of Corus ManuBuild Modules using Simulation modelling to develop manufacturing scenarios for the production of 3000+ modules per year.

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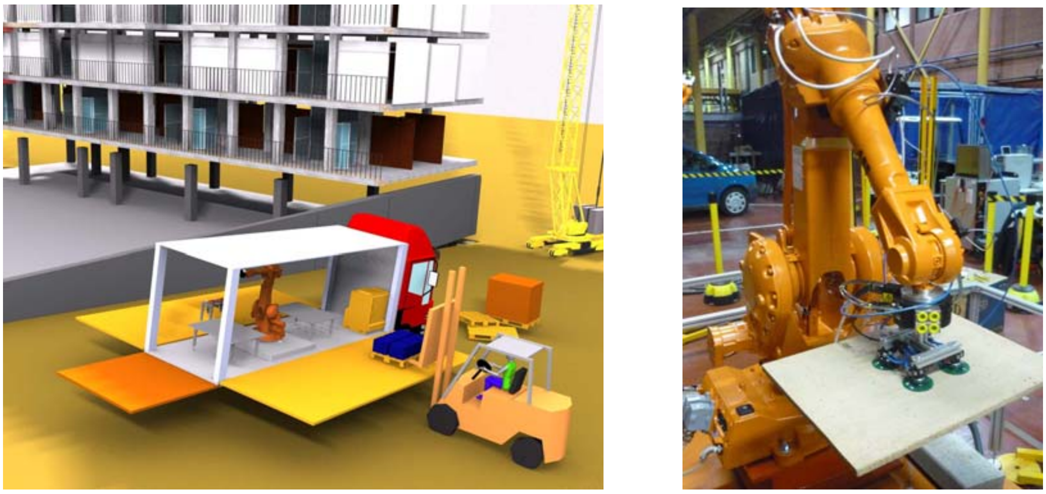
Key ManuBuild Contacts

COR, DRA, IVF, FCC, CA3, TWC, NCC, CON, MOW

Mobile Factory Concept

Industrial Context

In the past 50 years, construction has experienced an important industrial advance in two directions. On one part, numerous materials and systems have appeared as a result of general industrial advances in other sectors of industry. On the other hand, work at the construction site has experienced a process of accelerated mechanisation, which in developed countries, has greatly diminished labour at the site, and furthermore improved the work conditions for remaining labour force.



The visualisation of the Mobile Factory Concept and The Robot Prototype Tests

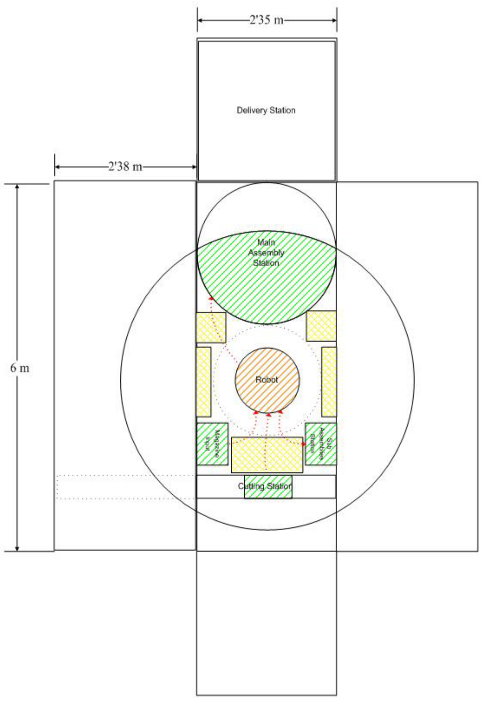
The Concept of the Mobile Factory

The concept of the mobile factory comprises three aspects:

1) The creation of an adequate environment for manufacturing at the construction site.
2) The mechanisation and rationalisation of production work
3) The mobility of the factory itself.

ManuBuild has developed and tested the flexible, mobile and autonomous factory for on-site automatic (robotized) manufacturing and assembly of pre-fabricated parts and systems. The optimisation of transportation, installation and dismantling costs, the JIT concept and flexible adaptation for changes in the process are the main innovative aspects of the mobile factory.

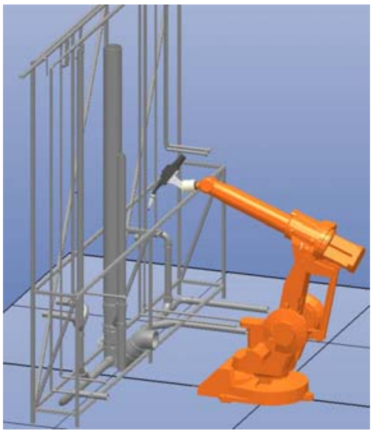
The mobile factory concept is container based with the ability to "link" containers together on-site to produce a variable and extendable factory. The container-based factory can be moved by lorry from one site to another whenever and wherever it is needed. The factory has autonomy in energy, management and operational senses. The factory is flexible, provides safe working environments and is reconfigurable for multipurpose on-site activities and materials.



Relationship between the mobile factory and the fixed factory

The cost of component transport and the costs of implantation and disassembly at the construction site play a relevant role in the construction of buildings. This is due to the fact that the transport of prefabricated components involves three phases, loading, transport itself, and unloading, of which the transport component is the variable, depending on mileage (when done by land) and of even more conditioning factors if carried out by sea. Therefore, depending on distance from the factory to the construction site, the construction of prefabricated components outside of the construction site may be profitable or not, when compared to a more traditional construction method. Based on the importance and volume of the construction work, it is sometimes preferable to install a prefabrication factory at the construction site, in spite of the costs of transportation, implantation, and later disassembly of the factory.

Simulation and Demonstration



A series of computer simulations and laboratory trials were carried out using a Service Core to demonstrate of an assembled component. The Field Factory and the Service Core were modeled in 2D and 3D for different for process flow simulation, layout optimization, spatial distribution into the container, etc. With these simulations the physical design of the Field Factory and the product fabrication were tested. The demonstrator used a robot arm to carry out the automated assembly process. Within the laboratory environment a full-scale prototype of the systems included in the Field Factory was developed in order to validate the computer design of the Field Factory made in the previous stage.

Key Results

The mobile factory concept has been simulated and physically demonstrated within ManuBuild. The Service Core was the initial demonstrator with the CNC cutting of complex shapes for paving slabs being demonstrated within the final demonstration tasks of the project.

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Key ManuBuild Contacts

CA3, DRA, COR, FHG

Logistic Solutions

Industrial Context

The need to control and identify movement of components is central to the needs of a Logistics Guide. The elimination of lost time on site waiting for deliveries, or the identification of movement and handling of components is paramount to create an efficient Construction Process. ManuBuild has studied the issues relating to these themes and A Logistics Guide has been produced. The scope of the logistic guide covers: Fabrication (manufacturing and assembly), Warehousing and Despatch areas of a fixed factory, Transport from factory to site, (via intermediate holding area if required), and On-site reception and Handling. The use of component tagging systems has been seen to be a supporting technology that should be considered.

The Need for a Logistic Solution

Visits and reflections on current Construction Industry Practice has identified:

- Cranes are in repeatedly waiting mode - can the delivery of materials/supplies be more precise?
- Why isn't there anybody on site that unwraps and prepares delivered goods as to facilitate for the workmen to start working directly?
- The sites have lots of waste material
- The sites have lots of wrapping material
- Many trucks arrive to the site half empty.
- Many complain that there is a lack of space on the construction site.
- Supplies are left unprotected to weather and machines.

Other industry sectors, especially manufacturing and retail, have made huge advances in improving logistics, whereas the construction industry does not seem to be taking advantage of these opportunities.

Logistics Management

"Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements."

The management of information needs to move from that shown in Figure 1 to one where information is controlled and shared as shown in Figure 2.

Figure 1 Disjointed Information Flow

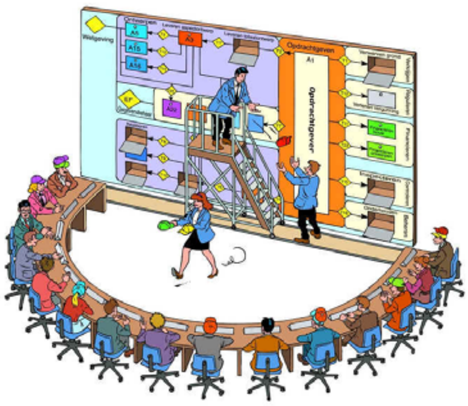
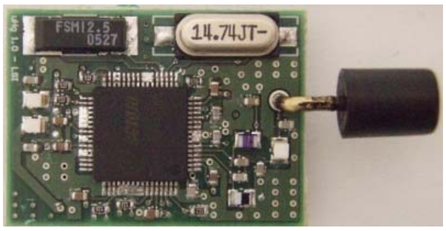


Figure 2 Organised sharing of information

Tagging Technologies

There are a number of solutions for "tagging" whether it is a simple numbering system, bar codes or electronic tagging devices. Smart cards using RFID technology is an important automatic identification technique which can give accurate data. They differ from barcodes in performance and have the possibility of containing more data. Essentially it is a technology that connects components to the Internet or to system databases. This allows the components to be tracked and also allows companies to share data about their components.



Case Studies

Two case studies have been carried out and reported to test the validity of the Logistics solutions being described.

Luxcool Heating Element

A case study investigating the data requirements and initial ICT solution for the manufacture of a LuxCool heating element was carried out. Here considerations for the supply chain, component availability and construction sequencing, (product tracking) were the main areas for consideration.

Corus ManuBuild Module

A second case study involving the handling requirements of the Corus 3D module and its comparison with a traditional construction solution was carried out. Here the benefits of an industrialised construction method were identified through the different activities and scheduling of the module on site. An in-depth construction schedule was analysed looking at handling (crane) and manpower requirements for the construction phase.

Key Results

An assessment of a complete solution for all the relevant parts of the whole manufacturing process was undertaken. Data requirements at various stages of the process were identified and discussed which were then used as part of the two case studies to test the content and functionality of the Guide's information.

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Key ManuBuild Contacts

FCC, COR, DRA, TWC, NCC, YIT

Rapid Connection and Assembly Methods

Industrial Context

Component construction process can be simplified by good design practice. Easier assembly translates to faster processing time either on-site or in the factory. Rapid connection and assembly methods could reduce overall component costs when compared with traditional methods of joining and assembling components. ManuBuild has investigated the methodologies required to address and support rapid connections and assembly with a view to proposing process changes, adding value to the component construction process and identifying health and safety improvement opportunities.

The concept of DFMA in Connection Design

The need to design connections which most likely will be produced in relatively small quantities, and the need to be flexible, requires a methodology which assists the designer to achieve certain design criteria such as design for assembly and manufacturing (DFMA). DFA (Design for Assembly) determines how a product is designed for effective assembly while DFM (Design for Manufacture) enables the manufacturing of the different parts. DFMA analysis helps to evaluate different designs with regard to their functionality and manufacturability.

Connection Requirements

When considering connection and assembly criteria, connections should have:

- Fast and Flexible operations
- Lower Part Count
- High Reliability
- Repeatability
- High Quality

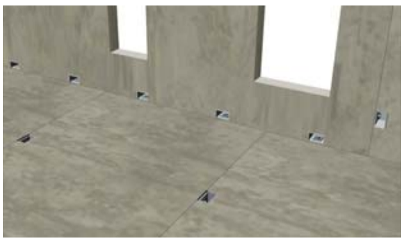
Case Studies

Within ManuBuild there have been a number of connections developed and analysed using DFMA principles including:

- For Concrete – The Consolis connection and
- For Steel – The Corus Cold formed steel connection (Dipple Klick).

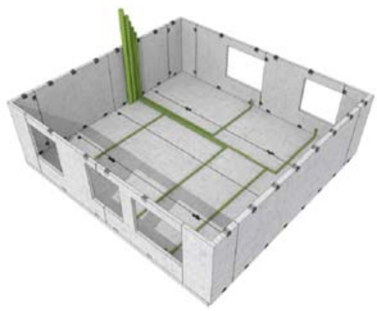
Consolis Connection

The function of the connection is to connect pre-cast concrete elements together. This is done by using a bolted arrangement thus making possible dry and quick installation without special supports during the erection.



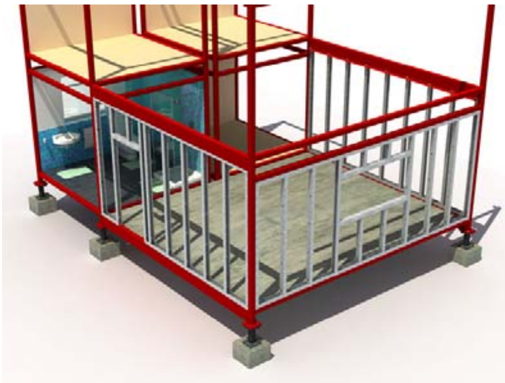
The idea of ConBolt is to erect a house:

- very fast,
- with minimum labour and minimum installation cost,
- with prefabricated concrete elements and
- To create a very flexible solution for the architects
- To design the basic appearance of the house and
- To plan a proper lay out for the needs and tastes of future users of the apartments.



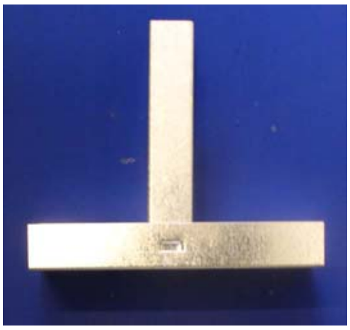
Corus Connection (Dipple Klick)

The function of the Dipple Klick connection is to connect cold formed light gauge steel components together. The connection can be used in infill panels such as floors, walls and ceilings using cold formed sections. Traditionally mechanical fastenings are used, i.e. rivets, screws, welds etc. The Corus connection uses pre-formed pressings and slots to create a rapid connection method. Assembly time is reduced; part count (fasteners) is reduced from traditional methods and by removing the need to drill or rivet on site. Health and safety improvements were derived as a result.



ManuBuild and DFMA connection criteria met were:

- Self locating and positive connection
- Reduced Part Count
- Manufacturability – the connection could be manufactured at low, medium and high volume requirements
- Easy Assemblability – by either machine or manual operation over given section sizes
- Comparable structural performance with mechanical fixing methods
- Ability to disassemble without the need for complex tools or machinery



Key Results

ManuBuild has shown new and innovative connections and assembly methods for building components. Multi-material connections were identified to simplify assembly methods, improve building assembly times and health and safety while reducing overall construction costs.

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Key ManuBuild Contacts

COR, DRA, IVF, FCC, CA3, TWC, NCC, CON, MOW

Section V

IT System Architecture and Tools for Open Building Manufacturing

- ManuBuild System Architecture
- Open ManuBuild System Platform
- Tool: Product Modelling Ontology
- Tool: Intelligent Catalogues & Building Templates
- Tool: Catalogue Server
- Tool: Design Configurator
- Tool: Sales Configurator
- Tool: Manufacturing Configurator
- Tool: Logistics and Assembly Planning

ManuBuild System Architecture

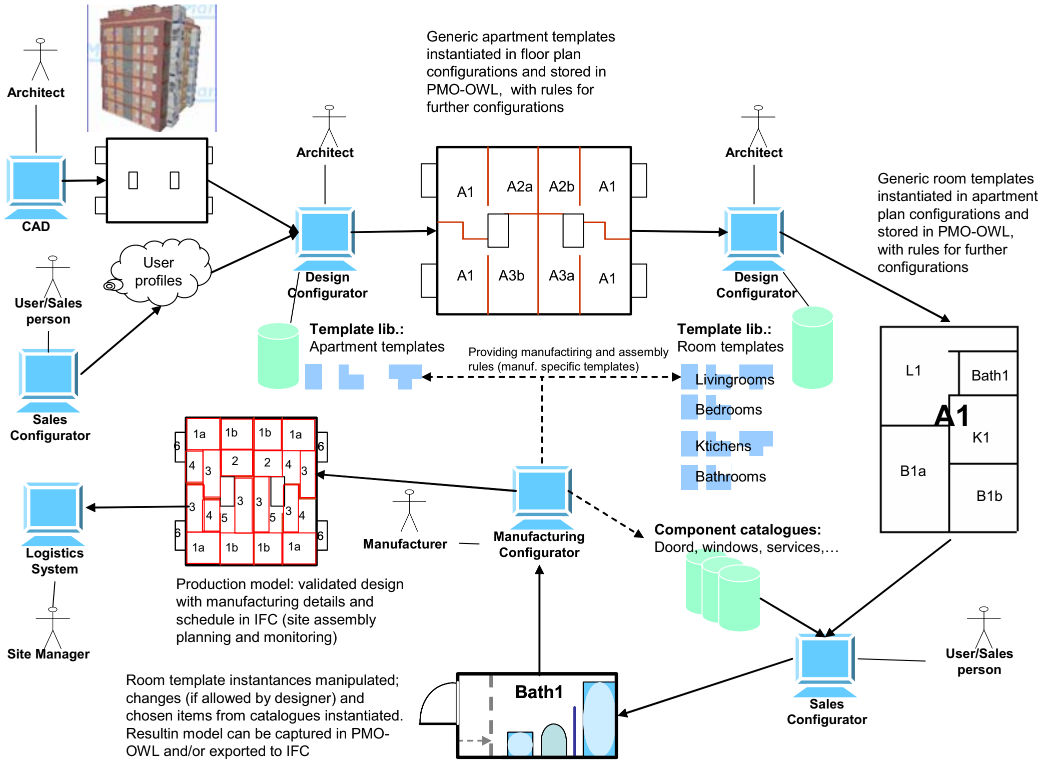
Industrial Context

The system architecture is a high level view of the Information Communications Technologies (ICT) system and its parts, representing the components of the system and their relationships. The ManuBuild target ICT system architecture supports distributed building manufacturing, the ManuBuild System and identifies the necessary ICT components and interfaces, as well as the standards, for example:

- Product Modelling Ontology (PMO) based upon the Web Ontology Language (OWL),
- BuildingSMART's Industry Foundation Classes (IFC) and
- XML, to be supported in order to achieve the desired level of openness.

Business Process Scenario

The system architecture has two different target audiences: end users and software developers.



Business process scenario supported by ManuBuild ICT tools

Essential Components

The ICT target system identifies the essential components which are needed to support the ManuBuild System and are listed as follows:

- The Intelligent Component Catalogues provide open access for component catalogue items to all participants in the building process. Manufacturers and catalogue information providers will create, maintain and deliver catalogue items for parametric building products.
- Building templates created based on existing CAD model layouts for a dwelling. Each building object in a template can contain a list of parameters and their associated constraints and rules. The Design Configurator tool will be used to add the appropriate constraints and rules to a building template. The outcome will be a building template which is capable of representing parametrically defined models.
- Different variants for that layout of a dwelling can then be configured, based upon a generic building type.

- Potential purchasers can use the Sales Configurator to customise the design of a dwelling, according to the rules embedded in the building template. Catalogue items can be added or modified in the dwelling design.
- A configured dwelling (an instance of a building template) is passed to the manufacturer for detailing. The Manufacturing Configurator details the dwelling as a series of modules and creates a schedule of the appropriate information needed for their manufacture and assembly.
- Manage the supply and assembly of the modules. The appropriate building information model is created together with both construction and manufactures schedules. Based on this information a detailed assembly and delivery plan is created and maintained.

Exchange Requirements

The ICT system architecture provides a development roadmap which suggests possible ways to move from current industry practices towards improved and innovative manufactured building business by uptake of ManuBuild ICT.

The information that is required to be exchanged and/or shared by the various ICT components within the ICT System Architecture are defined using the Information Delivery Manual (IDM), which has been developed by BuildingSMART and will be published as an ISO international standard. The IDM specifies:

- A methodology that unites the flow of construction processes with the specification of information that is required by this flow,
- A form in which the information should be specified,
- An appropriate way to map and describe the information processes within a construction lifecycle

Interoperability Standards

The standard will facilitate interoperability between software applications used in the construction process, promote digital collaboration between actors in the construction process and provide accurate, reliable, repeatable and high quality information exchange.

Contributions towards future standardisation work activities resulting from the ManuBuild ICT developments have been outlined to ensure compatibility with mainstream industry solutions in the future.

Key Results

The ICT system architecture provides a specification for how ICT tools can communicate with each other. The following ICT tools and services have been implemented using the ICT System Architecture as the specification to enable their tools to communicate using PMO, IFC and XML:

- Catalogue Server and related tools for hosting catalogue items, building templates and building models.
- Design, Sales and Manufacturing configurators, respectively.
- Enterprixe Supply Chain Management system.

References

Hyvärinen, J., Stephens, J., Nummelin, O., Ristimäki, T., Maseda. JM., Owolabi, A., Bonsma, P., Kopyto, M. (2006) ManuBuild WP5 deliverable D5.1-1, Target ICT system architecture.

Hyvärinen, J., Stephens, J., Ristimäki, T., Maseda. JM., Owolabi, A., Bonsma, P., Hajas, T. (2007) ManuBuild WP5 deliverable D5.1-2, Target ICT system architecture.

Hyvärinen, J., Stephens, J., Ristimäki, T., Maseda. JM., Owolabi, A., Bonsma, P., Hajas, T. (2009) ManuBuild WP5 deliverable D5.1-3, Target ICT system architecture.

Key ManuBuild Contacts

VTT, TWC, LAB, YIT, ESL, TNO

Open ManuBuild System Platform

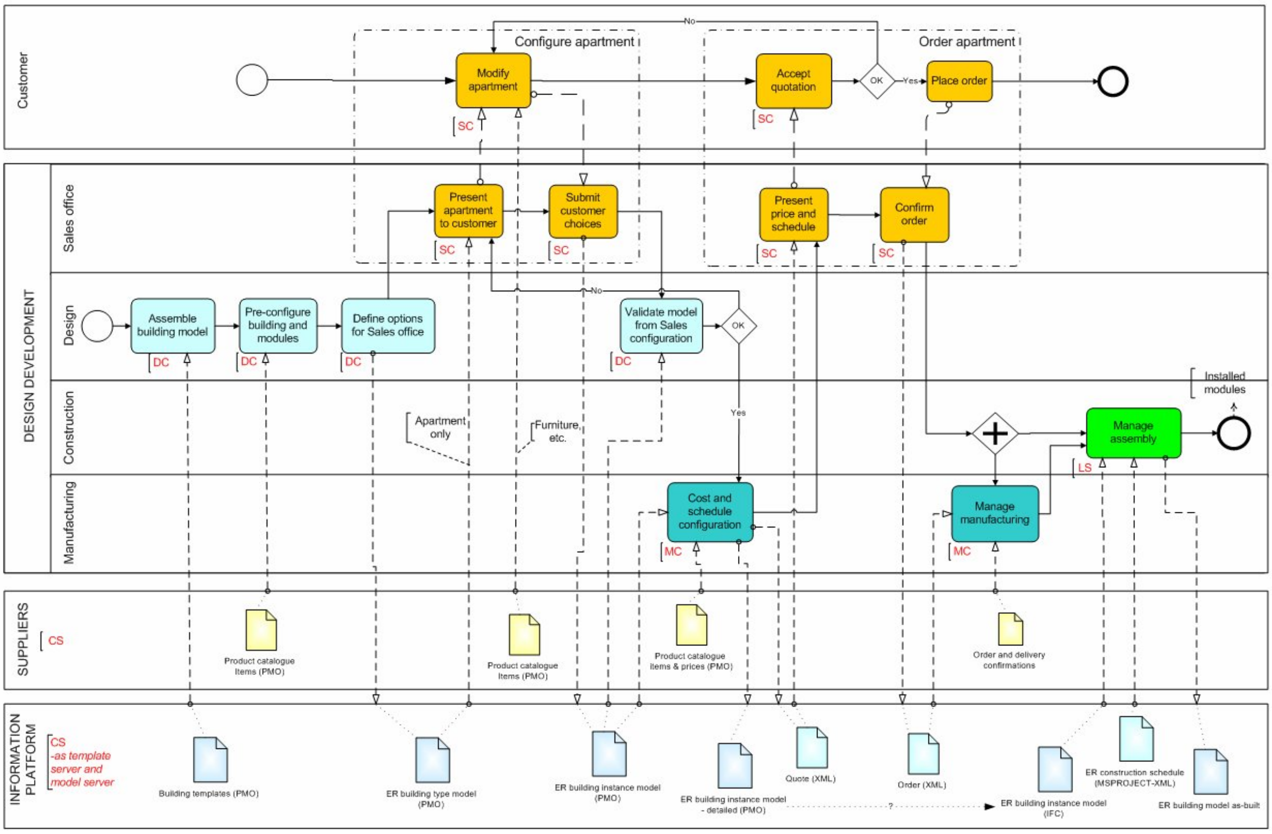
Industrial Context

The Open ManuBuild System Platform supports the Information Communications Technologies (ICT) tools and services that are required to support the following activities:

- Design for manufacture,
- Offsite manufacturing, and
- Logistics and assembly planning.

Common Understanding of Information

For the Open ManuBuild System Platform (OMSP) to be successfully implemented it is required to support more than a number of tools interacting at the level of sharing individual files. To be successful a common understanding of the meaning of the information in a file must be agreed and documented to capture the Exchange Requirements between that various processes, as shown in the figure below.



ManuBuild design for manufacture process diagram

By having a common understanding of the information it enables the various ICT tools and BIM applications to effectively share information and more importantly enable other new applications to successfully share and use the Product Modelling Ontology (PMO) information that the OMSP is built upon. Therefore, it is a specification that will enable ICT tools to communicate to enable the so called ManuBuild System to be supported.

Information Delivery Manual

The information that is required to be exchanged and/or shared by the various ICT components within the OMSP are defined using the Information Delivery Manual (IDM), which has been developed by BuildingSMART and will be published as an ISO international standard. The IDM specifies:

- A methodology that unites the flow of construction processes with the specification of information that is required by this flow,

- A form in which the information should be specified,
- An appropriate way to map and describe the information processes within a construction lifecycle

From an IDM point of view the following must be considered:

- How will it be defined? (for example, using BuildingSMART Industry Foundation Classed (IFC) or PMO schemas)
- What is it? (using Infrastructure for Dictionaries (IFD), property definitions)
- Which information? (using the exchange requirements)
- Whom does it belong? and
- When is it exchanged?

ICT tools and Services

The OMSP is conceived as the sum of these ICT tools and services that share information and provide services that make feasible to perform the demonstration scenarios identified in Manubuild.
Therefore, the OMSP will support and facilitate an integrated, streamlined construction process and collaborative business models. The ideal is a construction process that is receptive to innovation with:

- All the various phases thoroughly integrated;
- consistent and timely information to the construction site;
- Non-adversarial, partnering agreement among all stakeholders in the construction process; and
- Integrated ICT tools that link all capabilities across all phases of the process from conception to operation.

The OMSP identifies the required exchange requirements by tools, based on the analysis of the different data models of the tools developed in order to facilitate sharing and reuse of information.

Key Results

Open Manubuild System Platform (OMSP) involves by definition the use of open methods and tools to design and implement an ICT System Architectures that is expandable in both capacity and features. Such a platform would support flexibility in the use of hardware and software eliminating fears of lock-in, high costs, and technological obsolescence. Future feature expansion would be easier as the industry steps towards open systems and the nature of competition and distinction between industry tools would be changed.
The OMSP documents the exchange requirements that will support the seamless access to all the ICT tools and services that have been developed:

- Intelligent Catalogues;
- Design, Sales and Manufacturing configurators,
- Logistics Management and Assembly Planning,
- Sales Office demonstrator,
- ICT aspects related to various ManuBuild building demonstrators: Swedish, Spanish and UK Mixed Use.

References

The following ManuBuild reports are available on the ManuBuild Community of Interest website at http://www.manubuild.net.

Alberto Bonilla, A., Maseda, JM., Mediavilla, A., Perez, J., Juha Hyvarinen, J. (2008) ManuBuild WP5 deliverable D5.6-1, Open ManuBuild System Platform Concept.

Alberto Bonilla, A., Maseda, JM., Mediavilla, A., Perez, J., Juha Hyvarinen, J. (2009) ManuBuild WP5 deliverable D5.6-2, Open ManuBuild System Platform Prototype.

Key ManuBuild Contacts

LAB, VTT

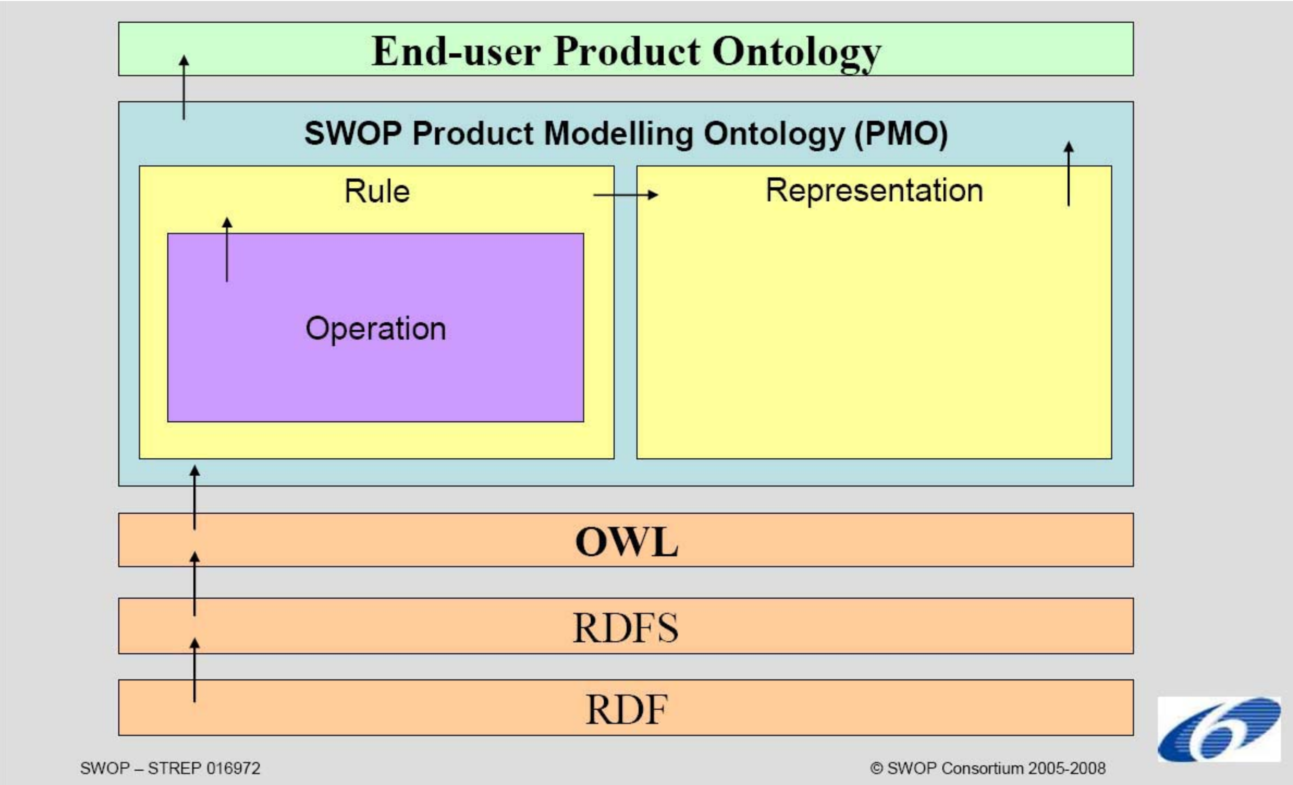
Tool: Product Modelling Ontology

Industrial Context

It is common for catalogue information to only be available in a form that can be viewed by a customer. However, ManuBuild user requirements require additional functionality in the form of rules being applied to catalogue items that will enable product options, variations and the interaction of items with other components to be defined. Such intelligent catalogue information can then be reused by other systems, for example by the design, sales office and manufacturing configurators.

In order to support this, product descriptions based upon the Web Ontology Language (OWL) schema called Product Modelling Ontology (PMO) have been developed. The resulting product descriptions will enable software applications to perform assembly configurations, design for manufacturing and value engineering functions on the data provided by the catalogues and naturally by utilizing addition external data such as building design information, legal and building code requirements.

PMO and the Web Ontology Language



PMO sits on top of OWL

The approach is based on existing software tools for catalogue management and enhanced by building on the results of the SWOP project (http://www.swop-project.eu). SWOP offered an open and extensible approach for ICT support in fast and flexible production of customised but industrialised complex products and services.

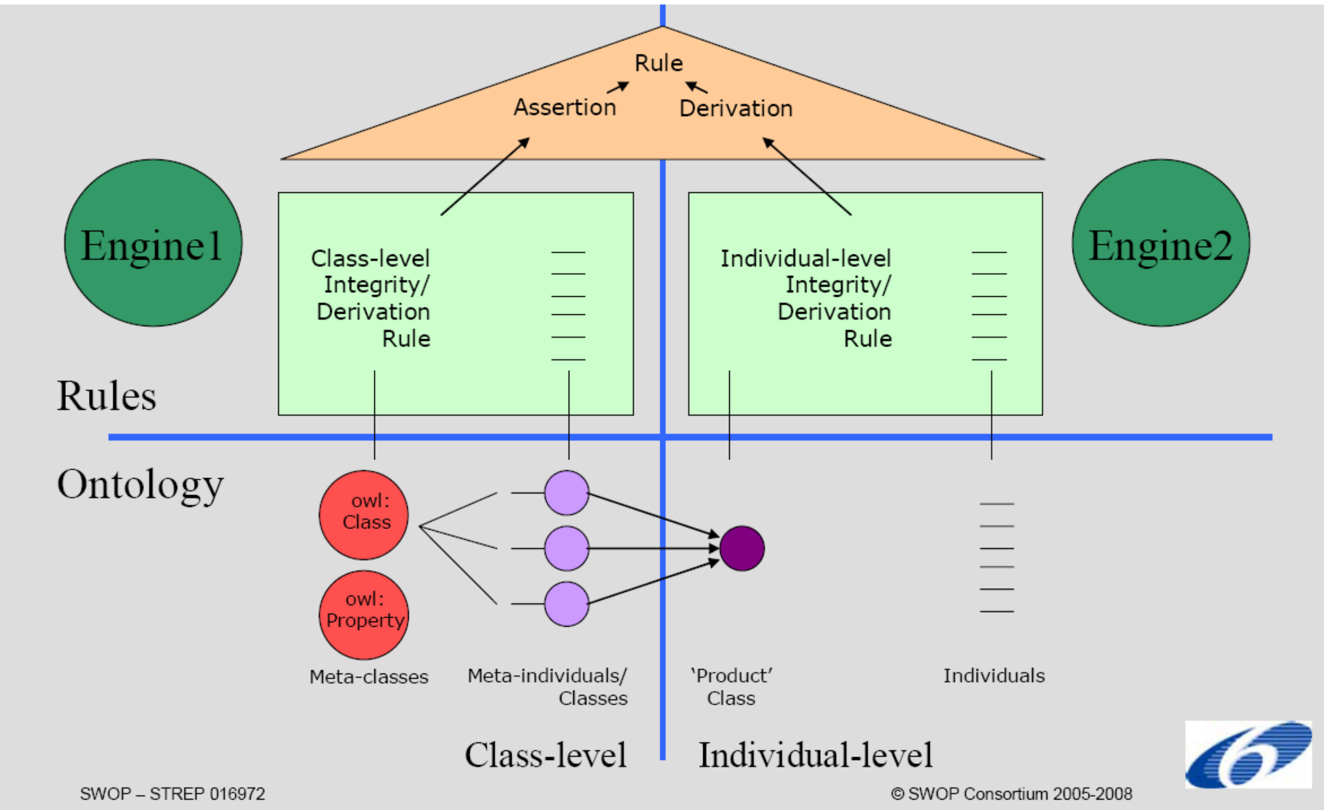
The PMO language extends the XML based OWL language for product modelling, so it is compatible with recent semantic web developments and will support the needed universal access to distributed information sources. The resulting PMO product catalogues will not replace existing component catalogues, for example the Geometric Description Language (GDL) for part descriptions, which Graphisoft have developed in the past. While GDL is primarily preoccupied to describe the behaviour and appearance of a product family benefiting mostly the designer, the PMO catalogue can be utilised to describe in an explicit way the population, structure, options and variations of product lines benefiting the later phases of the construction process by providing a platform for the specification, selection and procurement of building parts.

PMO based product catalogues can be created directly using commercial off-the shelf applications and tools and then converted for example from GDL to PMO using a GDL to PMO export tool. The PMO catalogue descriptions in themselves are sufficient to allow part selection and may refer to more involved part description, potentially in multiple formats and other parts descript formats used by CAD and design applications.

Tools to visualize and interact with the PMO catalogue objects, for example the PMO Viewer, have been developed and are freely available for use.

PMO Rules

In PMO, rules can also be defined as a meta-ontology. This implies that PMO must define and implement its own rule engine aside from OWL. This approach was necessary for the flexibility to define domain specific rules not supported by generic 'engines'.



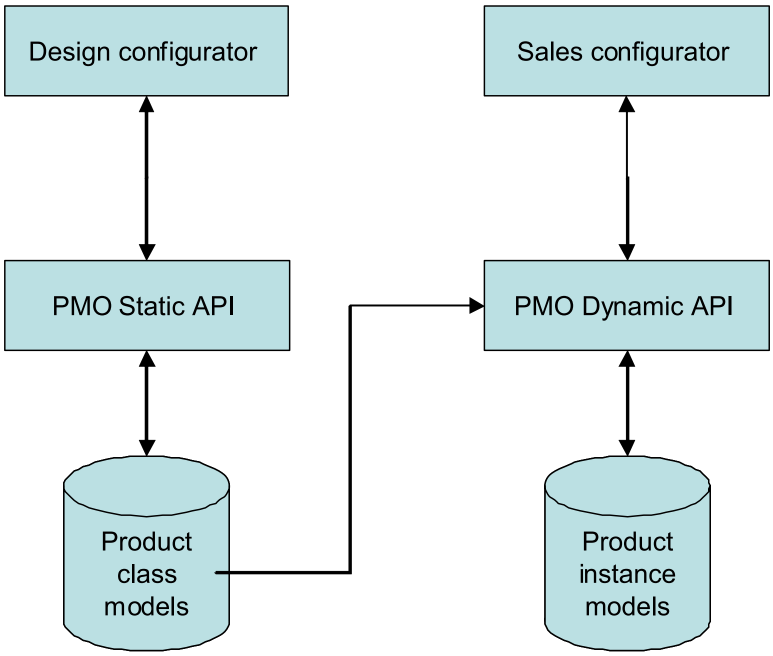
Rule types in PMO

Engines are needed as modules to check/validate and/or do/execute with respect to the underlying ontology. Engine1 is dealing with the class level rules, while Engine2 with the individual-level rules. The latter rules are all instances of a rule structure that only 'knows' PMO's generic 'Product' class. It cannot be dependent on end-user product ontology classes, since the structure of these rules is to be processed by a generic Engine2 module.

The PMO rules can be applied to catalogue items but also to PMO based building templates, which are more complex PMO models that could represent for example the layout of a dwelling and contain the rules and options on how a potential purchaser could customise the dwelling.

Interfaces and Tools to support PMO

To enable PMO data to be visualised and manipulated TNO have developed a number of PMO interfaces and tools. Two sets of functions have been developed to either operate on PMO data at a product class level (using a static PMO API) or at a product instance level (using a dynamic PMO API). The static API can be viewed as supporting compile time activities as creating of changing product class models, while the dynamic interface can be viewed as supporting run time activities as instantiating product classes into product instances, evaluated rules and generating 3D shape structures. Therefore the static interface is by nature primarily supporting the facilities of the design configurator, while the dynamic interface is primary meant to support the sales configurator sessions.



Two different API's give access to either PMO product class models or PMO product instance models.

Key Results

A Product Modelling Ontology enables the creation and distribution of intelligent catalogue and building template information. For example, an end-user customising a dwelling to suit their requirements and then the detailing of the modules needed to manufacture the dwelling.

TNO have developed as suite of tools to support PMO:

- Viewing PMO models: PMO Viewer,
- Configuring PMO models and adding rules: Design Configurator,
- Merging PMO models,
- PMO to IFC export tool, to enable any PMO catalogue items or configured building templates to be utilised by the current state-of-the-art CAD applications or BIM server systems.

References

Hajas, T., Reinecke, W., Nummelin, O., Bonsma, P., Kopyto, M. (2006)
ManuBuild WP5 deliverable D5.3-1, Intelligent Component Catalogues.

Hajas, T., Orosz, T., Florian, A., Bonsma, P., Williams, P. (2007)
ManuBuild WP5 deliverable D5.3-2, Intelligent Component Catalogues.

Hajas, T., Orosz, T., Florian, A., Bonsma, P., Williams, P., Stephens, J., (2008)
ManuBuild WP5 deliverable D5.3-3, Intelligent Component Catalogues.

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2007)
ManuBuild WP5 deliverable D5.4-1, Concept for Design Configuration and Decision Support Tool.

Owolabi, A., Willems, P., Montoiro, S., Hajas, T., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-2, Implementation of ManuBuild Configurator.

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-3, ManuBuild Configurator.

Key ManuBuild Contacts

TNO

Tool: Intelligent Catalogues and Building Templates

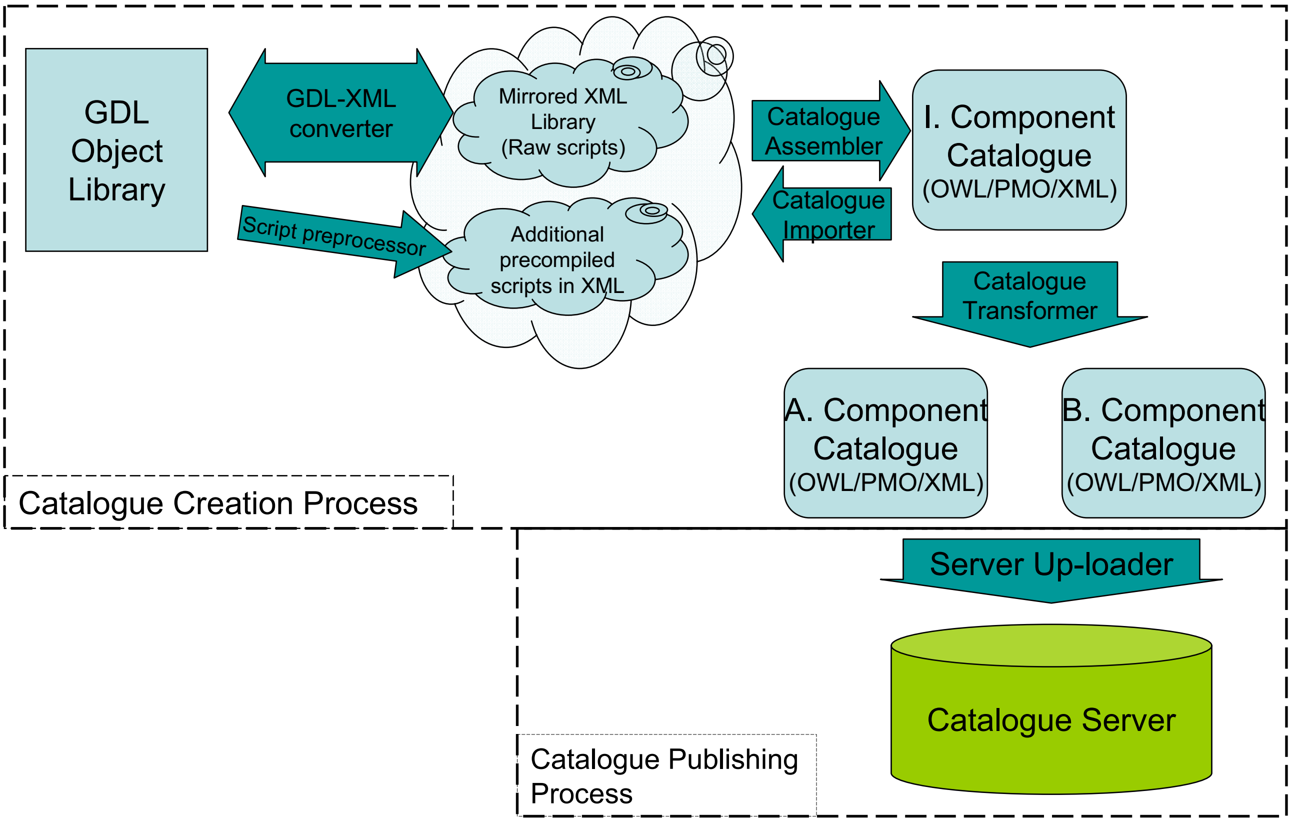
Industrial Context

Intelligent building catalogues are provided by CAD vendors to represent generic building parts for the purpose of exploring design alternatives. Sometimes, they are even created by the designers or by third parties specialised to assist designers in their design work.
Manufacturer specific building parts are created and published by the manufacturers as part of their general marketing activity to inform designers and particularly construction contractors and subcontractors about the actual properties, design variations and constraints of their products.

Product Modelling Ontology based Catalogue Items

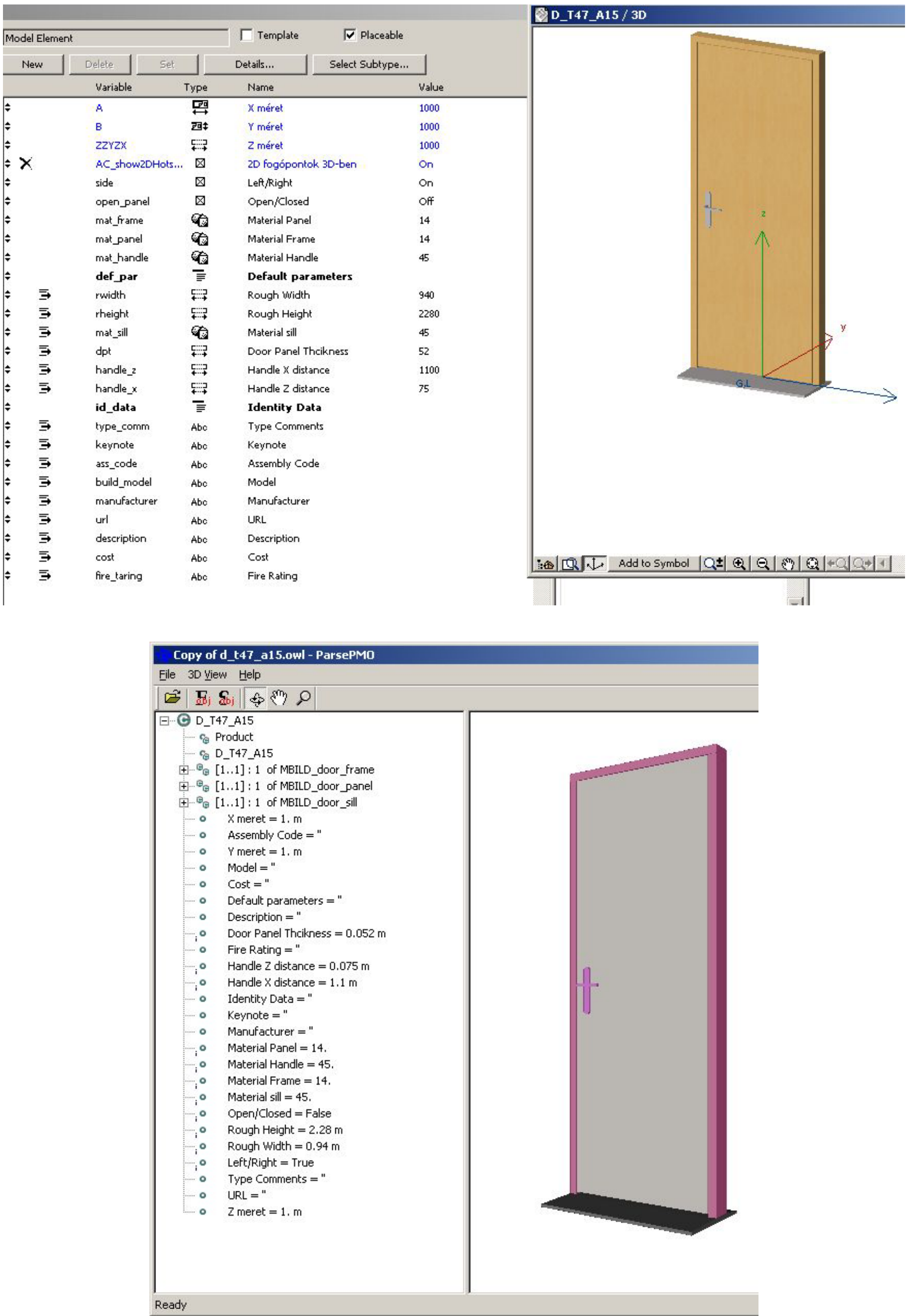
The complexity building components of these parts can vary from a simple plumbing fixture to the most complex assemblies like a fully configurable pre-manufactured bathroom module or the layout for an apartment. The primary requirements for building components in a catalogue include:

1. Easy data creation to define: behaviour, rules, constraints and representation;
2. Low cost of maintenance (Generic parts must reflect changes on the market and follow the overall product development of the offering of the construction industry, Specific, branded parts must closely follow the product development cycle at the brand owner firm);
3. Follow and fit into the process of catalogue creation of the product manufacturer;
4. Parts must be easy to find by designers, and easy to utilise within the tools of choice for the designer; and
5. Provide smooth transition from the use of generic parts to specific parts, and thus support the process of specification and value engineering.



Catalogue creation workflow

The Product Modelling Ontology (PMO) based catalogues have been created directly using commercial off-the shelf applications and tools and then converted for example from GDL to PMO using a GDL to PMO export tool.
The PMO catalogue item descriptions in themselves are sufficient to allow part selection and may refer to more involved part description, potentially in multiple formats and other parts description formats used by CAD systems and design applications.
Therefore, once the catalogue items have been created they can by uploaded into the catalogue server, which can be accessed using a web browser interface or other ICT tools by utilising the catalogue server's web services.
A 'simple' product is likely to be supplied by a manufacturer as a catalogue item, for example, a door set as shown in the figure below. Such items could also contain information for installation and maintenance, which must be associated with the actual catalogue item as reference data.

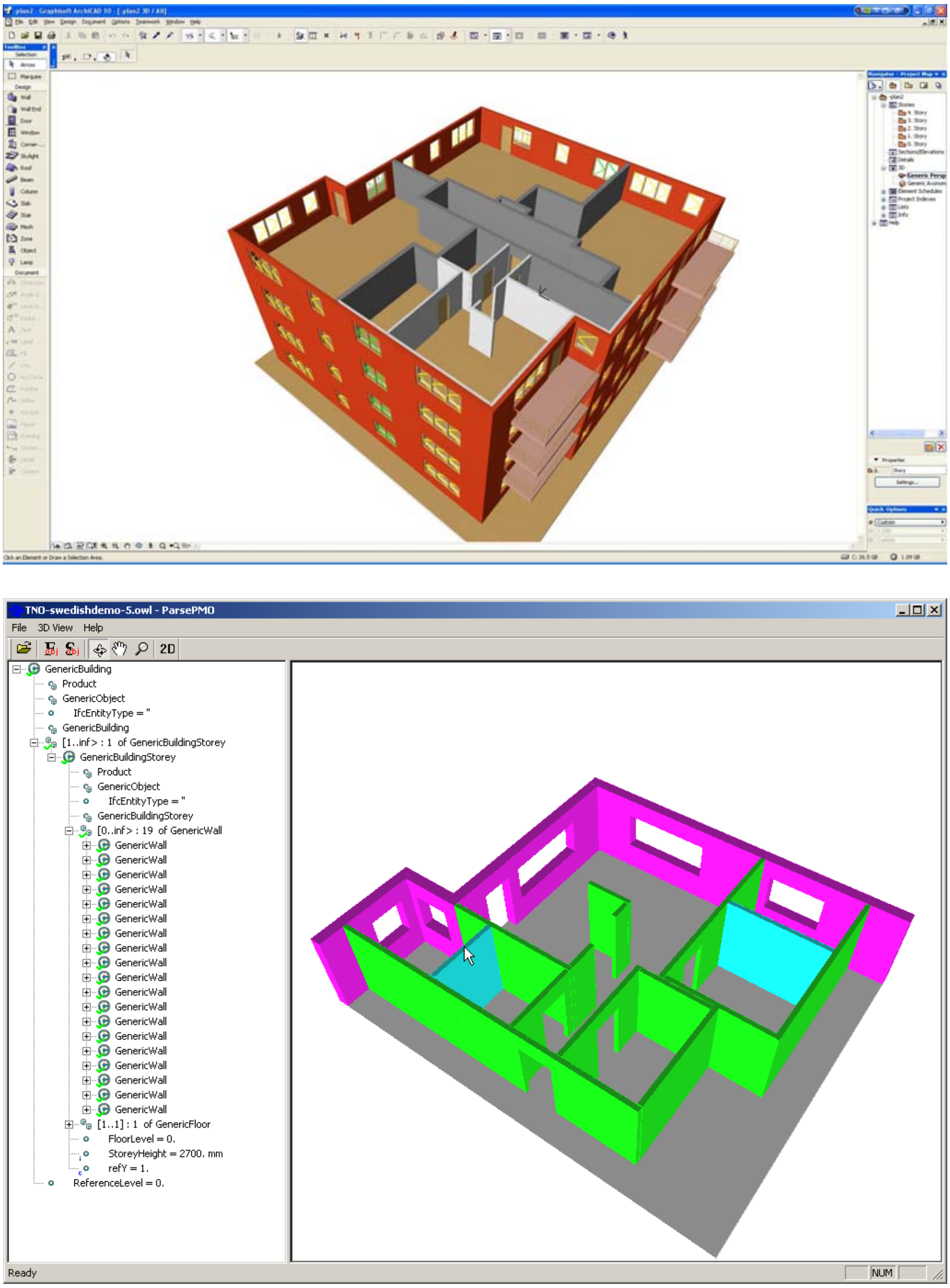


Door catalogue item in GDL and converted into PMO

Building Templates

The door set could be placed into an opening in a wall panel that is part of a building template for the layout of an apartment.

The following figure shows a simple building template created from an ArchiCAD building model and converted to PMO format using the ArchiCAD to PMO add-on developed for the ManuBuild project. Such building templates can then be uploaded to the Catalogue Server and processed by various configurator applications using the web services available form the catalogue server.



A building template created from a CAD model

Similar simple building templates could alternatively be created by hand using the Design Configurator tool that has been developed by TNO.

Tools to support Intelligent Catalogues

To support the creation of PMO base intelligent catalogues Graphisoft have developed the following tools:

GDL to PMO export tool

To validate the viability of a PMO based Intelligent Catalogue structure one needs a number of diverse objects created in PMO to assess its usability and conformance. The GDL to PMO export tool serves this purpose. It is desktop application that receives GDL files in its input folder and generates .owl files in its output folder. By dropping the resulting .owl files onto the PMO Viewer one can inspect the results.

ArchiCAD to PMO export tool

This tool allows the designer or architect to create building templates in a familiar CAD environment using familiar export-import capabilities to move Building Information Modelling data around and give flexible tools to edit and change the model should the need arise. Once the model is completed, it can be exported to PMO. The ArchiCAD to PMO export tool is an ArchiCAD add-on that needs to be installed in the ArchiCAD add-on folder. As a result, a new menu item is inserted to the ArchiCAD menu bar.

Key Results

Graphisoft have developed tools to create intelligent catalogues and building templates, which support the design configuration for the layout of a dwelling. For example, to support an end-user customising a dwelling to suit their requirements and the detailing of the modules needed to manufacture the dwelling.

Intelligent Catalogues and Building Templates are utilised by the Design, Sales and Manufacturing Configurator tools which are used by the various ICT tools that support:

- Sales Office Demonstrator,
- ICT aspects related to the Building Demonstrators: Swedish, Spanish and UK Mixed Use.

References

Hajas, T., Reinecke, W., Nummelin, O., Bonsma, P., Kopyto, M. (2006) ManuBuild WP5 deliverable D5.3-1, Intelligent Component Catalogues.

Hajas, T., Orosz, T., Florian, A., Bonsma, P., Williams, P. (2007) ManuBuild WP5 deliverable D5.3-2, Intelligent Component Catalogues.

Hajas, T., Orosz, T., Florian, A., Bonsma, P., Williams, P., Stephens, J., (2008) ManuBuild WP5 deliverable D5.3-3, Intelligent Component Catalogues.

Key ManuBuild Contacts

GST, YIT, TNO

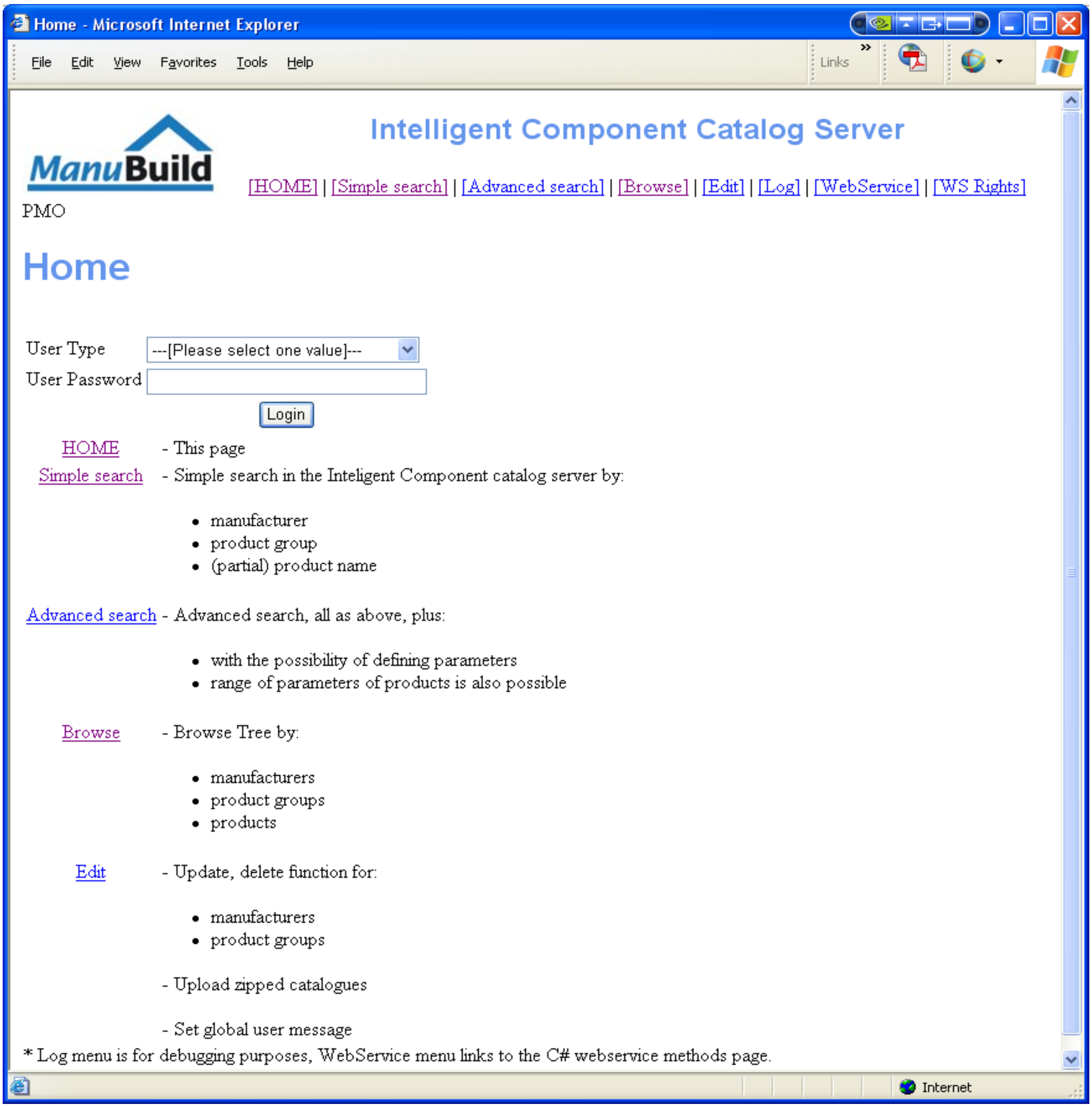
Tool: Catalogue Server

Industrial Context

The role of a Catalogue Server is to host the intelligent catalogue information and to provide access both end-users and software applications. The catalogues can be simple component based catalogues, but also building templates that can be used by end-users with support from a sales office configurator to customise a dwelling to suit their individual requirements.

Catalogue Server functionality

The Catalogue Server has the necessary administrative capabilities to identify access rights for the publishers and clients of catalogues, and provides a user interface where the users of catalogues can enter search criteria to locate a specific part or parts and then return relevant catalogues items for parts that meet the search criteria. An end user is therefore able to search for components by any criteria like type, manufacturer, price range etc.



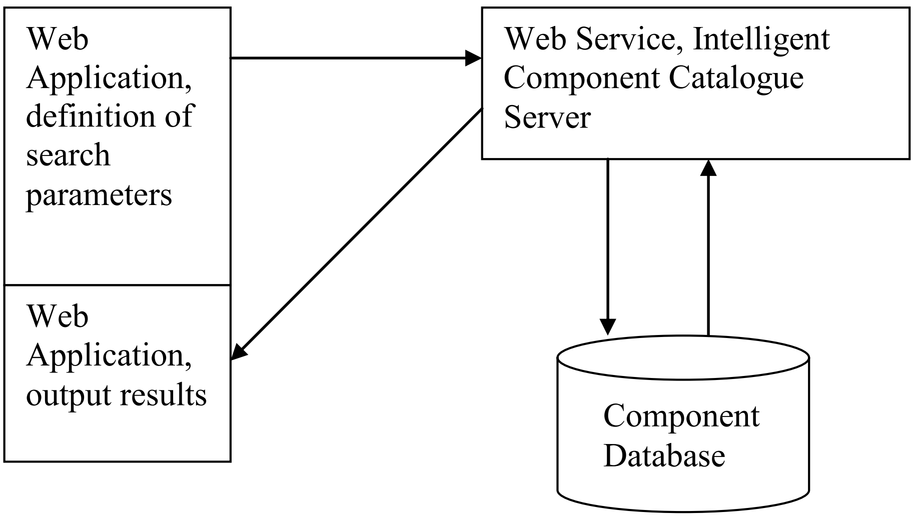
Catalogue Server functions available using a web browser

In order to search for relevant catalogue items the catalogue server component database must know about the relevant parameters and possible values for each component, as well hold the representation of the component itself in PMO format. Additional information can also be referenced that is relevant to a catalogue component, for example a high quality image or a specification document.

Implementation of Catalogue Server

The Catalogue Server is a Microsoft Active Server Pages web services (ASP.NET) server coupled with a mySQL database. These technologies enable software programmers to easily create dynamic web applications. Information is served from catalogue server, which is placed into the 'demilitarised zone' and protected by the corporate firewall in Graphisoft's network infrastructure.

The Catalogue Server supports a number of web services that enable remote software applications to access catalogue information, for example the Design, Sales and Manufacturing configurators can all access catalogue items and building templates.

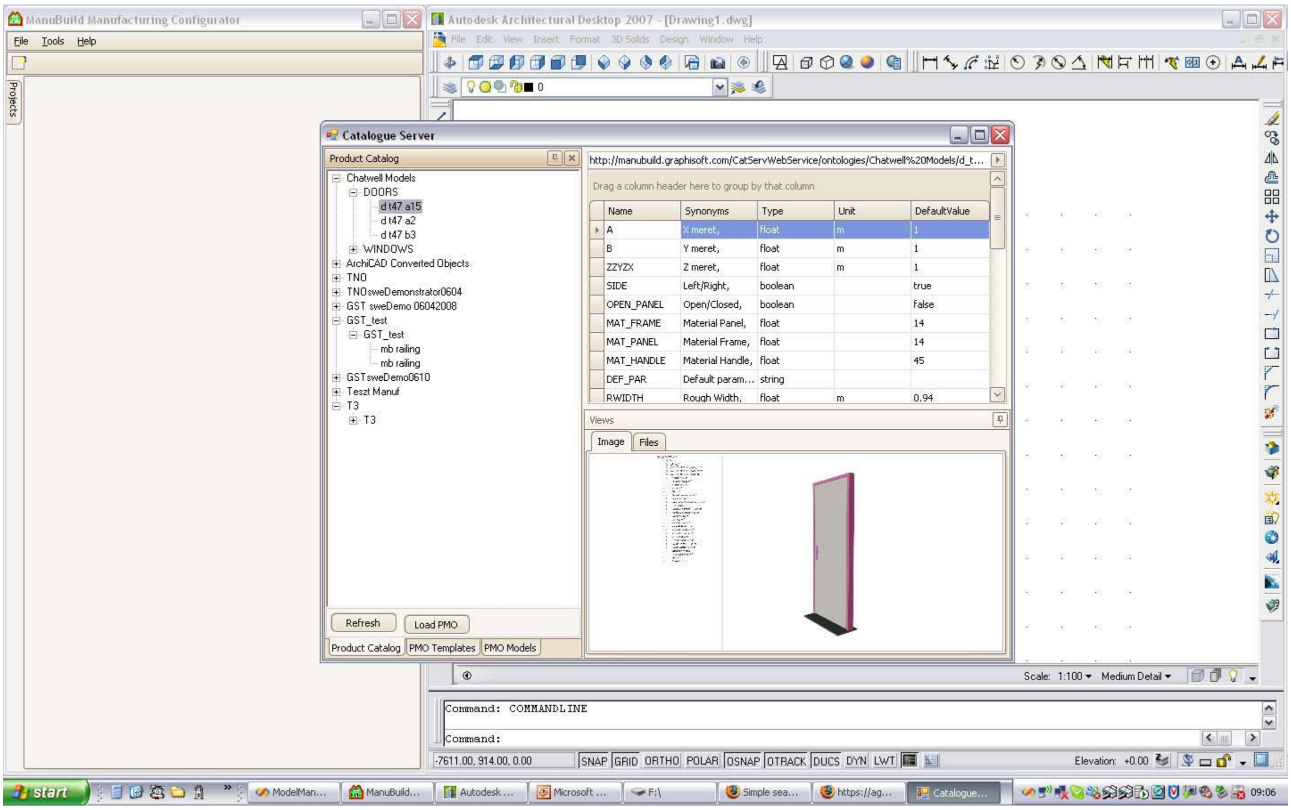


Intelligent component catalogue server

Therefore, it possible for a software application to automatically submit a search query to the Catalogue Server for a specific component type (e.g. a door set), along with a value that relates to a specific parameter that are associated with that component (e.g. the required width of door). The Catalogue Server will then return a list of parts and the catalogues containing them that in this example will represent a door that can be supplied from a manufacturer.

Software applications accessing catalogue data

The figure below shows the Manufacturing Configurator searching the Catalogue Server for possible doors, which meet the search criteria, and could then be inserted into an opening in a wall panel. Similarly, the Design Configurator and Sales Configurators can also access the web services of the Catalogue Server and enable the drag and dropping of catalogue components into building objects that are in for example a building template that represents that layout of a dwelling.



Manufacturing Configurator accessing the Catalogue Server web services

Key Results

Graphisoft have developed tools to manage and distribute intelligent catalogues and building templates, which support the design configuration for the layout of a dwelling. For example, to support an end-user customising a dwelling to suit their requirements and the detailing of the modules needed to manufacture the dwelling.

Intelligent Catalogues and Building Templates are utilised by the Design, Sales and Manufacturing Configurator tools which are used by the various ICT tools that support:

- Sales Office Demonstrator,
- ICT aspects related to the Building Demonstrators: Swedish, Spanish and UK Mixed Use.

References

Hajas, T., Orosz, T., Florian, A., Bonsma, P., Williams, P. (2007)
ManuBuild WP5 deliverable D5.3-2, Intelligent Component Catalogues.

Hajas, T., Orosz, T., Florian, A., Bonsma, P., Williams, P., Stephens, J., (2008)
ManuBuild WP5 deliverable D5.3-3, Intelligent Component Catalogues.

Key ManuBuild Contacts

GST, TNO, TWC

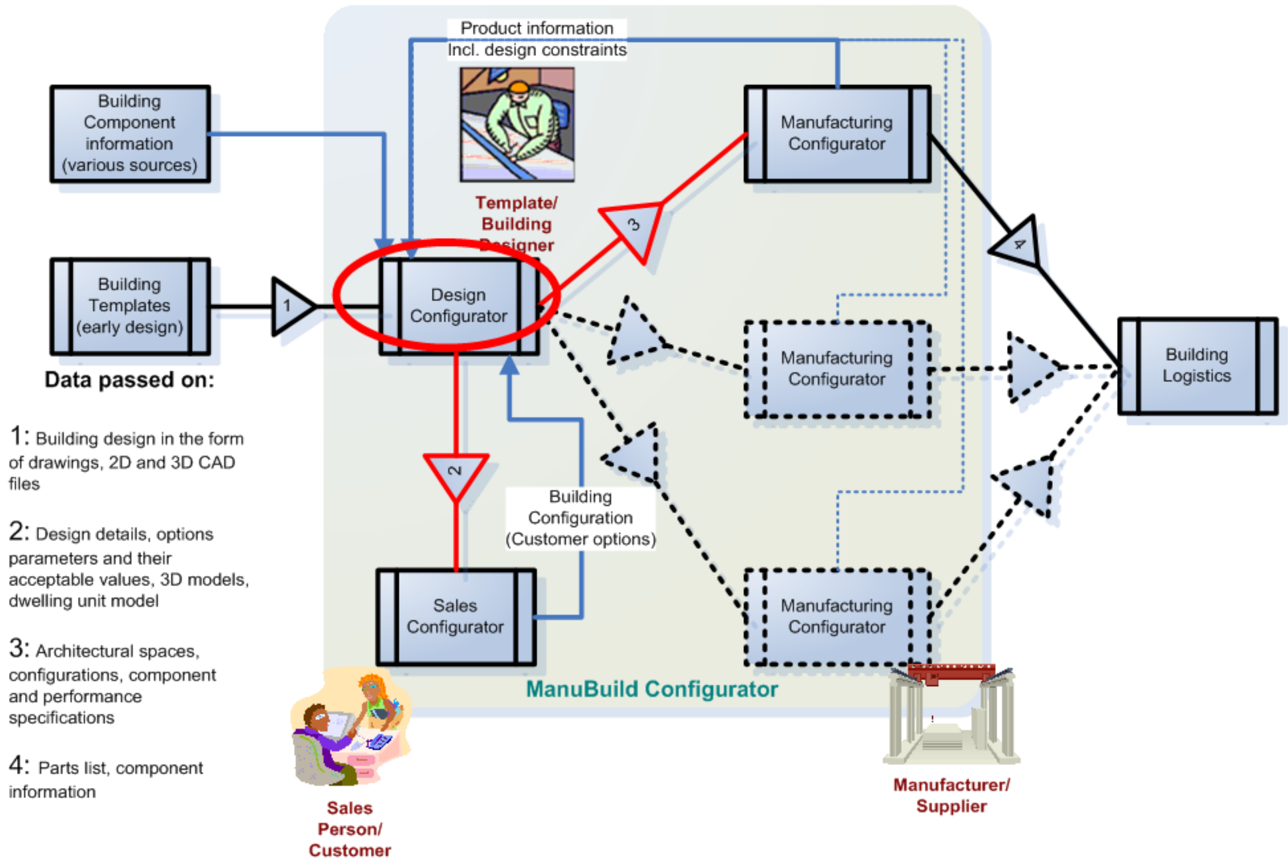
Tool: Design Configurator

Industrial Context

The Design Configurator is an application capable of supporting the multiple needs and activities presented during the design phase of a building project. In the design development phase the early conceptual design is turned into a 3D building model using generic parts and generic construction elements. The initial building services requirements are included, structural design and verification is performed.

In the design detailing phase the building model is reviewed and modified based on the inclusion of manufacturer specific pre-manufactured modules. The building design is separated into the structural and service core parts that belong to the core of the building and to apartment modules, built up based on the apartment module designs of the building template.

A number of prototype configurator applications are indicated in the data flow diagram below with the Design Configurator identified.



The Design Configurator in the ManuBuild ICT data flow diagram

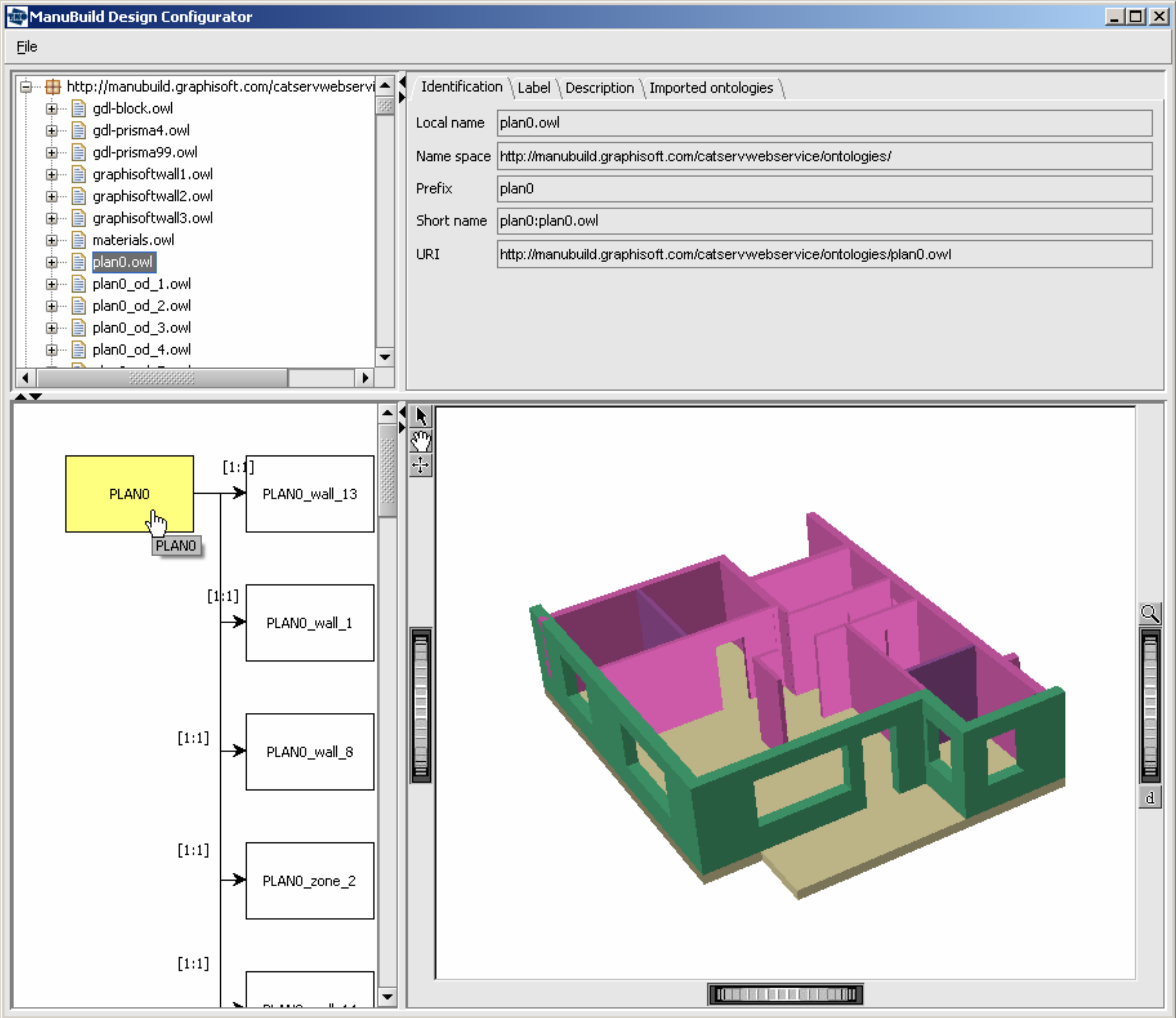
Design Configurator functionality

A summary of Design Configurator functionalities implemented to support the process as described below:

- *Loading a product class model and all indirectly referenced product class models*.
  In most cases a product class model will refer to a set of other product classes. For a proper understanding those classes must be loaded too. The result could be a large structure of interrelated product class models.
- *Saving a single or multiple product class models*.
  Saving a model is done on the local file system. To make this model reachable for other partners the updated model must be uploaded to a public server.
- *Creating a new product class model*.
  A new model can be developed in a local environment before it is published on a server.
- *Browsing the content of all loaded product class models*.
  This includes the properties, rules, operations, constructor scripts, sub/supertype and decomposition definitions.
- *Adding, deleting and updating the product class model content*.
  Changes can only be made public if one is authorized to access to the server hosting the product model.
- *Create a product instance model*.
  A product instance model may hold the instances of more than one product class model.
- *Browsing the content of a product instance model*.
  Facility is primarily meant to check the validity of the involved product class models.
- *Viewing the 3D shape of a product instance model*.
  Also meant to visually check the validity of the involved product class model.

Configuring a Building Template

Building templates are implemented by the design configurator which captures and codifies all the information and knowledge including constraints to support the sales configurator and guarantee buildability. The design configurator enables a building designer to assemble building templates into specific dwelling type models and to incorporate catalogue items into building designs.

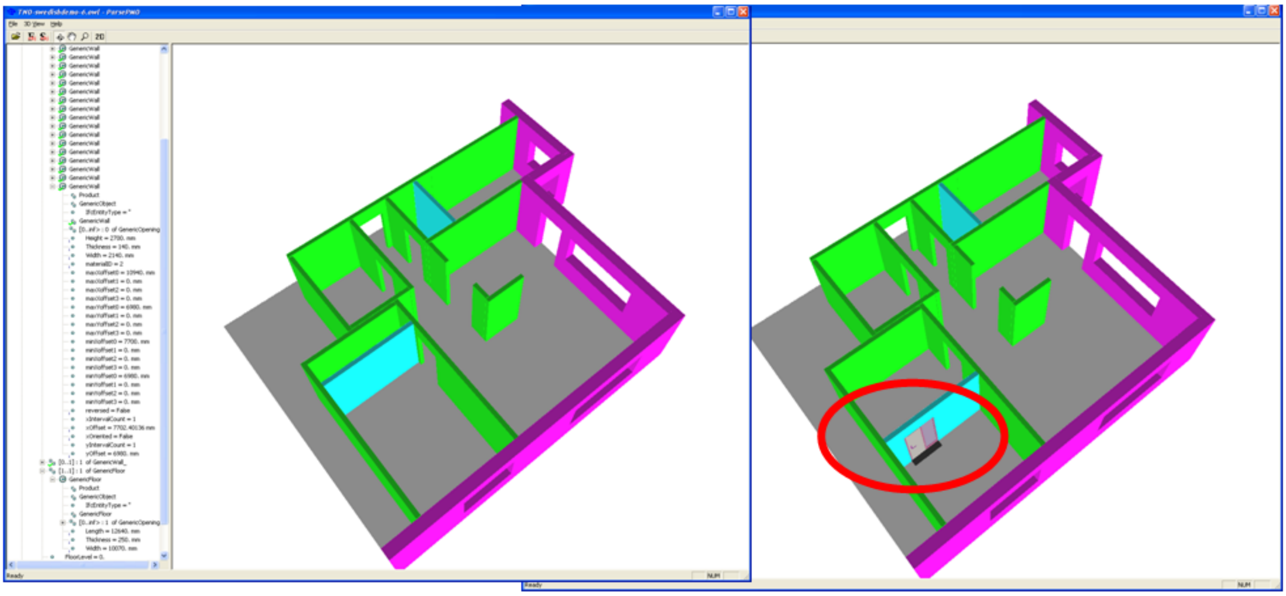


Design Configurator user interface

The Design Configurator interprets distributed PMO structured models at runtime. Changes are localised to each model although some changes could affect the whole model, e.g. removing a published property. This behaviour is similar to object-oriented modelling where published interfaces represent a contract between models and the system is guaranteed to function properly as long as the published interfaces remain.

By design, the configurator does not separate data and application scripts because application scripts use derivation rules to fill in derivable properties and to generate the actual 3D shape. The fact that both ingredients are combined into one file enables perfect integration.

The figure above shows a building template for an apartment being configured in the Design Configurator. For example a rule could be applied to limit the position of an internal wall, and that it must include am opening for a door. The figure below show such a configured building template being displayed using the PMO Viewer, where an user has dragged am internal wall in a room and can only release to the right hand side of the door. In addition, this internal wall panel must include an opening to enable access to the new space that has been created.



A constrained internal wall being moved within a room

Key Results

TNO have developed tools to create and configure a building template, which will enable an end-user to customise a dwelling to suit their own requirements.
The rules that can be applied could include architectural, building regulation and manufacturing constraints.
Possible end-users, for example are architects of designers, when future versions of the design configuration tool with a more appropriate user interface enables non PMO language experts to easily configure building templates and add rules.
The Design Configurator will be used as follows to support:

- The Sales Office Demonstrator,
- ICT aspects related to the Building Demonstrators: Swedish, Spanish and UK Mixed Use.

References

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2007)
ManuBuild WP5 deliverable D5.4-1, Concept for Design Configuration and Decision Support Tool.

Owolabi, A., Willems, P., Montoiro, S., Hajas, T., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-2, Implementation of ManuBuild Configurator.

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-3, ManuBuild Configurator.

Key ManuBuild Contacts

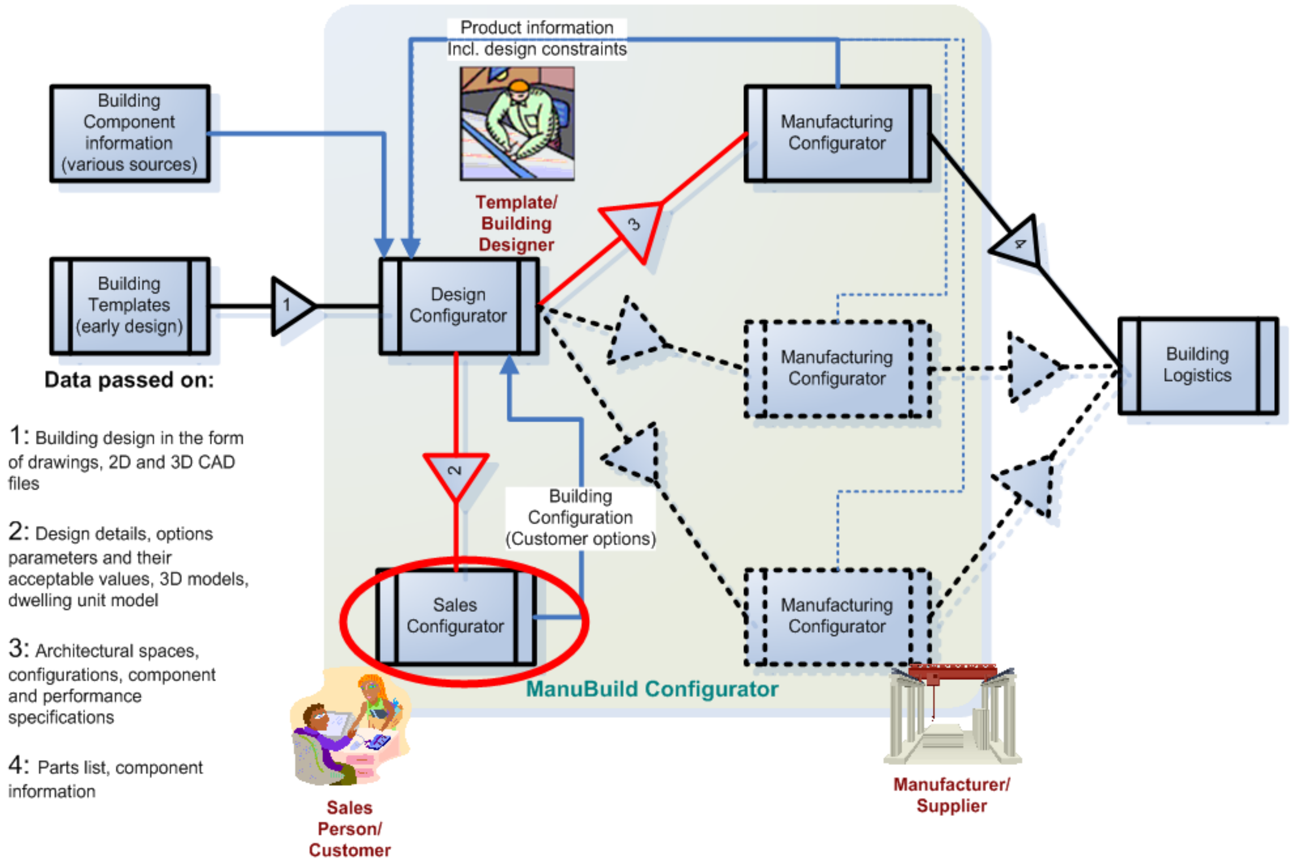
TNO

Tool: Sales Configurator

Industrial Context

The Sales Configurator is the tool that enables the end user to customise a dwelling according to his/her preferences. The salesperson and customer would generally explore building customisation options including architectural solutions, spaces, servicing, component inter-changeability, compatibility and customisation. The available customisation options are continually updated based on rules specified by the building designer and they depend on the stage where the salesperson/customer is the building customisation process.

A number of prototype configurator applications are indicated in the data flow diagram below with the Sales Configurator identified.



The Sales Configurator in the ManuBuild ICT data flow diagram

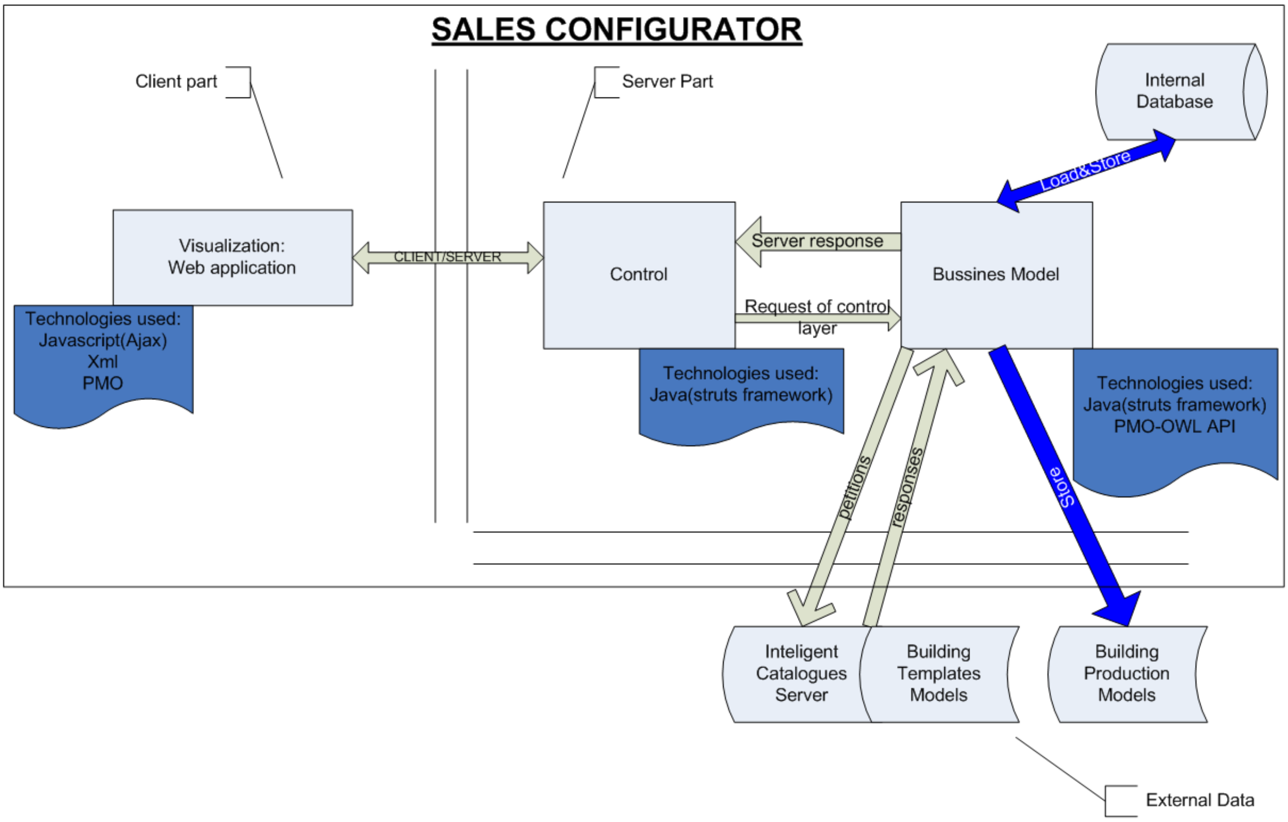
Sales Configurator Scenario

The scenario for configuring a dwelling using the Sales Configurator is outlined below:

- Access the system via an intuitive interface. This should have a 3D view and may use the ubiquitous Web interface.
- Start the process of designing their dwelling by picking from pre-designed dwellings possibly after choosing the geographical location or site.
- Progress through the dwelling customisation in a well defined, progress-tracked process, for example, dwelling types, floor plans, etc.
- Receive prompt feedback with every change or option selection about presentation (look and feel rendering), feasibility (or buildability), cost implications, time implications, other related options, etc.
- Have the option of navigating back to previously configured options to make changes, revert to (undo/redo) configured dwelling snapshots.
- Compare a number of configured dwelling snapshots.
- Complete and order a configured dwelling.

Sales Configurator communication

During the sales process layouts of the individual dwellings and the overall building design are stored in the Catalogue Server and made available to the Sales Configurator. This application is divided in two parts: the client and server, as shown in the figure below.



Sales Configurator Web Application

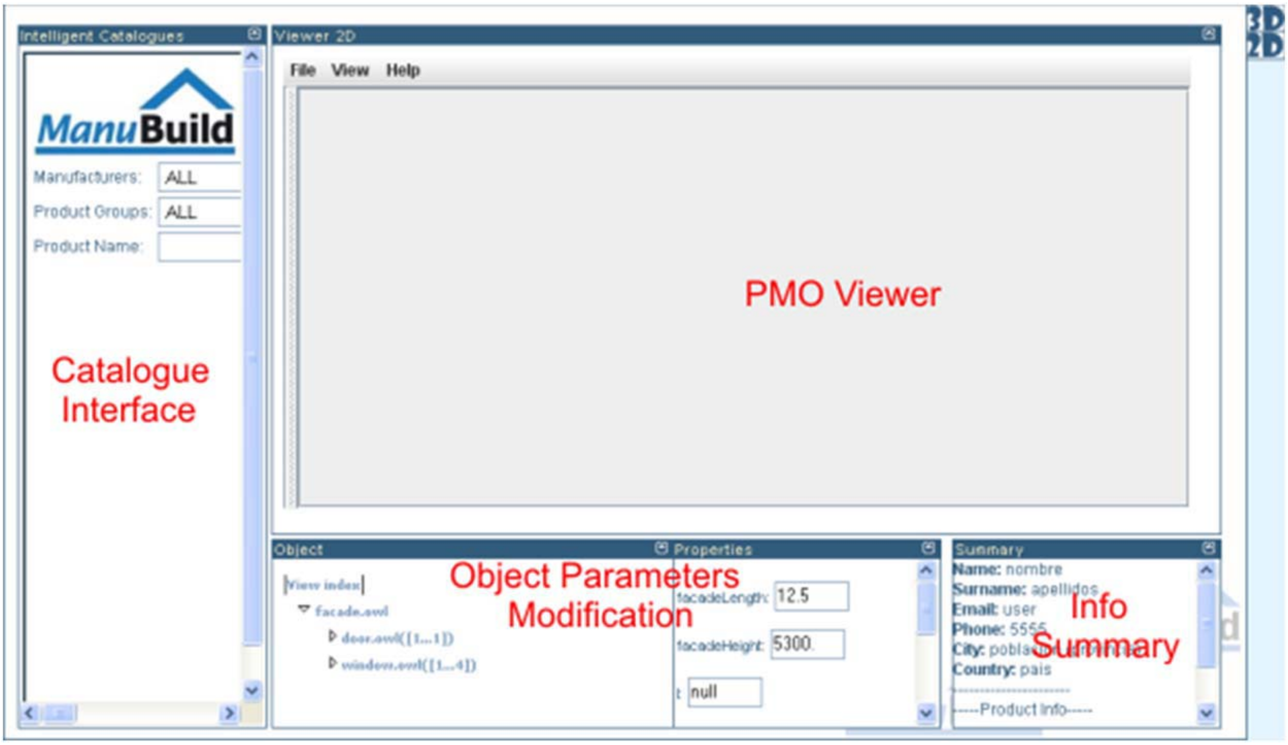
Communication between the Sales Configurator and the Design Configurator is performed via a dynamic PMO Application Programming Interface (API) which provides read, write and model creation functionalities for PMO/OWL-structured XML data. The PMO structured XML data contains records of the already booked or sold dwelling units reflecting actual customer choices for corresponding dwelling modules.

Based on the embedded design rules in the building template that represents the layout of a dwelling, the Sales Configurator also allows the user to enter or modify the parameters available with the chosen dwelling. The Sales Configurator also supports stored transaction processing, allowing the user to reserve units, revisit the parameters of the chosen dwelling and finalize the transaction.

In a separate local database, pricing information related to the combination of configurator options may be provided to allow the operator of the Sales Configurator to provide a quote (mark-up or discount) for the selected options. The information from this process is stored in the user's local database that supports the Sales Configurator tool.

If the configuration is approved the manufacturing process using the Manufacturing Configurator can start, otherwise the dwelling should be reconfigured until the design is approved.

User Interface



Sales Configurator User Interface

The figure above shows the user interface of the Sales Configurator. The left side of the screen shows the catalogue interface where the user can search for catalogue items to import to the viewer. The catalogue items are obtained from the different categories offered by the Catalogue Server. Interchangeable 2D and 3D views are presented in the PMO Viewer in the top right, while in the bottom centre of the screen information about the current selected object and its modifiable properties are displayed. A summary report including user's data, as well as the total price for the model or the object selected, is presented on the bottom right corner. In addition, in this last frame there is a report generator that provides the information about the configured dwelling.

Key Results

To enable a potential purchaser of a new dwelling, to select one from a list of possible offerings and then customise it to suit their own individual requirements. This could be the end user (or occupier) of the dwelling or possibly an investor.

The salesperson and customer would generally explore building customisation options including architectural solutions, spaces, servicing, component inter-changeability, compatibility and customisation. The available customisation options are continually updated based on rules specified by the building designer and they depend on the stage where the salesperson/customer is the building customisation process.

The Sales Configurator will be used as follows to support:

- Sales Office Demonstrator,
- ICT aspects related to the Spanish Building Demonstrator.

References

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2007)
ManuBuild WP5 deliverable D5.4-1, Concept for Design Configuration and Decision Support Tool.

Owolabi, A., Willems, P., Montoiro, S., Hajas, T., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-2, Implementation of ManuBuild Configurator.

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-3, ManuBuild Configurator.

Key ManuBuild Contacts

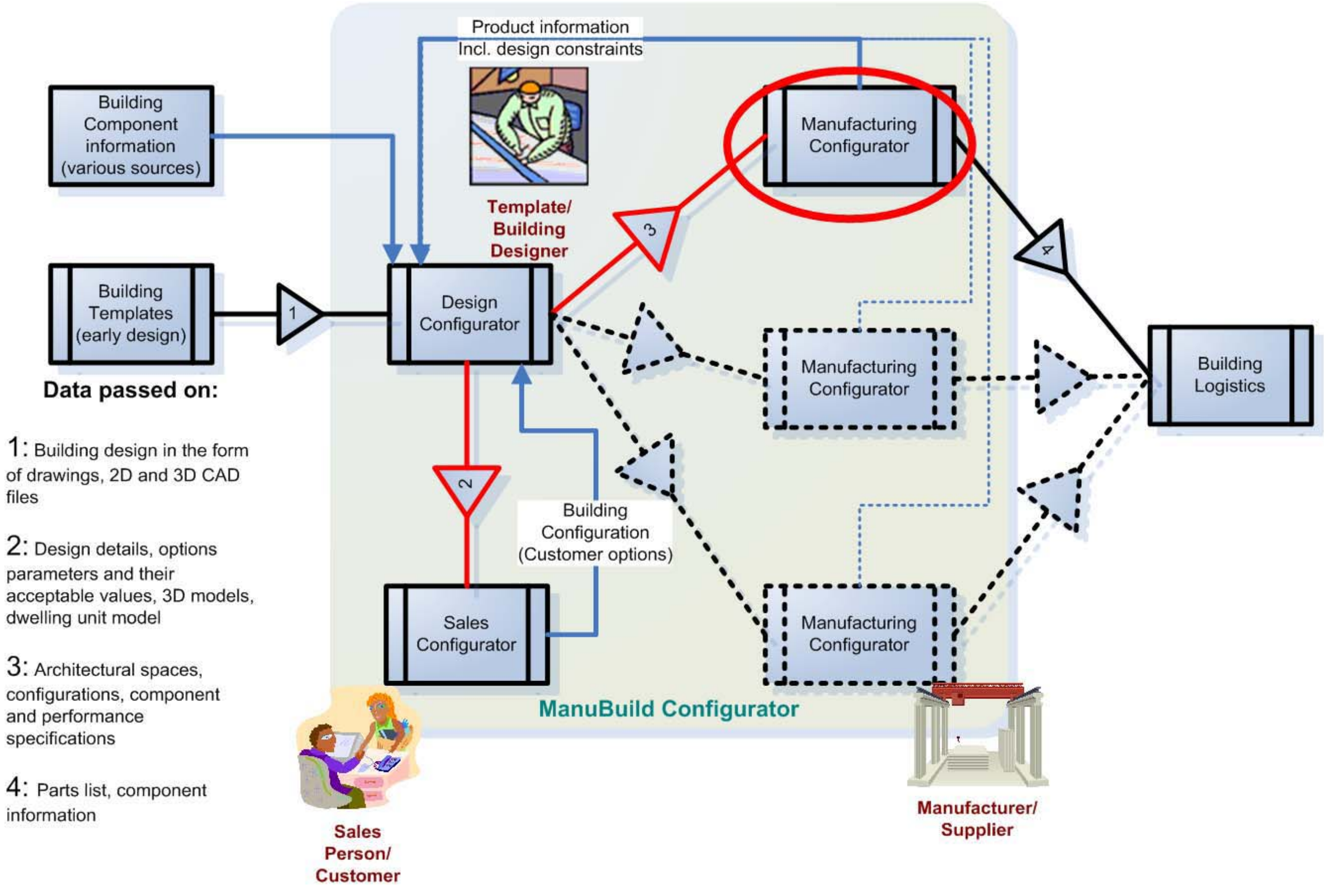
CA3, TNO

Tool: Manufacturing Configurator

Industrial Context

The manufacturer has detailed and specific product engineering and assembly knowledge. The product manufacturer, including fabricators and suppliers, is a key participant in the design for manufacture, assembly and construction supply chain. To support a seamless supply chain interaction, the product manufacturer requires a system that can capture product requirements from external systems, such as those used by the building designers and sales persons, to check manufacturing rules and constraints and provide adequate feedback to the external systems.

A number of prototype configurator applications are indicated in the data flow diagram below with the Manufacturing Configurator identified.



The Manufacturing Configurator in the ManuBuild ICT data flow diagram

Manufacturing Configurator requirements

The product manufacturer is the target user of the Manufacturing Configurator which has the following requirements:

- Manufacturing product template creation including assembling of catalogue items and other product templates.
- Import of relevant part of building models from external systems or BIM server.
- Product model creation including visualisation.
- Export of relevant costing, materials, logistics and planning information.
- Interfacing with manufacturer ERP systems and Logistics and Assembly Planning systems.

Manufacturing Configurator functionality

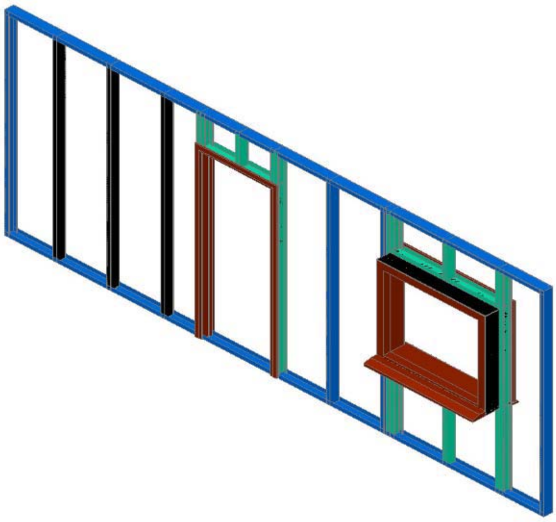
The Manufacturing Configurator facilitates detailed product design and detailing by codifying the product knowledge in software objects. To do this, the software needs to capture information about products and rules for assembling or fabricating them in a repeatable manner. The Manufacturing Configurator achieves this through parametric modelling of products and template-based product assemblies.
There are three groups of functionalities provided by the Manufacturing Configurator:

- Definition and creation of product classes or assemblies;
- Management of product instances; and
- External interaction with models including model export.

Products and templates are programmed and compiled into .NET object libraries using base libraries from the Manufacturing Configurator and other precompiled libraries. Each library represents a logical grouping of interrelated objects e.g. products from a particular supplier.

A product class is a digital representation of a collection of real world objects, manufactured, supplied or created for incorporation into a construction project. It can be linked to catalogue items for additional information including technical information, specifications, drawings, samples pictures, costs and discounts, sources of supply and delivery, test reports, installation, operation and maintenance instructions, and disposal or recycling requirements. Performance information and user feedback could also be incorporated to aid user selection.

Modelling of product classes within the Manufacturing Configurator assumes the existence of an electronic product information source and is currently linked to a prototype implementation with a view to linking to intelligent component catalogues whish are hosted on the Catalogue Server.

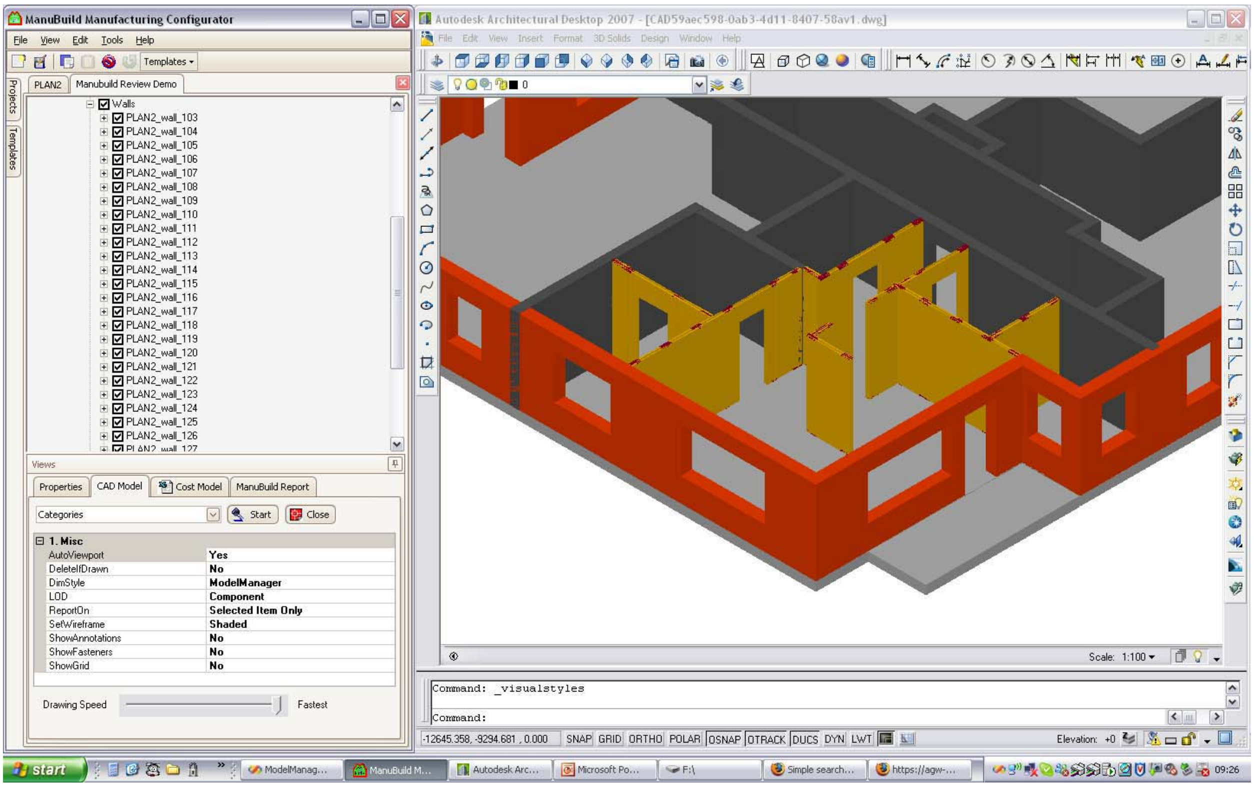


Simple wall panel with door and window

To model a library of products using the Manufacturing Configurator, a programmer is expected to create product classes, which are modelled by deriving new classes from existing base classes and implementing interfaces which depicts possible usages. A library of standard construction products and assemblies can then be created. The figure above shows a simple wall panel assembled using a number of construction products.

Supporting configuration rules

Such wall panels, as shown in the figure below, can then be applied to form the internal walls that are modelled in a Building Template, which the Design Configurator has created and the Sales Configurator has added and end-user customisation based upon the limitations defined by the rules embedded into the building template.



Wall Panels detailed using the Manufacturing Configurator

Key Results

The Manufacturing Configurator supports the design for manufacture methodology, which will enable the efficient offsite manufacture of buildings. Such an approach is based on the use of pre-designed building templates and intelligent component catalogues which can incorporate rules which can govern how such a building can be configured by end-users.

The Manufacturing Configurator will be used as follows to support:

- Sales Office Demonstrator,
- ICT aspects related to the Building Demonstrators: Swedish, Spanish and UK Mixed Use

References

The following ManuBuild reports are available on the ManuBuild Community of Interest website at http://www.manubuild.net.

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2007)
ManuBuild WP5 deliverable D5.4-1, Concept for Design Configuration and Decision Support Tool.

Owolabi, A., Willems, P., Montoiro, S., Hajas, T., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-2, Implementation of ManuBuild Configurator.

Owolabi, A., Willems, P., Vadillo, J., Harper, C., Bonsma P. (2008)
ManuBuild WP5 deliverable D5.4-3, ManuBuild Configurator.

Key ManuBuild Contacts

COR, TNO

Tool: Logistics and Assembly Planning

Industrial Context

All the parties involved in the supply chains of offsite manufactured building components are potential users of the Enterprixe Supply Chain management system. A list of company types include: design consultancies, fabricator companies, transportation companies, Erector/Assembly sub-contractor companies and main contractors. Listed by professions the users include managers, engineers, foremen and construction workers.

Logistics related problems and risks

To properly manage many supply chains on a construction project is a demanding task. Several problems and risks occur in a typical delivery of prefab building components. The list of the most important and well-known difficulties and defects include:

- Monitoring the whole supply chain is difficult and can lead to the poor control of deliveries, which often lead to an increased risk to fall into unwanted situations,
- Several parties involved in the chain, each of them trying to have a time buffer to be able to optimise their own task/business can lead to only focusing on sub task optimisation rather than optimising at the level of the whole project,
- No information of communication system available, which leads to difficult communication of changes of situations between the parties.

Most of the problems described above are related to producing, maintaining and sharing of project information.

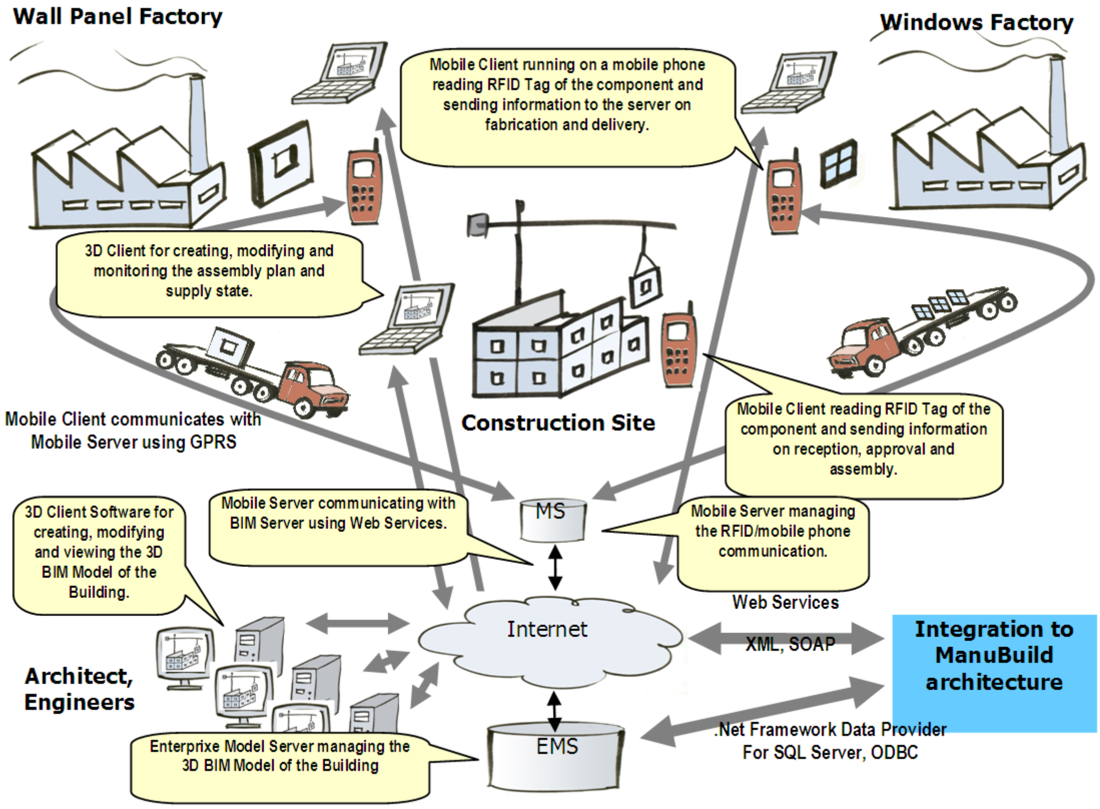
Logistics solution

To be able to solve them two things are needed:
1.) Services for producing and maintaining the information,
2.) An ICT system for storing and sharing the information.

The Enterprixe Supply Chain Management System supports the fluent information handling using an Internet based model server system. The most important requirements for the system are:

- Features for easily prepare and maintain plans for erection and assembly works -> 3D/4D modelling
- Ability to store and maintain the information efficiently -> 3D/4D modelling
- Ability to present the information in easily readable format -> 3D/4D modelling
- Ability to easily share the information between several parties -> model server

A software system fulfilling these requirements can solve problems that are related to the poor communication and information handling within supply chain teams.
The system is based on a model server technology and uses dedicated client software for all the parties involved in the supply chain so they can simultaneously access the single, common 3D/4D BIM model of the building, also called in this context a production model, containing the relevant supply chain management information.



Enterprixe supply chain management of manufactured components

Integration to ManuBuild architecture is realized through external interfaces. Several alternative external interface possibilities are offered, most important being an IFC import functions for building models and XML import for construction and manufacturers schedules.
Target users of the system are all the parties involved in supply chains of prefabricated building components.

Key Results

Features of the Enterprixe Logistics and Assembly Planning system cover the main needs of the supply chain management of the prefabricated building components including functions for:

- Monitoring the fabrication drawings production,
- Creating the plans for the assembly and erection works,
- Monitoring the fabrication, and
- Managing the logistics.

The Manufacturing Configurator will be used as follows to support the ICT aspects related to the UK Mixed Use Building Demonstrator.

References

Ristimäki, T. (2007) ManuBuild WP5 deliverable D5.5-1, Logistics Management, Assembly Planning and Monitoring Tool.

Ristimäki, T., Stephens, J., Nummelin, O., Hyvärinen, J., Hannus, M. (2008) ManuBuild WP5 deliverable D5.5-2, Logistics Management, Assembly Planning & Monitoring Tool.

Ristimäki, T. (2009) ManuBuild WP5 deliverable D5.5-3, Logistics Management, Assembly Planning & Monitoring Tool.

Key ManuBuild Contacts

ESL, VTT

Section VI

Training Solutions for Open Building Manufacturing

- Training Courses
- Teaching Factory
- Virtual Reality Interactive Training Environment
- University Education on Offsite Manufacturing

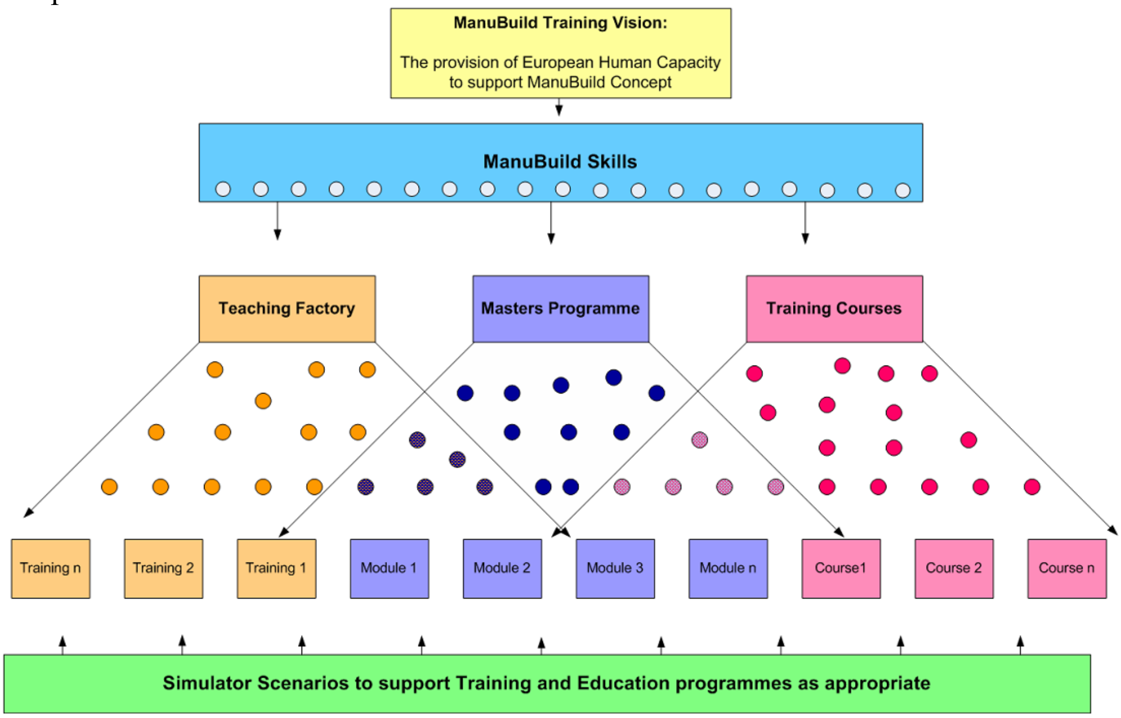
Training Courses

Industrial Context

*Manu*Build Training and Education concept encompasses the innovative linking of theoretical knowledge with the practical experience required for implementing the *Manu*Build concept through the integration: of industrial Training Courses, University Education, Teaching Factory and a Construction Site Simulator. This will ensure that future industry professionals are adequately equipped with the appropriate skill sets to adopt new OSM technologies and working practices produced as a result of *Manu*Build

Training concept

*Manu*Build "practice-based" training and education aims to equip students and professionals with timely and relevant skills to successfully apply the *Manu*Build concept. Consequently, Training and Education will ameliorate the skills gap paradigm by leveraging stakeholders' needs and expectations, thus creating a 'win-win' working relationship. In this regard, Training and Education can be seen as an investment which prepares organisations not only to adapt to the changing environment, but also to remain competitive.



ManuBuild training vision - interrelation between training and education

Industrial Training Package Design Considerations

- Research methods
- Methods of learning and their application
- Levelness of information

Chan et al (2002) state that the construction industry requires that education be more skill and knowledge based. Training and education can play an important role in communicating and demonstrating technological solutions and benefits to stakeholders (WP10.1 Training Concept, UoS). The aim is to develop a training concept that enables the innovative delivery of both training and education that encompasses the specifics of the *Manu*Build themes.

The basis of the industrial training packages lies in the need to link both the educational and industrial requirements of the project. Case study research has a long tradition in higher education (Yin, 2002) and the industrial examples provided will ensure technical understanding of the concepts in the appropriate context.

Get SMART with Offsite Manufacture (21st October, 2008)

An industrial training package was designed, developed and delivered based on the case study information that was available as a direct result of WP 2 (SMART components).

This package was delivered as a one day information session/workshop and included presentations from industry professionals who are closely associated with the project.

This course was promoted through the community of interest the Industrial Training Network that was developed through the ManuBuild project. Other avenues for promotion of the event were established through existing industry networks (e.g. CPN).

Attendees included a mix of academic and industry professionals with an interest in offsite manufacture.

Key Results

Overall

The industrial training packages are designed to address for a multidisciplinary audience to:

- Support the paradigm shift from the current "craft/resource-based driven construction" towards a "knowledge/ value-driven industry"
- Embrace national, EU and global contexts

Get SMART with Offsite Manufacture Feedback

The feedback from the attendees of the event indicates that the primary objectives of the package were met. All of those who responded to the online questionnaire attended the workshop to obtain information concerning offsite manufacture. 25% of respondents were also there to develop skills. A further 25% were there to improve/adapt attitudes and cultural change to new technologies.

Suggestions were also made regarding the development of future training packages for offsite manufacture. These were:

- Pods, internalisation and EU future projects
- Modularisation
- Improved collaboration within the industry between individual companies

Constraints

The major constraint to the successful implementation of the whole *Manu*Build training and education concept (during the lifetime of the project) was the lack of case study information, which is vital to the success of the project.

References

Chan, E et al (2002) Educating the 21st century construction professionals: Journal of Professional Issues in Engineering Education and Practice, 128, 44-51

Yin, R. K (2002) Case study research. Design and methods. Third edition. Applied Social Research Method Series. Volume 5: SAGE publications

Key ManuBuild Contacts

CIR, UOS, COR

Teaching Factory

Industrial Context

The Teaching Factory is aimed at delivering hands-on vocational training to all stakeholders within the remit of off-site manufacturing (OSM). Essentially, the core principle behind the teaching factory is to enhance the level of training delivered through Manubuild by recreating on-line production processes off-line and within the environment of an operational factory rather than a classroom environment.

The scenarios in which the Teaching Factory can be used to train individuals depends on the individual's specific requirements. That is to say, the Teaching factory offers flexible and dynamic training programmes that can be tailored to suit the type of skills that need to be honed prior to working on an operational production line. For example in the case of a production operative, production processes can be repeated off-line to increase productivity and ensure adequate QA prior to carrying out work on a live production line. In addition, in the case of an Architect/designer, the Teaching Factory can be used to enhance understanding of the limitations of OSM ensuring cost effective design and manufacture through an educated design process.

Value Added Benefits

Off-Site Manufacture (OSM) remains a growth sector, coupled with a downturn in traditional construction and the construction industries drive to deliver projects on tighter budgets and margins, the transition of skilled workforces from on-site to off-site working environments needs to be addressed. The Teaching Factory is able to provide a safe training environment in which the skills of tradespeople can be adapted to suit high repetition and high volume production rates offered by OSM. The key is hands-on training without adverse effects on production rates due to defects which are all part of the learning curve. Once operatives can demonstrate the required level of competency they progress to live production facilities with seamless results.

Multidisciplinary Scenario Based Learning

In order to highlight the detrimental impact of late design changes on manufacturing processes and subsequent production rates the Teaching Factory bases part of its learning on multidisciplinary design workshops focusing on OSM design issues. This training programme is suited to those involved in upstream activities such as detailed design etc. A suggested workshop could be where 'trainees' are asked to redesign an OSM component individually. Trainees are then asked to form design partnerships with members of the production team so as to critique the design process. As a result of the critique a secondary unified design solution is produced with input from the all members of the team. The multidisciplinary design is then embedded into a process simulation model whereby an accurate assessment of the impact on production processes and rates is quantified.

The underlying principle of the Teaching Factory Workshops is to primarily highlight the potential impact of changes past a certain point within any project. However, in addition to this, other issues such as fit for purpose design, design for manufacture (DfM), design for assemble (DfA) and multidisciplinary working with others from within the OSM community are bought to the fore. The end result is reduced risk when adopting OSM for the first time. For those familiar with OSM, the outcome is a deeper understanding of the limitations of OSM, which in turn demonstrates the freedom offered through OSM.

Teaching Factory Matrix

The Teaching Factory Matrix was developed in order to rationalise the disparate training needs of various stakeholders, ranging from Designers/Architects to operatives and building occupiers. The Teaching Factory Matrix rationalises the scope of training offered into four umbrella categories, whilst stakeholders and potential trainees are categorised into seven groups (see table below). By structuring the Matrix using the categories listed in Table 1, it is possible to pick and choose the modules (of which there are 29, ranging from conceptual understanding of OSM and open building manufacture to plant/tool training) best suited to the requirements of the trainee. An example of the training offered to an Architect and an operative is listed in Table 2.

Table 1. Training & stakeholder categories taken from the Teaching Factory Matrix.

Training Categories	Modules	Stakeholders /Trainees
Conceptual	8	Professionals
Manufacture	10	Management
Logistics	9	Operatives
CI	2	Contractors
		Clients
		Manufacturers
		Suppliers

Key Results

- Teaching Factory concept development
- Development of Teaching Factory Matrix
- Defined individual teaching requirements
- Development of demonstration scenarios and workshops

References

Khan, A. (2008). Teaching Factory, M36 report. Manubuid Website.

Contact

COR, UOS, CIR

Table 2. Teaching Factory Matrix showing training categories & modules required for an Architect & Manufacturing Operative. Highlighted cells indicate training required. CI = Continuous improvement.

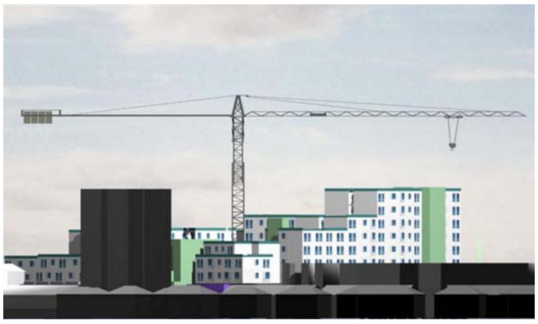
	Modules	Architect	Operative
Conceptual	Conceptual understanding of the OBM	highlighted	
	Awareness of the Environmental and Sustainability credentials of OBM	highlighted	
	Awareness of constituent materials and material performance	highlighted	
	Understanding of component manufacturing process	highlighted	
	Understanding of component interaction and interfaces	highlighted	
	Awareness of OBM morphological and system limitations	highlighted	
	Structural design of the OBM system	highlighted	
	Ability to design OBM components	highlighted	
Manufacture	On-site resource requirements	highlighted	
	Component delivery methods	highlighted	
	On-site installation procedure	highlighted	
	Knowledge of fixing methods and finishes	highlighted	
	Knowledge of mechanical services integration	highlighted	
	Understanding of building services systems integrated into OBM	highlighted	
	Material quality and quantity	highlighted	
	Appreciation of the management structure needed to deliver OBM	highlighted	
	Site Safety	highlighted	highlighted
	Specification and details of requirements and service routes	highlighted	highlighted
Logistics	Maintenance specification, requirements and intervals	highlighted	
	Awareness of operational procedure	highlighted	
	Understanding of the OBM constituent systems	highlighted	
	Inventory for OBM system	highlighted	
	Timescales and understanding of critical paths	highlighted	
	Delivery schedules and order of work for on-site installation	highlighted	
	Factory material flow streams and just-in-time requirements	highlighted	
	Order of assembly and job requirements	highlighted	highlighted
	Technical details concerning component manufacture	highlighted	highlighted
CI	Materials handling and safe working practices		highlighted
	Machine / Plant / tool training		highlighted

Virtual Reality Interactive Training Environment: Offsite Manufacturing

Industrial Context

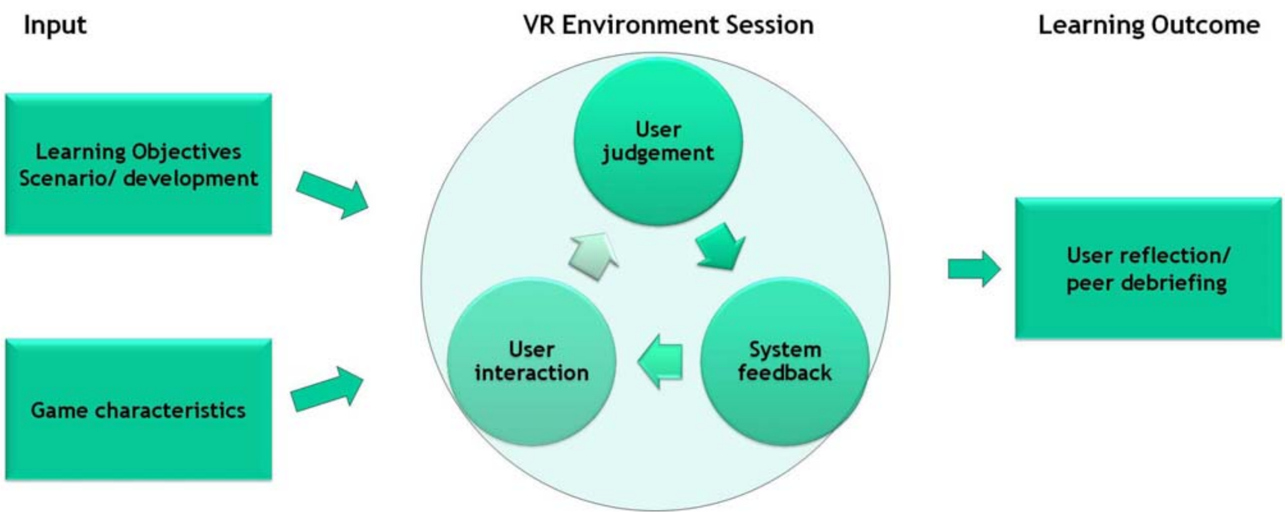
The ManuBuild project aims to promote the construction industry beyond the state of the art by introducing Offsite Manufacturing (OSM) concepts; targeting a radical breakthrough from the current "craft and resource-based construction" to a "knowledge-based Open Building Manufacturing" industry.

In this context, in order to achieve the ManuBuild vision; there was an exigent need to 'expose' construction industry stakeholders to the new concepts of OSM in a 'safe' and 'controlled' environment without the 'do-or-die' consequences often faced on real construction projects. In this respect, a Virtual Reality (VR) environment was developed to enable multidisciplinary stakeholders to experience working in an OSM environment using experiential learning.



The VR Environment Concept and Development

The VR environment concept was chosen as an approach through which incongruent stakeholders could be exposed to OSM using the mantra 'learning by doing'. In this respect, a 'live' project with real project data was embedded into the VR environment for simulation, modelling, and decision making purposes. The rationale for this approach was to place users out of their 'comfort zone' in order for them to experience new and 'non-traditional' challenges often associated with OSM. In this respect, users are placed in charge of a project through this environment, where they are challenged with a number of OSM issues to resolve. They are therefore put under pressure from the moment they engage with the system regarding the decisions they take and the respective implications these will have on project cost, time, resources etc. The development process of this concept embodies three main components: Input, VR Environment Session; and Learning Outcomes.



The VR Environment Development Process
(adapted from Garris *et al.*, 2002)

Input

This component includes different scenarios and storyboards often associated with OSM commercial practice. Key learning outcomes are subsequently 'mapped' across from this area for incorporation into the VR environment, along with seminal gaming characteristics and traits (to make the environment more challenging/engaging).

VR Environment Session

This is the main environment where the users interact with the system. For example, during an interactive session, users are required to make several initial and high-level decisions, the implications of which directly affect the scenario direction and all succeeding decisions. This requires user judgement and experience, as implications of not being able to foresee the effects of any action or decision will have direct consequences. Upon completion, feedback is provided to users in respect of the decisions made, the issues and problems encountered, and the impact these had on time, project cost, and resources used.

Learning Outcomes

This component is used to critique learners' understanding of OSM in respect of their performance in the VR environment session. This typically involves a peer-group setting, through which learners are encouraged to share their thoughts and experiences regarding their results. For example, what issues were encountered? How did these affect the overall project with respect to cost/time/resources etc? how can these issues/problems be mitigated for future projects? etc. Primary learning outcomes include:

OSM Strategies
OSM Business Processes
Procurement Methods
Health and Safety Issues
Open Systems
Logistic Solutions
New Manufacturing Technologies

Key Results

The Virtual Reality Interactive Training Environment is an invaluable tool which can allow stakeholders with different technical backgrounds to learn and appreciate OSM issues outside their own discipline area. In this respect, it can help learners to better understand and appreciate OSM within their own sphere of work, along with other project participants' perspectives – thereby improving the communication process. In addition, this tool can also be used to support training and education programmes in order to reinforce theory, and also to help deliver continual professional development (CPD) programmes on OSM.

References

Alshawi, M., Goulding, J. S. and Nadim, W. (2007), Training and Education for Open Building Manufacturing: Closing the Skills Gap Paradigm. In: Open Building Manufacturing: Core Concepts and Industrial Requirements. Kazi A.S., Hannus M., Boudjabeur S. and Malone A.

Goulding, J. and Nadim, W. (2007) "Construction Site Simulator", ManuBuild Open Building manufacturing Newsletter (6). ManuBuild Website

Garris, R., Ahlers, R. and Driskell, J. E. (2002), Games, Motivation, and Learning: A research and Practice Model, Simulation Gaming 33(4): 441-467.

Key ManuBuild Contacts

UOS

University Education on Offsite Manufacturing

The Industrial Context

The University Education aims to promote ManuBuild concepts to disparate stakeholders in order to equip them with the relevant required skills needed to meet industry needs for Offsite Manufacturing (OSM). In this respect, a 'proactive training and education approach' (Buckley and Caple, 2004) was adopted for ManuBuild Education, which is particularly suitable for introducing new technologies and processes, especially as OSM is likely to necessitate the creation of entirely new jobs and allied skill sets.

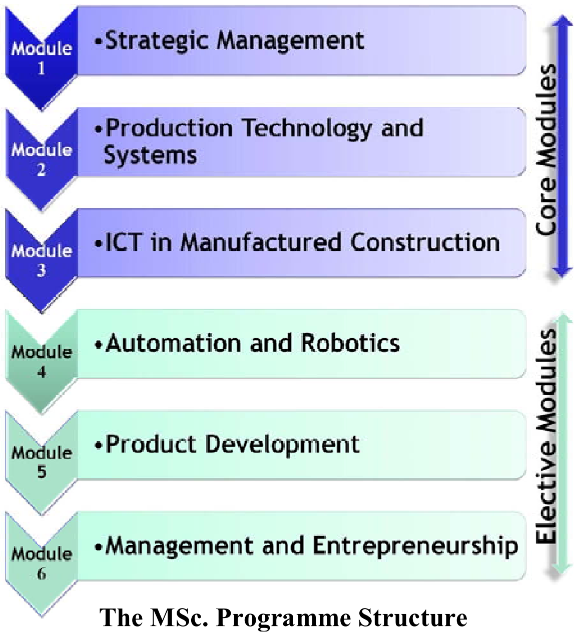
The MSc. in Advanced Construction Manufacturing

An MSc. in Advanced Construction Manufacturing has been developed which embodies the overall ethos of ManuBuild and OSM, the content and structure of which allows learners to blend theory with practice.

Programme Structure

The programme structure is composed of two types of modules: 'Core' modules and 'Elective' modules. Each module contains six learning packages, and each learning package is comprised of a problem, case study, seminal text, and lecture/tutorial support material.

This programme is a completely new, novel, innovative and timely. In this respect, it is specifically geared to exploit the specific needs of the industry in respect of OSM requirements e.g. new business imperatives/drivers, etc. This philosophy reflects the transition from a predominantly craft-based resource-driven economy to one that is mainly knowledge-based.



The MSc. Programme Structure

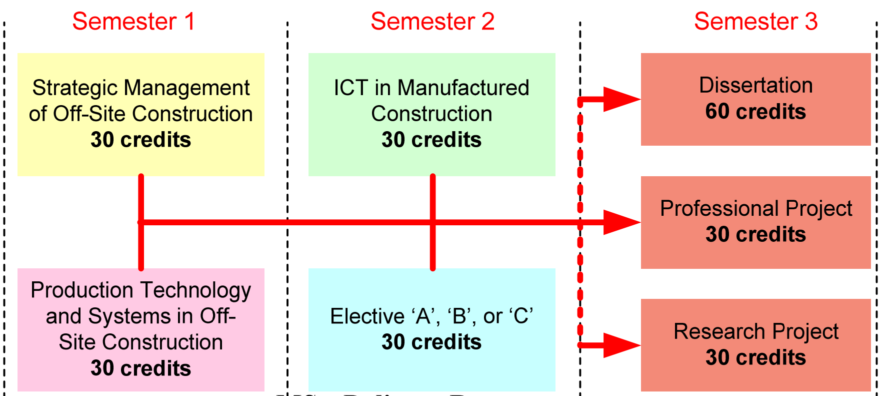
Delivery Routes and Awards

This programme offers three different delivery routes:

- Full time (FT)
- Part time (PT)
- Distance learning (DL)

Three possible awards are offered:

- Master of Science (MSc.)
- Postgraduate Diploma
- Postgraduate Certificate

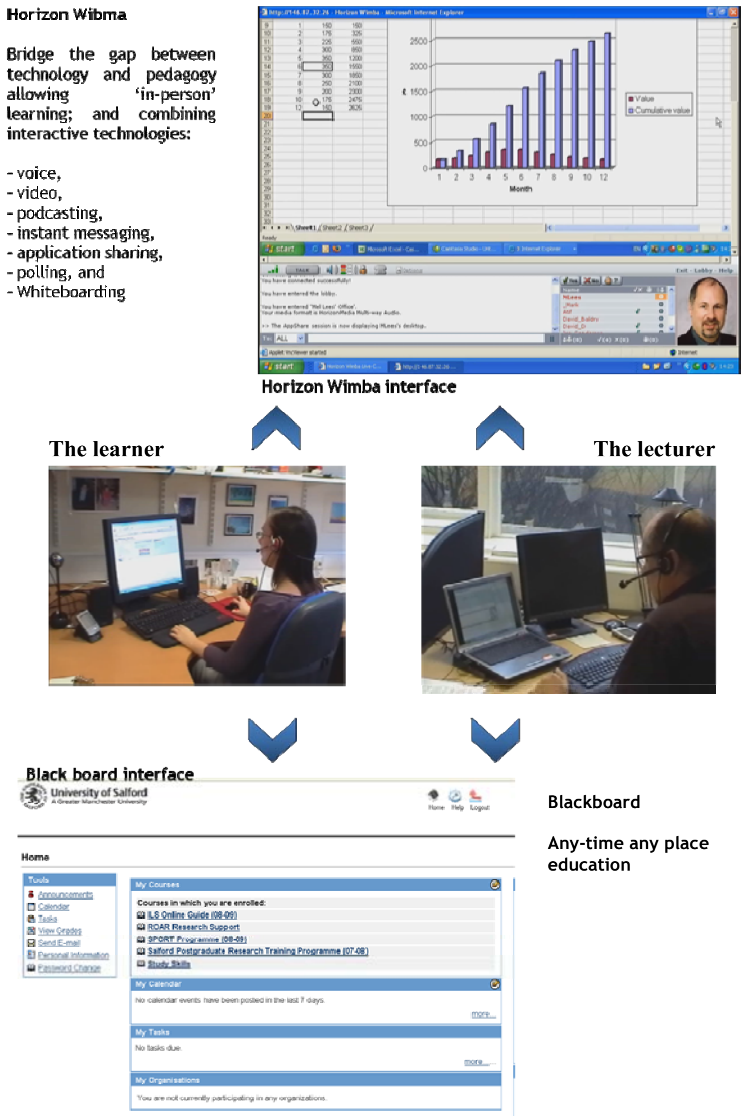


MSc. Delivery Routes

Delivery Mechanism and Transferable Skills

The MSc. programme focuses on a ‘learning environment’ rather than a ‘teaching environment’. In this respect, innovative delivery mechanisms are employed such as Horizon Wimba© and Blackboard© to optimise the learning experience. In addition to delivering OSM learning outcomes, this programme also embodies the following transferable skills:

- Flexible and creative thinking;
- High level problem-solving and decision making skills in complex and unpredictable situations;
- Self-management and personal responsibility skills;
- High level communication skills;
- Critical reflection and appraisal of personal and professional self-development.



Key Results

The MSc. programme caters for a multidisciplinary audience which:

- Supports a paradigm shift from the current “craft/resource-based driven construction” towards a “knowledge/value-driven industry”;
- Embraces National, EU and global contexts;
- Help learners better manage OSM projects both on the manufacturing floor as well as on the construction site.

References

Alshawi, M., Goulding, J. S. and Nadim, W. (2007), Training and Education for Open Building Manufacturing: Closing the Skills Gap Paradigm. In: Open Building Manufacturing: Core Concepts and Industrial Requirements. Kazi A.S., Hannus M., Boudjabeur S. and Malone A.

Buckley, R. and Caple, J. (2004), The Theory and Practice of Training, Biddles Ltd, King's Lynn.5th ed

Key ManuBuild Contacts

UOS

Section VII

Open Building Manufacturing Demonstrators

- ManuBuild Demonstrations
- Low Rise Housing in the UK
- Medium Rise Apartments in the UK
- High Rise Apartments in Madrid
- Medium Rise Apartments in Sweden

ManuBuild Demonstrations

Project Context and Demonstration Themes

The objective of the ManuBuild demonstrations is to demonstrate results of the research and technical developments undertaken within the ManuBuild project and to prove the viability of the ManuBuild vision and results within the commercial environments of real construction projects including property developments in Spain, United Kingdom and Sweden. The demonstrations provide examples of how the construction industry, its customers and supply chain can move the industry from a mainly craft production and closed way of working towards the vision of an open system building manufacturing approach.

Sales Office Demonstrations

The primary goal is to demonstrate customer driven seamless design & configuration of manufactured dwellings. Information and Communication Technology (ICT) tools have been developed and prototyped to support this goal plus related tools which support downstream activities including manufacturing and logistics. The topics demonstrated and validated within the Sales Office include:

- **A suite of configuration tools** comprising a sales configurator, design configurator and manufacturing configurator. They demonstrate how pre-engineered dwellings can be configured by the various stakeholders in the specification and design process.
- **A logistics and assembly planning** system related to off-site production and site assembly.
- **Intelligent component catalogues** and building templates to model catalogue components and dwelling layout templates.
- **An innovative component description language** called the Product Modelling Ontology (PMO) which is an open technology which conforms to the W3C Semantic Web initiative.
- **Open ManuBuild System Platform** based upon a System Architecture which shows how tools from different vendors might be integrated.

The topics have been demonstrated using details and information from the ManuBuild demonstration buildings in Spain, the UK and Sweden.

Manufacturing Demonstrations

A range of discrete demonstrations of ManuBuild results relating to manufacturing technologies, the factory requirements (fixed and/or mobile), and logistics for a complete manufactured component supply chain whilst understanding: handling, moving, lifting, components and the tracking of information related to them. Also, there were demonstrations of solutions addressing manufacturability and buildability issues for connections and interfaces that create easy, safe and speedy installation on site. The five threads of manufacturing demonstrations follow:

- **New manufacturing technologies** suitable for being used for construction projects and related manufacturing are presented on a web based ManuBuild Manufacturing Guide. The specific topics addressed are: lean production, benchmarking with learning, product development, production processes, automation and case studies.
- **Autonomous high volume fixed factories** demonstrating the development of a production line concept to manufacture the Corus ManuBuild Multi-Function Module at a rate of 3000 units per year. The demonstration explored alternative processes and optimisation methods within the manufacturing environment. An assessment of economies of scale was undertaken.
- **Flexible and mobile factories** demonstrating a container based truck transported facility for mounted, on-site, automatic (robotized) manufacturing and assembly of pre-fabricated parts and systems.
- **Logistic solutions guide** is demonstrated on two case studies one relating to the manufacture, supply and site assembly of multi-functional ceiling units and the other to the manufacturing, supply and final assembly of 3D accommodation modules for apartments.

- **Rapid connections and assembly methods** are being demonstrated in the form of Corus Dipple-Klick connectors for cold formed steel sections and the Consolis ConBolt system for connecting pre-cast concrete wall, floor and corner units.

Training Demonstrations

The new ways of working promoted by ManuBuild require manufacturing type discipline and a more open collaborative way of working. This will require a change in behaviour for both companies and individuals. ManuBuild is demonstrating results which address this.

- **Training course for industry** delivered and demonstrated as practice based training courses on building manufacturing for the construction industry and promoted through national industry training boards (CIRIA).
- **Academic courses** delivered and demonstrated as new European training and educational programmes curricula leading to Masters degree, Postgraduate certificates/ CPDs in Construction Manufacturing.
- **Teaching factory** environment and training material suitable for use within a factory environment demonstrated as two scenarios; one highlighting the impact of late design changes on the manufacturing process and the subsequent effect on production rates and the other demonstrating the flexibility of the teaching factory concept by utilising the teaching factory matrix to address the disparate training and educational needs of professions and operatives
- **Construction site simulator** being a virtual environment for skill development, training and practicing the new working conditions of the "construction site of the future". The simulator was demonstrated on the UK medium rise building of 200 comprising apartments.

Building Demonstrations

The aim is to demonstrate as many ManuBuild results as possible on real buildings. There are three building demonstrations each one showing different aspects of the ManuBuild results:

- **High rise in Madrid** including fifty social housing apartments which incorporate flexibility in layout. The apartments use the ManuBuild design philosophy, incorporate service modules and have been represented as templates.
- **Low rise housing in UK** design for a terraced house using corner supported modules. The design development included solutions to meeting the UK Code for Sustainable Homes Level 4 with a migration path to Level 5.
- **Medium rise in UK** including 200 apartments composed of Corus ManuBuild Multi-Function Corner Supported Modules. The main emphasis of the work was how to model complex buildings and the logistics of manufacturing, and site assembly.
- **Medium rise in Sweden** built to ManuBuild principles has seen Mostostal walls fitted and used to collect end user comments on living in buildings of this type.

References

Harper C., (2009) ManuBuild WP8 Deliverable 8.2 Sales Office and ICT tools Demonstration ManuBuild Website

Shaw, D., Ng EG., and Parkin P., (2009) ManuBuild WP8 Deliverable 8.3 Manufacturing, Logistic and Assembly Demonstrator Report, ManuBuild Website

Nadim W., (2009) ManuBuild WP8 Deliverable 8.4 Training Demonstrators, ManuBuild Website

Barcena C.., (2009) ManuBuild WP8 Deliverable 8.5 Building Demonstrators, ManuBuild Website

Key ManuBuild Contact

TWC

Low Rise Housing in the UK

The UK low-rise housing demonstration is focussed on the smallest terraced house designed for the Telford Millennium Community project. The house type is called Chatwell. The ManuBuild demonstration house is volumetric modular to exploit off-site production and will move house designs towards the greater sustainability and energy efficiency required by the proposed changes to the UK Building Regulations which reflect the requirements of the European Energy Directives.

The design development includes solutions which comply with the UK Code for Sustainable Homes Level 4 with a migration path to Level 5. Although the design could not achieve a Code Level 6 performance, it includes features common with the most recent passive house designs but is still competitive in price.

The typological core spaces and rooms in this two story two bedroom house are parametric and can be re-used in 2½, and 3 storey houses which have more bedrooms and bathrooms.

The aim of the demonstration is to reduce assembly time on site and to improve the finishing quality of the house

ManuBuild results being demonstrated

Architectural Design Methodology

This project demonstrates how to create a system in which the dwellings can follow modern lifestyles; adapting and changing according to the users' necessities. This implies the creation of flexible and adaptable spaces which allow certain variations depending on the users needs.

EMVS have demonstrated how a survey of potential customers can be used to influence the design and distribution of different apartment types within the building.

The diagrams below show possible distributions of two bedroom apartments in the demonstration building:

Design Configurator

The demonstration of an architects design tool which can manipulate generic building space templates into templates specific to house designs and instances of specific houses. The end results are templates for use by Sales Office and manufacturing configurators.

Manufacturing Configurator

The demonstration of a manufacturer's software tool which inputs the results of design and sales office configuration to and generates manufacturing details, schedules and c.n.c. input for machine tools.

Building Templates

Demonstration templates have been prepared for this house type. The templates need to include mirroring both ways, horizontal & vertical steps between houses and extra windows on the houses at the end of rows.

Sales Office Configurator

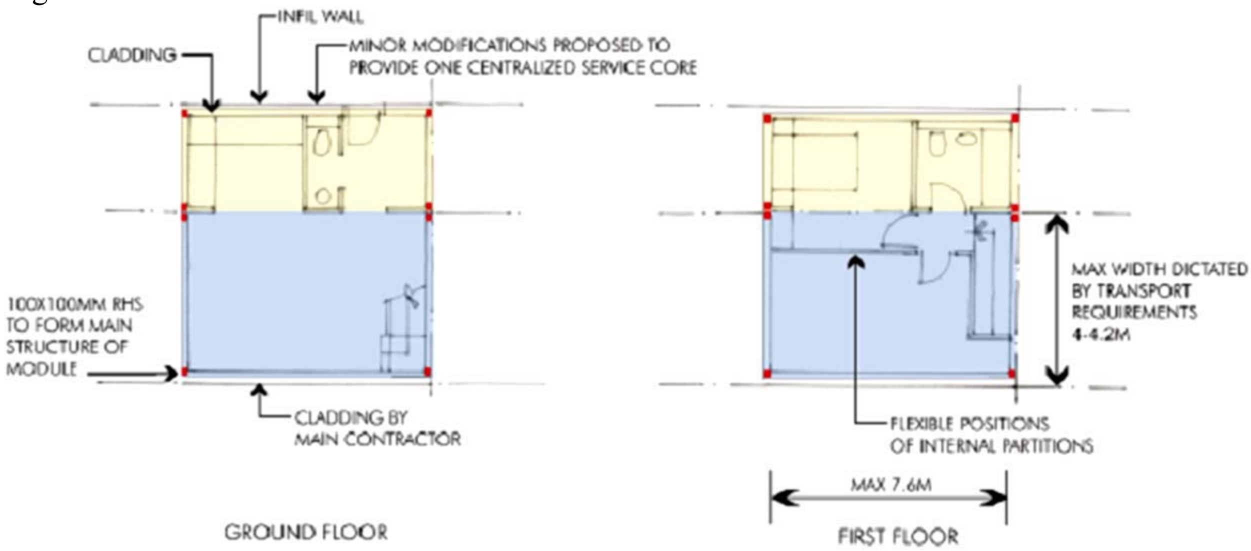
The demonstration of a software tool which uses design templates to collect customer choices and transfer them accurately to back office systems and the manufacturer's configurator.

Intelligent Component Catalogues

The demonstration highlights the approach for creating intelligent catalogue items and using the related catalogue server for building templates and items incorporated in houses such as windows doors and bathroom fittings. This also demonstrates the Product Modelling Ontology (PMO) which is an open technology description language which conforms to the W3C Semantic Web initiative.

Corus ManuBuild System

The house demonstration uses the corner supported volumetric modules which are part of the Corus ManuBuild System. The system includes floor, wall and ceiling cassettes and can incorporate different types of wall cladding such as brick, render, timber or metal and a metal roof incorporating solar thermal and photo-voltaics. Innovative connections between modules can also be used to lift the modules during assembly. This requires remotely latching attachments on a lifting frame. A typical arrangement of modules is shown below:



System Architecture & Open ManuBuild System Platform

The ManuBuild system architecture, based on the PMO and Industry Foundation Classes (IFC) standards has been used to exchange information between the software components. The innovative Information Delivery manual has been used to capture and describe the information flows in the supply chain.

References

Barcena C., González C., Leonard C. D., Claeson-Jonsson C, (2009), ManuBuild WP8 Deliverable 8.5-4 Building Demonstrations

Key ManuBuild Contact

TWC

Medium Rise Apartments in the UK

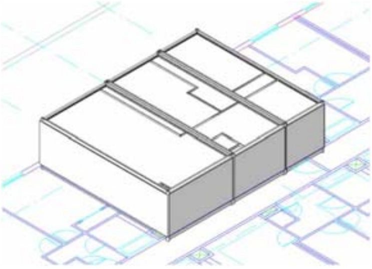
This demonstration project is a mixed use development in south London at a place called New Addington in the borough of Croydon. The project is a supermarket with up to seven storeys of apartments built on its roof. The 196 one and two bedroom apartments include social housing, shared ownership and private ownership and have a construction value of roughly £14 million. The project is in a very congested suburban location with restricted access and there is a site programme requirement to construct the apartments in 10 weeks.

The demonstration provides an opportunity to explore the limits of off-site manufacturing of modules and to compare ManuBuild methods with those in common use. The demonstration emphasis is on planning, logistics and training.

ManuBuild results being demonstrated

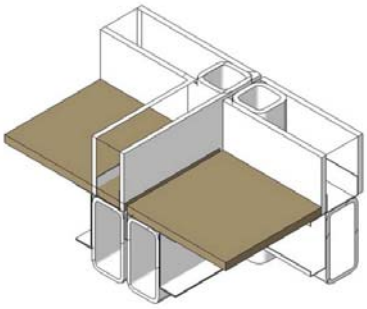
Building Templates

A typical two bedroom apartment has been divided into three modules and modelled to the level of services outlets. Templates suitable for the design, sales and manufacturing configurators have been derived from the module models. The templates can hold intelligent catalogue information.



Corus ManuBuild System

The Corus ManuBuild System corner supported modules have been used for the apartments and 2D panels have been used for roof units and corridor floors. The structural philosophy and reference details such as structural & services connection have been explored. The modules have a welded tubular steel frame with serviced infill panels consisting of cold formed sections, insulation and boards.



Design for manufacture and assembly

The design of the modules took into account the architectural design, manufacturing, transportation, safe site assembly and the finishing and commissioning of the apartments. This was an incremental interactive process. The site crane requirements are part of this.

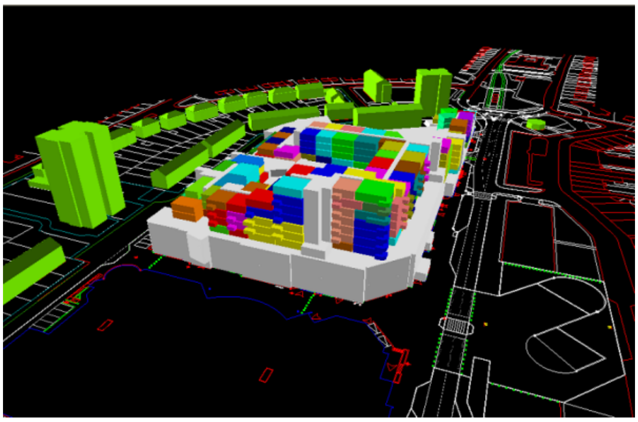
System Architecture & Open ManuBuild System Platform

The ManuBuild system architecture, based on the PMO and Industry Foundation Classes (IFC) standards has been used to exchange information between the software components. Information

Delivery Manual (IDM) has been used to capture and describe the information flows in the supply chain. The system platform comprises largely of agreed standards, APIs and exchange requirements between tools. Partners have agreed ways of modelling objects and naming parameters and properties.

Logistics solution

This project uses information from the Logistics Guide and demonstrates the Logistics Solution software. The demonstration explores all the relevant considerations and lists all the structured information from the manufacturer through transportation to final assembly on site. This information is relevant to all things being delivered to construction projects. The logistics model was prepared in REVIT and Synchro and the Exterprixe Systems Ltd logistics solution was used to show how a product model server could be used to undertake assembly planning and monitoring across a supply chain.



Unique connectors were developed to make vertical connections between modules. The connectors could also be used for lifting modules and a remotely operated lifting frame was developed for site use.

Intelligent Component Catalogues

The demonstration highlights the approach for creating intelligent catalogue items and using the related catalogue server for building templates and items incorporated in houses such as windows doors and bathroom fittings. This also demonstrates the Product Modelling Ontology (PMO) which is an open technology description language which conforms to the W3C Semantic Web initiative.

Design and Sales Office Configurators

This demonstration building will demonstrate the use of the design configurator which is an architect's design tool for manipulating generic building space templates into templates specific to apartment designs. The end results are templates for use by Sales Office and manufacturing configurators.

Manufacturing Configurator

The demonstration of a manufacturer's software tool which inputs the results of design and sales office configuration to and generates manufacturing details, schedules and c.n.c. input for machine tools.

Training

This demonstration project has been used as a case study and as an example features in the Construction Site Simulator.

References

Barcena C., González C., Leonard C. D., Claeson-Jonsson C, (2009), ManuBuild WP8 Deliverable 8.5-4 Building Demonstrations

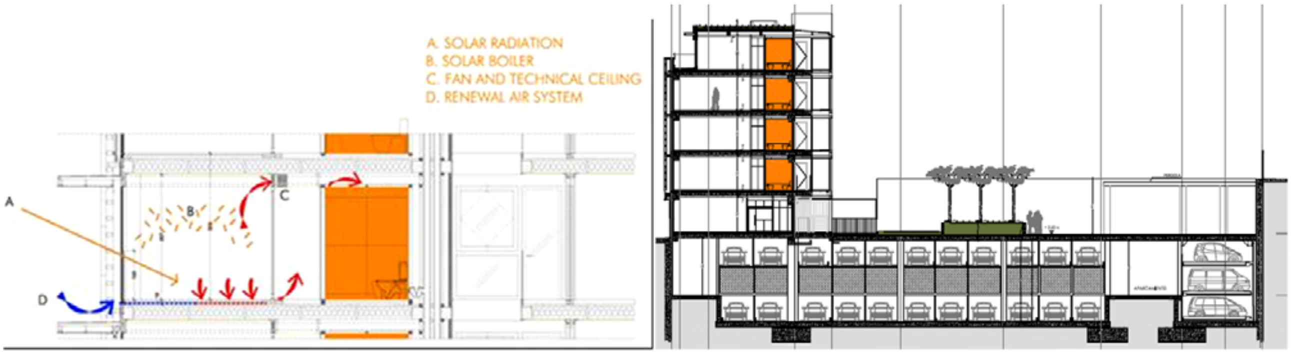
Key ManuBuild Contact

TWC

High Rise Apartments in Madrid

A housing development constructed for the Empresa Municipal de la Vivienda y Suelo de Madrid (EMVS). The Municipal Housing and Land Authority of Madrid, EMVS, is a publicly funded company which deals with all housing matters for and belongs to the Madrid City Council.

The development, comprising of 25 renting apartments, is located in Southwest Madrid, in the "Ensanche de Carabanchel". The apartments are distributed in one independent block that has 4 stories and a penthouse. There is an underground semi-automatic car park with 115 parking spaces which will connect this block with one to be built shortly on the North side of the lot.
The architectural design was prepared using ManuBuild principles following a two stage architectural competition.



The dwellings have been conceived by means of a typological 3 m square module, an industrialised technical spine, a glass gallery and an interior patio. The building has passive energy systems for heating, ventilation, illumination and photo-voltaic panels (which deliver energy to the grid).

ManuBuild results being demonstrated

Architectural Design Methodology

This project demonstrates how to create a system in which the dwellings can follow modern lifestyles; adapting and changing according to the users' necessities. This implies the creation of flexible and adaptable spaces which allow certain variations depending on the users needs.
The EMVS has demonstrated how a survey of potential customers can be used to influence the design and distribution of different apartment types within the building.
The diagrams below show possible distributions of two bedroom apartments in the original design of the demonstration building:

Building Templates

A Building Template approach has been demonstrated, which allows the architect to have a tool to facilitate the design process. The Building Templates help the architect design a building which can be adapted to its potential End Users requirements. The idea is to allow the End User to be involved in the design process and customize his/her dwelling based on a general structure and some fixed elements (such as bathrooms), and certain restraints determined by the designing team. The End User will refer to a catalogue with a range of possible options, products etc.

Sales Office

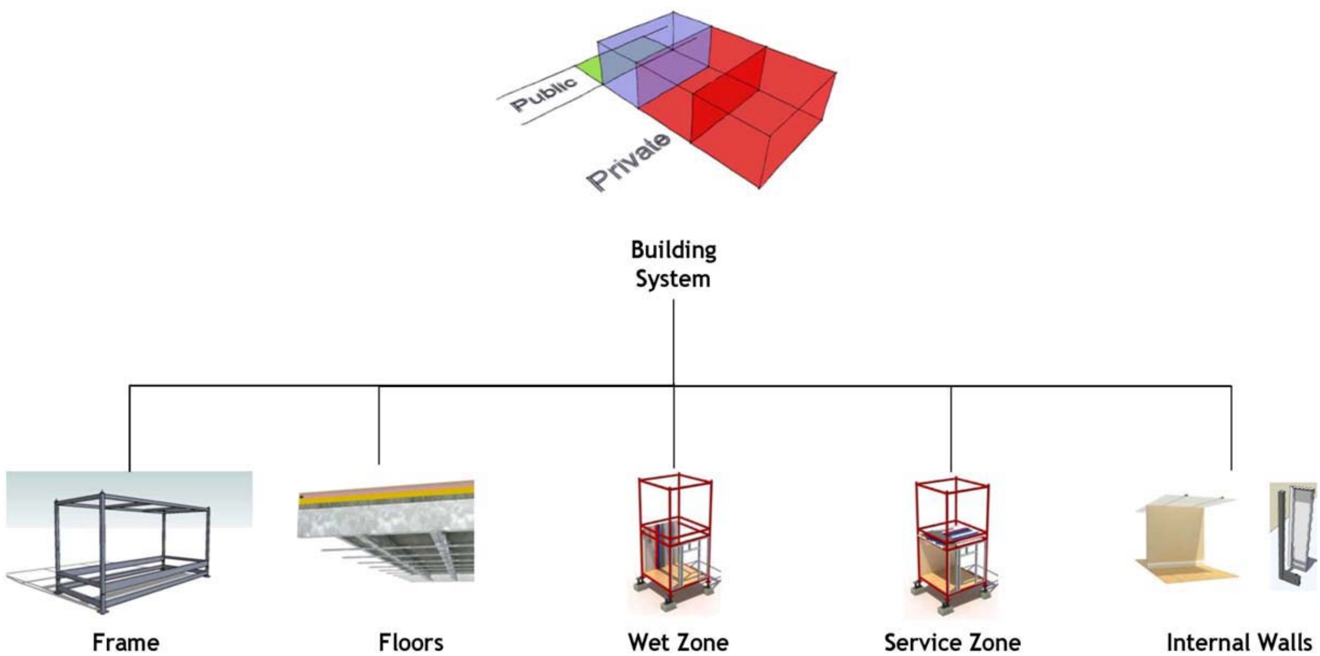
ManuBuild partners have used the Madrid development to demonstrate how a user friendly sales office software application can be used to present dwelling templates to potential customers for them to customise within a range of options.

Service Core

The objective of the Service Core is the prefabrication of one storey high vertical service nucleus. This nucleus must be custom-built according to the project, this means without giving up the designing freedom, adapting its contents, shape and dimensions to the project.
The demonstration shows that it is possible to industrialize the vertical services by moving on-site work to a factory. This results in better working conditions, a decrease in timings and a better finished final product. The service Core includes Solar Chimney pipes accompanied by lateral air ducts for every storey, two independent air extract ducts, one for the bathroom and one for the kitchen, a separate kitchen fume extract duct and rain water pipes.

Corus ManuBuild System

The penthouse levels of the Madrid buildings demonstrate the use of the Corus ManuBuild Building System. This consists of volumetric and panel modules using rectangular hollow section structural frames which support floor, ceiling and wall cassettes cold formed steel sections, insulation and building boards complete with connections and services. The modules are to be manufactured off-site complete with finishes.



References

Barcena C., González C., Leonard C. D., Claeson-Jonsson C, (2009), ManuBuild WP8 Deliverable 8.5-4 Building Demonstrations

Key ManuBuild Contacts

EMV, DRA, COR

Medium Rise Apartments in Sweden

Developed by NCC, The NCC Komplett™ system is a radically new building manufacturing system to construct high quality multi-storey apartments in a factory based on the customer's requests. This system allows building houses in half the time and to a lower cost compared to ordinary construction methods. The approach takes a radical step – the step into the factory with the construction industry having to familiarize itself with concepts such as just-in-time, modularization and lean production.

Many of the concepts that NCC have developed and implemented into this system go very well with the building manufacturing principles that we are working on in ManuBuild. An NCC Komplett™ building is therefore the ideal setting for demonstrating a number of the tangible ManuBuild results.

The first apartment building that was built in the house manufacturing plant of NCC is a four-storey residential building with four apartments on every floor, erected in the center of Hallstahammar for the public utility organization.

ManuBuild results being demonstrated

Architectural Quality

In this demonstration building, the architectural values inherent in building manufacturing has been demonstrated and evaluated (using the six design values approach).

Partition Walls

An opportunity was taken to install two examples of the innovative Fibre Reinforced Polymer partition walling system developed by Mostostal. The partition components were prefabricated in Poland to dimensions in the NCC building model. The components fitted without modification in less than 45 minutes per complete partition, including doors and frames.

Building Templates

The apartment design was converted into a template to demonstrate how an end user could configure a new partition in their apartment using Design and Sales Office configurators.

Design for manufacture and assembly

The different components and modules, including connections and interfaces, have been designed for manufacture, logistics and assembly. It has also illustrated the use of plug-and-play components.

Multi-functional material

The demonstration building consists of components made from high-performance concrete, a material exhibiting excellent characteristics regarding drying time, strength, casting properties, durability etc. Furthermore, the Mostostal panels are made of FRP.

Tolerance analysis

The building was manufactured and assembled to a tolerance of ±1 mm. This building demonstrates that this accuracy can be routine. An appraisal of the building tolerances has been undertaken. This work emphasised the importance and consequences of controlling tolerances.

End user review

The purpose of this study is to analyze the impression the end-users have of the NCC Komplett™ building. Which qualities do they see and are there any deficits? Important questions addressed by this study are:

- Has this had an effect of industrialization on housing and accommodation?
- Do recent approaches to industialised housing overcome the negative image from the 1950s and 1960s?
- Undertake a tenant survey and architectural critique of the building, based on the six design values:
  - Beauty
  - Functionality
  - Durability
  - Suitability
  - Sustainability
  - Buildability
- The tenants were asked to comment on the impression and usability of the spaces in the building:
  - Building entrance and lobby,
  - Building staircase and elevator,
  - Apartment entrance and hall,
  - Verandas and balconies,
  - Kitchens and fittings,
  - Dining areas,
  - Living rooms,
  - Storage rooms and cupboards,
  - Bedrooms,
  - Bath and laundry rooms.

Overall, the outcome of the survey was very positive and it showed that the efforts to design for living paid off.

References

Barcena C., González C., Leonard C. D., Claeson-Jonsson C, (2009), ManuBuild WP8 Deliverable 8.5-4 Building Demonstrations

Key ManuBuild Contact

NCC

ManuBuild Consortium

The ManuBuild consortium consists of 22 partners from 8 different European countries (Finland, Germany, Hungary, Poland, Spain, Sweden, Netherlands, and the United Kingdom)

ManuBuild Consortium

COR:	Corus Group www.corusgroup.com (Coordinator)	corus
VTT:	VTT Technical Research Centre of Finland www.vtt.fi (Technical Coordinator)	VTT
DRA:	Dragados S.A. www.grupoacs.com	DRAGADOS
EMV:	Empresa Municipal de la Vivienda, SA. www.emvs.es	emvs madrid Empresa Municipal de Vivienda y Suelo Área de Gobierno de Urbanismo, Vivienda e Infraestructuras
FCC:	FCC Construcción S.A. www.fcc.es	GRUPO FCC
FHG:	Fraunhofer Institut für Arbeitswirtschaft und Organisation www.iao.fraunhofer.de	IAO Fraunhofer Institut Arbeitswirtschaft und Organisation
MOW:	Mostostal Warszawa S.A. www.mostostal.waw.pl	Mostostal
NCC:	NCC Construction Sverige AB www.ncc.se	NCC
TWC:	Taylor Woodrow Construction Ltd. www.taylorwoodrow.com	TAYLOR WOODROW
YIT:	YIT Construction Ltd. www.yit.fi	YIT
CA3:	Universidad Carlos III de Madrid www.uc3m.es	

CIR:	Construction Industry Research and Information Association (CIRIA) www.ciria.org.uk
CON:	Consolis Oy Ab www.consolis.com
ESL:	Enterprixe Software Ltd. www.enterprixe.com
GST:	Graphisoft R&D Rt www.graphisoft.com
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IVF:	Swerea IVF www.swereaivf.se
LAB:	Fundación Labein www.labein.es
TNO:	TNO Building and Construction Research www.bouw.tno.nl
TUM:	Technische Universität München www.bri.ar.tum.de
UOS:	University of Salford www.salford.ac.uk
UST:	Institut für Arbeitswissenschaft und Technologiemanagement (IAT), University of Stuttgart www.iat.uni-stuttgart.de

*Manu*Build
Open Building Manufacturing
System Handbook

edited by:
Abdul Samad Kazi, Jochen Eichert 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.

This open building manufacturing system handbook showcases some of the key findings from the industry led ManuBuild project. ManuBuild's 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. This system handbook's contents include:

- Methods for the design and specification of open building manufacturing
- Products for open building manufacturing
- Manufacturing methods and techniques for open building manufacturing
- Business models and processes for open building manufacturing
- IT system architecture and tools for open building manufacturing
- Training solutions for open building manufacturing
- Open building manufacturing demonstrators

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GRUPO FCC
IAO
Fraunhofer Institut Arbeitswirtschaft und Organisation
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