# A Modular Construction System. How to design its Production Process

**F. van Gassel**, M. Roders
Technische Universiteit Eindhoven
PO Box 513, 5600 MB Eindhoven, The Netherlands
f.j.m.v.gassel@bwk.tue.nl

**KEYWORDS**

Modular Construction, Adaptable Building, Decision Support Tools, Design Management

**Abstract**

One type of architectural construction is a modular building. Specific requirements may motivate clients to opt for a modular building. However, designing such a system is a highly complex process and demands a systematic approach. This paper presents a brief introduction to this field of design management.

**Introduction**

When acquiring a new building, clients sometimes have specific demands, such as a short delivery lead time, a particular location, special financing or limited duration of use. In most cases, they opt for an adaptable building based on a modular construction system. The designer and builder of such a system have to bear these specific demands in mind. Moreover, they encounter the following challenges:

- There is no personal client, but a largely poorly defined market.
- The establishment of a production plan involves a substantial number of assumptions.
- The term for the amortisation of mechanising or robotising investments is unknown.
- The client and society want safe, sustainable and attractive buildings, not a semi-permanent solution.

To manage these challenges during the design process can be one of the tasks of the (architectural) design manager. Gray (2001) describes the task as follow '*to make sure that the organization of the design process is structured appropriately for the task at hand, and to ensure that there are sufficient integrative and co-ordinating mechanisms for the work to progress meaningfully*'. We think that in future one of the tasks of the design manager will also be to design the production process. Especially by modular building objects may play this an important role. The design scope of such objects includes long-term views and the involvement of a wide-range of design expertise. Also the influence of the client is important.
A method for the builder to design a modular construction system would be useful. This paper proposes one such method, which is based on the experience gained by the first author in designing three different Dutch modular construction systems.

**Modular construction system**

The Modular Building Institute (MBI 2006) defines modular construction as a method of construction that '*utilizes pre-engineered, factory-fabricated structures in three-dimensional sections that are transported to be tied together on a site*'. This definition, however, focuses solely on the production and form of prefabricated parts. Modular construction involves much more. In this paper, modular construction is characterised by the following (Van Gassel, 2006):

- Modular construction involves modular parts assembled in the factory, transported by road and installed on the building site to create a modular building.
- Modular parts have established grid dimensions.
- Parts just small enough to be transported by road are called modules.
- The modular buildings are assembled, transported and installed by specially trained professionals.
- The modular parts are connected using convenient dry-point and like connections.
- The components of the modular parts and modules are kept in stock at the factory.
- The point at which an order can be broken down into its individual components precedes the assembly of modular parts.
- Modular parts and modules are manufactured according to customer specifications.
- A modular building can be taken apart and then reused to create the same or another type of building.

See Figure 1 for a production scheme.

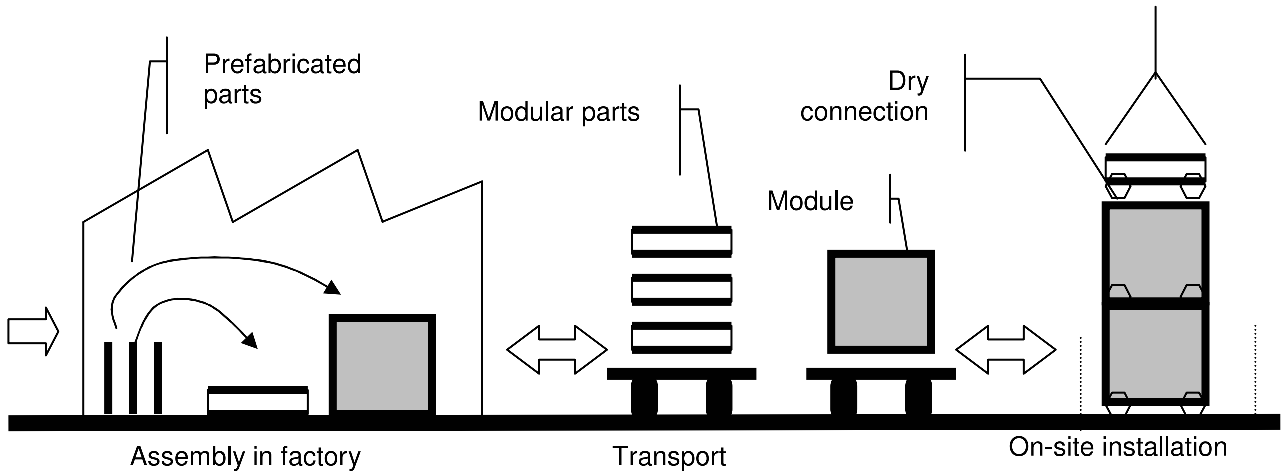


Figure 1. Modular construction system production scheme.

All over the world, modular builders have developed their own systems, based on the needs of their clients and on their own production skills and facilities. See Figure 2 for some examples.

Figure 2. Examples of modular construction systems.

**A design method for the builder**

When designing a modular construction system, a modular builder has to manage four processes, viz. market research, product development, production and sales. The method ensures that those designing the four processes constantly exchange information and feedback. The process designers should work together, taking a multidisciplinary approach. Feedback tools make sure that co-operation runs as smoothly as possible.
This paper only addresses the production process perspective of a design method. The method's description will consist of two parts: the structure and the content.

*Method's structure*
Three design feedback tools are developed:
- *an object tree*: a structured description and detailed explanation of the system
- *a guideline*: a four-step system analysis approach
- *a ranking system*: definition of the decision-making criteria and of the qualitative levels, presented as a coloured filter

The object tree schematically presents the interrelationship of all building parts and shows where the parts will be assembled. See Figure 3. The diagram resembles a 'product-tree' with boxes representing the building parts. Individual components are presented on the lower end of the object tree. Higher up, the modular parts resulting from the assembly of individual components are presented. Even higher, the modular parts are combined into a three-dimensional object. This can be part of the resulting building, a building module or the completed building itself. The assembly locations are categorised as: assembly at supplier, assembly at the factory or on-site assembly.

A step-by-step guideline is used to monitor the entire design process involved in creating the modular construction system. It takes into account the limitations of each of the four processes determining the modular building's design.

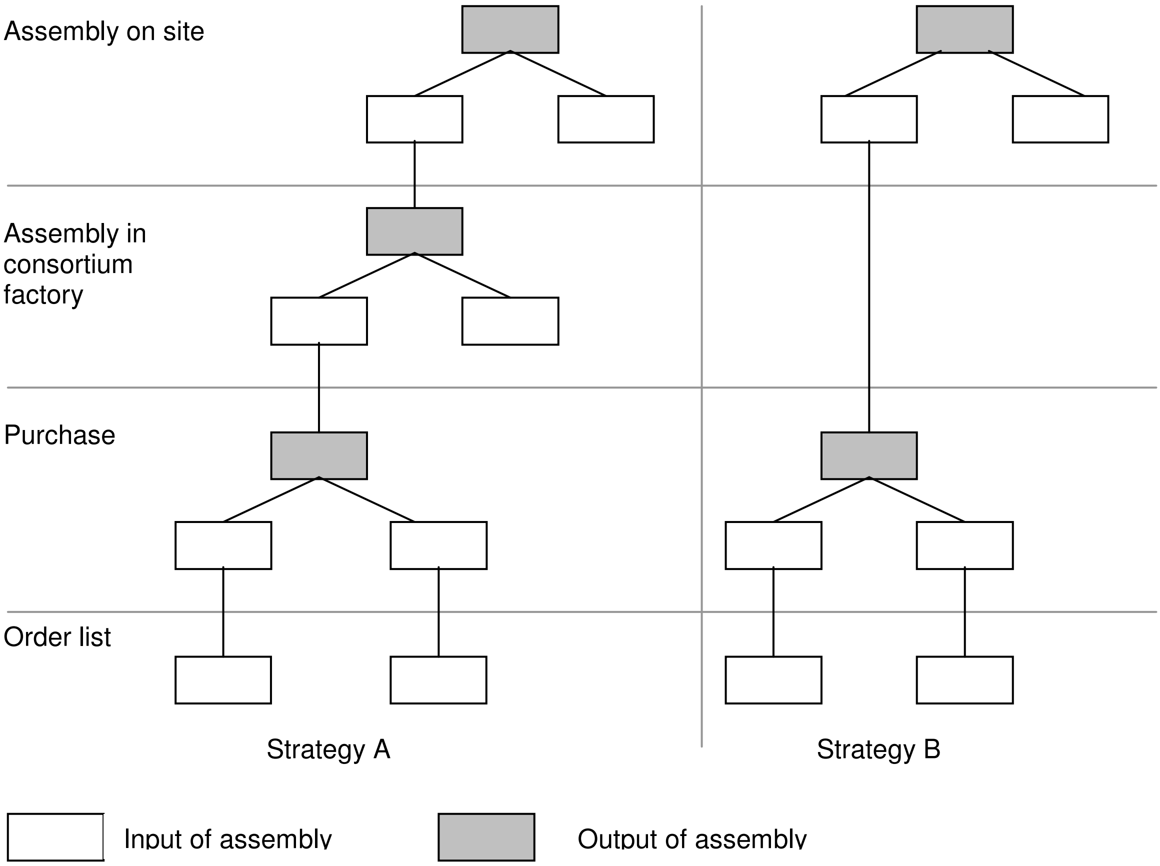


Figure 3. Two object trees. The configuration depends on the production strategy.

Each step of the guideline is divided into four parts:

- Part 1: input – the limitations that the final product must bear in mind
- Part 2: process – the elaboration of all input parameters
- Part 3: output – the changed product model
- Part 4: evaluation – a check is performed to confirm whether the output model takes all limitations into account.
  If the evaluation is positive, it will be necessary to determine whether the output model also takes into account the limitations identified in the previous steps. If this check is positive as well, the product continues to the next step. If the product fails one of the checks, it has to be modified as part of the current step or by going back to an earlier stage of the process and continuing from there.

See Figure 4.

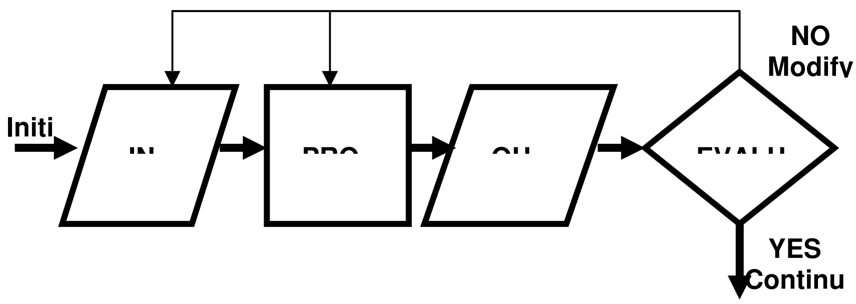


Figure 4. Description of a basic step.

In addition, a decision tool is created. This tool is actually a ranking system designed to be superimposed on the object tree. Coloured fields (i.e. filters) correspond to the assembly location level. The colour codes represent:

- red: The boxes in the red field will negatively impact the production system and should be placed in another assembly location.
- yellow: The boxes in the yellow field will have a neutral impact on the production system. Replacement is not necessarily required.
- green: The boxes in the green field positively impact the production system. As many boxes as possible need to be placed in this field.

The six criteria to be decided are on-site construction time, costs, on-site labour, transport risks, dimensions with respect to transport and freedom of choices for the client.

*Method content*
Different priorities and criteria can be defined as part of the method's structure. This may vary depending on the modular builder's strategy. For example, achieving the highest level of cost-efficiency and industrial production may be the top priority, while fulfilling the needs specified by clients may be less of a priority. For this research, we opted for a 'mixed' strategy, striking a balance between freedom of individual choice and optimising industrial production.

The market research, product development, production and sales processes each have their own priorities and limitations that the resulting construction system must bear in mind. In four steps, the method decreases the solution spaces. The descriptions or the decisions to be taken within the steps include:

- Step 1: Production typology (from traditional to industrial construction processes)
- Step 2: Client choices (from such production strategies as pure, segmented or customised standardisation to tailored or pure customisation)
- Step 3: Client choice (levels such as construction, shell, installation, infill or finishing)
- Step 4: Production systems (flow, job-shop)

(Van Gassel and Roders, 2004).

## Discussion

Some researchers already developed some types of methods to design building products, such as Quality Function Deployment (QFD) (Sarlemijn, 1995), Lichtenberg (2002), Austin et al (2001), Oostra (2001), Van den Thillart (2002) and Rutten (2004). These methods are mainly focused on the needs of the clients.
The method described in this paper is more based on the characteristics of modular construction.

## Conclusions

Modular builders develop building systems, elaborating on their market and production experience with other systems or building products already included in their portfolio. This reduces the risk of failure. They rarely begin from scratch. One of the pitfalls of this approach is that a building system may be developed that will compete with another of the modular builder's own systems. The application of the design method can reduce this risk by increasing the transparency of a large number of choices and by improving communication with others.

**Acknowledgements**

We would like to thank PRC Bouwcentrum in Delft for the commission to develop this method as part of the IFD Buildings European study project. Special thanks goes to Geert-Jan van den Brand for his guidance and support.

**References**

Austin, S, et al (2001) Design Chains. A handbook for Integrated Collaborative design. Loughborough University, UK.
Gray, Colin & Will Hughes (2001) *Building design management*. Butterworth Heinemann.
Lichtenberg, Jos (2002) *Ontwikklelen van projectongebonden bouwproducten*. Datawyse boekproducties, Maastricht.
MBI Modular Building Institute, Charlottesville, USA. Source: http://www.mbinet.org/About/Defined.aspx. Last viewed on 20 January 2006.
Oostra, Mieke (2001) *Componentontwerpen. De rol van de architect in productinnovatie*. PhD thesis Delft University of Technology, the Netherlands
Rutten, Maarten (2004*) Ontwikkelen van fotovoltaïsche bouwproducten: een leidraad voor betere aansluiting op behoeften van gebruikers*. MSc thesis TU/e, the Netherlands.
Sarlemijn, A and Henk Boddendijk (1995) *Producten op maat. QFD als gids bij productcreatie*. Boom, Amsterdam.
Van den Thillart (2002) *Customised Industrialisation in the Residential sector. Mass Customisation modelling as a tool for benchmarking, variation and selection*. TU Delft.
Van Gassel, Frans & Martin Roders, (2004) *IFD Buildings, Production Design Feedback Model*. A UCB report for PRC Bouwcentrum. Delft, the Netherlands.
Van Gassel, Frans, (2006) *Modular Construction*. ARKO In print.