 ISBN 978-84-88734-06-8

INTERFACE DESIGN FOR OPEN SYSTEMS BUILDING

Nijs, Jochem C.; Durmisevic, Elma & Halman, Johannes I.M.

Construction Management & Engineering.

University of Twente.

The Netherlands

ABSTRACT

Open Building and IFD (Industrial Flexible Demountable) building are philosophies that aim to create high quality buildings with increased flexibility and better environmental characteristics. However, a successful adoption of IFD principles has not yet occurred because of concerns for the types of connections that are needed between building components. Therefore, this paper describes PhD research at the University of Twente that has the objective of designing a typology of flexible interfaces for IFD building that can be widely applied in the construction industry and aims to standardize connections, at the various levels of technical composition of a building, to create compatibility between building products from different suppliers. Such a typology of interfaces will increase the re-use and recycling of building parts, resulting in the increased sustainability of the building process. Furthermore, it will help accelerate the industrialization of the housing industry and mass customization of housing. A preliminary case study, in which a sustainable, flexible bathroom is designed, illustrates the various types of interfaces that can be applied, based on existing research.

Keywords: Interface Design, Open Systems Building, IFD Building, Interface Typologies, Sustainable Building.

INTRODUCTION

The philosophy of Open Building suggests that a building is composed of different environmental levels, each with a certain lifespan. Ideally, independency between these levels is required, which achieves that building levels can be adapted separately, resulting in more freedom to *change*. Options to realize the ambitions of Open Building have been researched extensively (Brouwer & Cuperus, 1992; Cuperus, 1998; Kendall & Teicher, 2000; Cuperus, 2003; Habraken, 2003; Kendall, 2004; Durmisevic, 2006). In the Netherlands, the IFD (Industrial Flexible Demountable) concept has been introduced as a technique to create buildings with a higher quality, more flexibility and with better environmental characteristics. IFD is as an application of the Open Building philosophy (van Gassel, 2003; Scheublin, 2005; Durmisevic, 2006).

However, notwithstanding its clear advantages, the successful adoption of IFD principles has still not occurred. One of the main problems is the type of connections that are needed between building components. Therefore, this paper describes proposed PhD research at the University of Twente that aims to design a typology of flexible interfaces that can be widely applied in the construction industry and aims at the standardization of connections, at the various levels of technical composition of a building, to create compatibility between building products from different suppliers. This is achieved by applying methods from the field of Industrial Design Engineering. A compatible set of interface configurations will boost the industrialization of the housing industry and mass customization of housing.

First, the proposed research method for the four year PhD research will be described. Second, as an illustration of the proposed research, the design of a sustainable, flexible bathroom is taken as a preliminary case study, and discussed in this paper,

THEORY

Open Building aims to involve users in the building process and to create buildings that have increased flexibility. Habraken, the founder of Open Building, states that Open Building has two perspectives: social and technical. Firstly, the social perspective aims to respond to user preferences by offering flexibility of a building. Such flexibility makes it possible for (parts of) the building to adapt. Secondly, the technical perspective aims to divide a construction into several systems and sub-systems that can be “changed or removed with a minimum of interface problems” (Habraken, 2003) . However, applying Open Building principles in practice is challenging. Kendall explains that on the one hand it is essential to design a built environment that supports *stability*, which is important for long term community interests, but on the other hand, *change* is necessary to meet the individual preferences of users. This prompts the question of how we can plan and implement, as Kendall describes it, a “regenerative built environment” (Kendall, 2004).

If the capability to *change* is needed, a high number of options (or variants) need to be established in the house building industry. It is challenging to achieve this in a cost-effective manner in the building process. However, research indicates that applying *platform-based development* in the housing industry could achieve this (Halman *et al.*, 2008). Applying platform-based development increases flexibility in product design and increases the efficiency of product development (Halman *et al.*, 2003). However, applying a platform-based approach in the housing industry is difficult, as other studies indicate (Hofman *et al.*, 2006; Veenstra *et al.*, 2006). The proposed research in this paper aims to apply a platform-based design approach to design a typology of demountable connections for IFD building.

IFD building

A building method that aims to achieve flexibility as a key aspect in the construction industry is that of IFD building: Industrial, Flexible and Demountable building. It is a method based on the principles of Open Building and is increasingly applied in the Netherlands but also in the United States and Japan. The three aspects of IFD building are (van Gassel, 2003):

- *Industrial:* most of the construction takes place under factory conditions, compared to the conventional way of building that mostly takes place at the building site.
- *Demountable*: the connections that are made between the components of the building can be demounted, which make reuse, configuration and replacement possible.
- *Flexible*: the building is designed with the facility to make changes at the various levels of technical composition of a building.

One of the OBOM initiatives - "The Building Node Research Project" (Cuperus, 1998) - mentioned that the industry has to aim to agree on *a set of connection conditions for building parts*. The aim was to come up with building components that can be designed by different companies, while maintaining a certain type of standard, resulting in the mutual compatibility of components. To develop such a system, it is important to separate the functions of systems and subsystems so dependencies between components will be decreased (Brouwer & Cuperus, 1992). This is important for achieving flexibility. Figure 1 (left) shows the various levels of a building. The right diagram shows the hierarchy of the functional and technical decomposition of a building into independent systems and subsystems. The displayed composition is the ideal situation of a building in which every building function corresponds to an independent part of a building (Durmisevic, 2006).

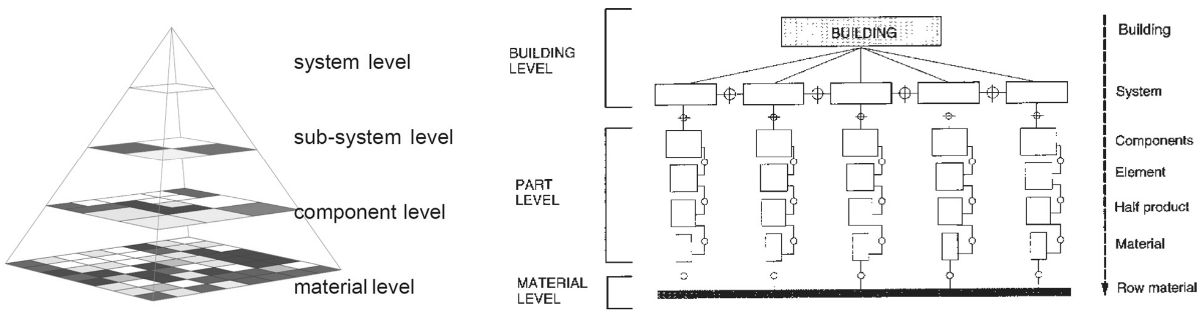

Figure 1: *The composition of different levels in a building (left) and the ideal situation in which every system is independent (right) (Durmisevic, 2006)*

Extensive research in the field of Open Building was performed by members of the OBOM group (van Randen, 1976; Brouwer & Cuperus, 1992; Cuperus, 1998; Durmisevic, 2006). Their research all stresses that a building must have the ability to adapt in response to changing circumstances. However, to realize flexibility, the connections between building components (called *interfaces*) also have to be adaptable. In research on flexible connections, Durmisevic defines two key criteria that determine the performance of a building configuration with respect to disassembly at connections: independency and the exchangeability of building components. The level of independency is determined by the functional decomposition of a building, while the level of exchangeability is determined by technical and physical decomposition (Durmisevic, 2006). Also, research has been conducted on the actual connections (or joints) between building components: Olie created a so-called "typology of joints" that supports sustainable development in building (Olie, 1996).

However, a uniform set of connections that can be applied by different manufacturers in the construction industry and aims at IFD building, is not yet available.

METHOD

The objective of the proposed PhD research as presented in this paper is to develop a typology of interfaces for the building industry that can be applied in IFD building which improves mass customization and industrialization of the building industry. In this context, an interface is defined as a common boundary or interconnection between systems. In the case of a building, the interconnections will be the joints that hold together the different parts (or building blocks) of the structure and which separate the different functions of the building. A typology is defined as a systematic classification of types that have common characteristics. Therefore, a typology of interfaces can be considered as a set of joints. From the research objective, the following research questions are derived:

1) *Theory:* What are existing interfaces in the construction industry?
    i. To what extent are these interfaces applicable for IFD building?
    ii. How can these interfaces be best arranged in a typology, taking IFD building as a criterion?
2) *Design:* How can interface typologies and interface configurations be designed for IFD building that are broadly applicable in the construction industry and aim to achieve mass customisation and industrialisation of building processes?
3) *Application:* How can the designed interfaces be applied and tested in the building industry?
4) *Reflect:* i. What are the improvements, limitations and applications of the designed interfaces? *(Conclusions)*
    ii. How can the limitations for further implementation be minimized, by improving the design? *(Recommendations)*

The three questions will be answered by dividing the research project into four phases, each with its own focus. Figure 2 shows the project schematically.

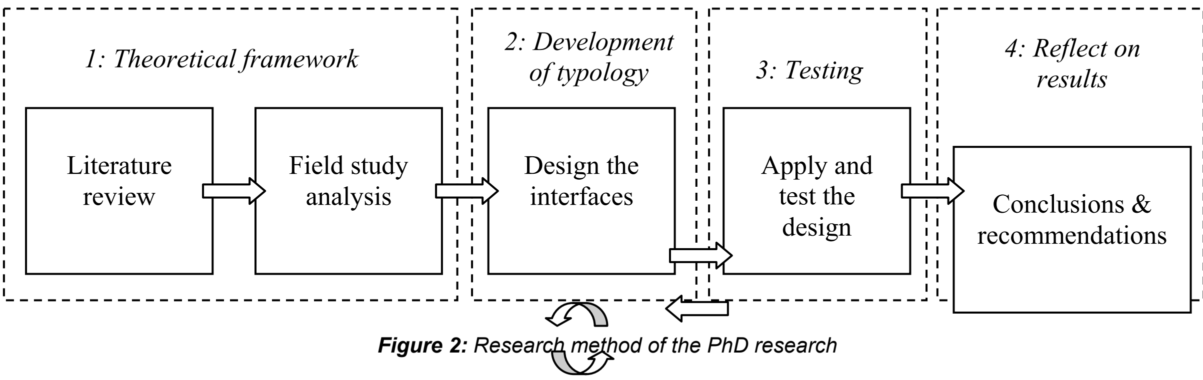

Figure 2: *Research method of the PhD research*

In the first phase, a theoretical framework will be built by reviewing the literature and conducting a field study analysis. The literature review is concerned with the research fields of Open Building, IFD building, joints, Industrial Design methods and Product Platforms. The field study analysis will be conducted by interviewing experts: both academics in the previously mentioned research fields, as well as construction companies that already apply the principles of Open Building and IFD building. The interviews in the field study analysis will complement the literature review, together creating a thorough theoretical framework.

Using the theoretical framework, in the second phase, different interface typologies and configurations will be designed. The deliverable of this phase is the design of a compatible set of interfaces at various levels of technical decomposition that can be widely applied in construction industry and conforms to IFD building principles. The design process is iterative and includes feedback from several construction companies throughout the process, hereby optimizing the design. This design will be presented as a detailed 3D CAD model, ready to be manufactured as a prototype.

In the third phase of the research, the design of the set of interfaces will be manufactured as a set of prototypes and tested at a test building site at the University of Twente. The application of the prototype will function as a test case, providing data about the functioning of the design. Again, companies will participate in this phase and give feedback. The result will be a working prototype which will lead to a set of conclusions and recommendations for the design in the fourth and final phase of the research.

Research will be conducted in close collaboration with several construction companies in the region of Twente, the Netherlands. The participating companies are members of a working group called IDF (Industrial Sustainable Flexible building) which focuses on IFD building. The participating companies are: 4D Architects, Winkels Techniek, de Woonplaats, Raab Karcher, Plegt Vos, van Dijk Groep, Hodes Bouwsystemen, de Groot Vroomshoop and Twinta. These companies are mostly construction companies, but also include housing associations, suppliers, installation companies and architectural firms. The research results will be applied in several of the participating companies.

To kick off the PhD project, a small pilot project was conducted, functioning as a preliminary case study for the research. In this project, a sustainable and flexible bathroom was designed as an illustration and clarification of the proposed research.

PRELIMINARY CASE STUDY

A case study was performed for the local district water board “Waterschap Regge en Dinkel” (WRD) in Twente, in the Netherlands. The requirement was to design an adaptable (and therefore flexible) bathroom that would also be sustainable by saving both water and energy. The project was executed in collaboration with two Masters Students in Architectural Building Component Design & Engineering at the University of Twente.

In the literature, several models are available that decompose a building into different levels. An example is the model developed by Duffy that defines a building through four different levels in terms of the so-called four S’s: *Shell, Services, Scenery and Set* (Duffy & Myerson, 1998). This model is shown on the left in Figure 3. Another systematization of building levels is the model developed by Brand which distinguishes six levels: *Site, Structure, Skin, Services, Space Plan and Stuff* (Brand, 1995). This model is shown at the right of Figure 3.

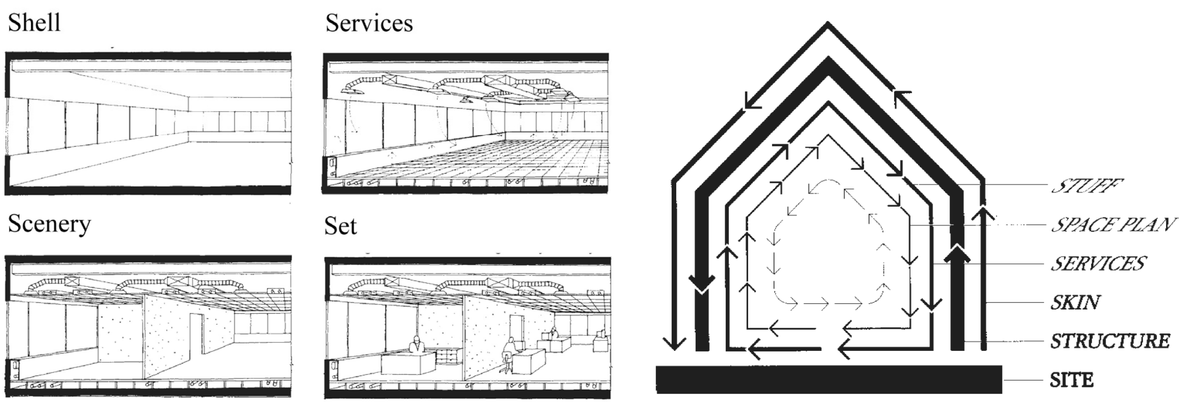

Figure 3: *Duffy's model (Duffy & Myerson, 1998) at the left and Brand's model (Brand, 1995) at the right*

Both Duffy's and Brand's models indicate that different levels of a building have different life spans. In conventional building, levels often overlap in functionality. If flexibility is to be achieved, it is necessary to design every level apart from one another. By doing this, conflicts of interfering level properties do not arise. Such separation of functionalities per level is applied in the design of the bathroom in the preliminary case study.

To help indicate the levels of the bathroom, the models of both Duffy and Brand were combined. This resulted in the following set of levels:

- *Shell:* this is the building in which the bathroom will be located; it is defined as the walls and floors of the building.
- *Structure:* this is the structure that holds together the bathroom; in this case the aluminium frames placed against the wall and the blocks on which the floor will be laid.
- *Services:* these are the technical components, such as piping, electrical wiring and ventilation ducts.
- *Scenery:* these are the covering of the walls and the floor with tiles.
- *Stuff:* these are the appliances such as the toilet, shower and sink.

Interfaces

The different levels of the building are connected with each other by means of *interfaces*. If flexibility is to be achieved, the interfaces have to be demountable. The research published by Durmisevic proposed a classification of seven different connections, ordered from fixed to flexible. Figure 4 shows the different principles behind these seven connections (Durmisevic, 2006). These will be used to illustrate the possible interfaces in this case study.

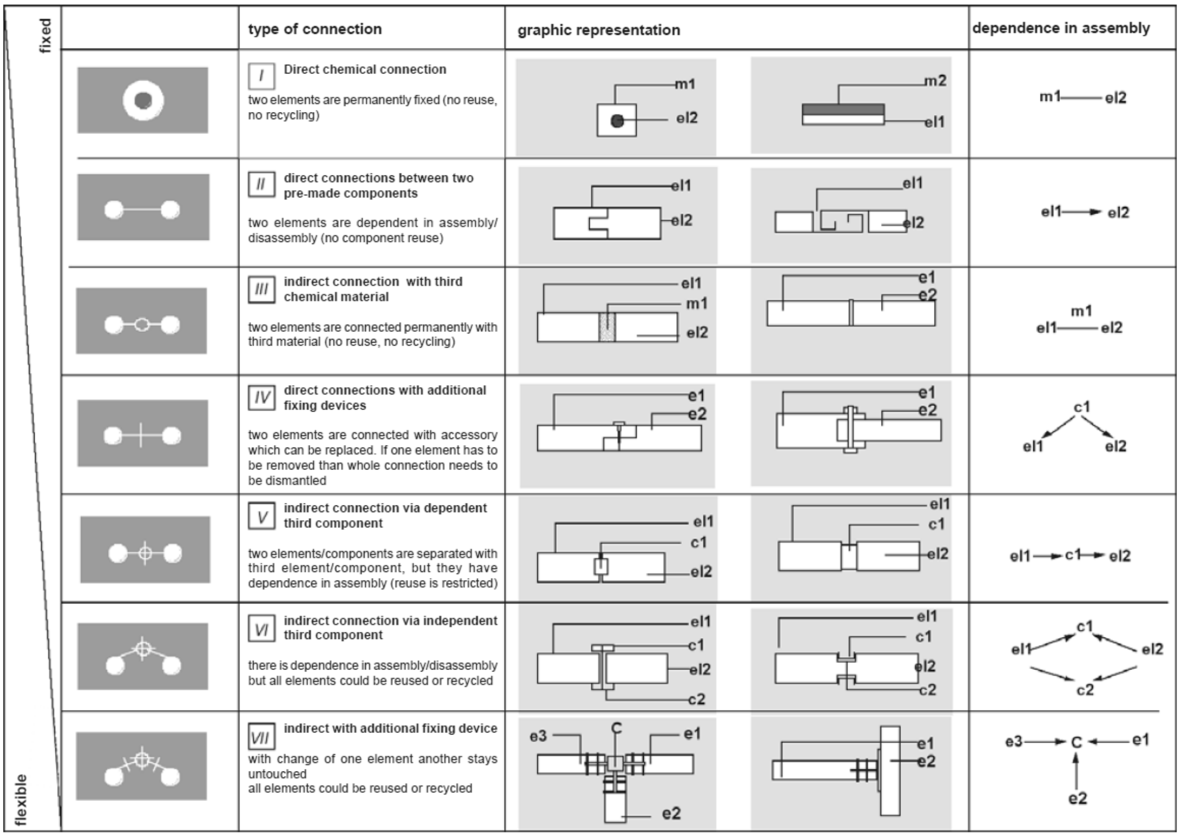

Figure 4: *Seven principles of connections, ranged from fixed to flexible (Durmisevic, 2006)*

Design

The new bathroom design consists of different levels, with each level providing an individual function. This offers a flexible design because changes can be made per level. Figure 5 shows the design and illustrates the different levels, following the combined models of Duffy and Brand. The interfaces between the levels of the design are demountable, thereby offering flexibility. In Figure 5, the *shell (1 & 2)* of the bathroom consists of the walls and floor of the building in which the bathroom will be realized. The *structure* of the bathroom consists of aluminium frames *(3)* and small blocks for the floor *(4)* that form a pattern. The *services,* such as piping and electrical wiring *(5),* are mounted within the aluminium frames, as well as the tubing for the floor heating *(6)*. The *scenery* of the bathroom consists of wall tiles *(7)* and floor tiles *(8 & 9)*. Finally, *stuff (10)* represents the bathroom appliances such as the toilet, shower and sink.

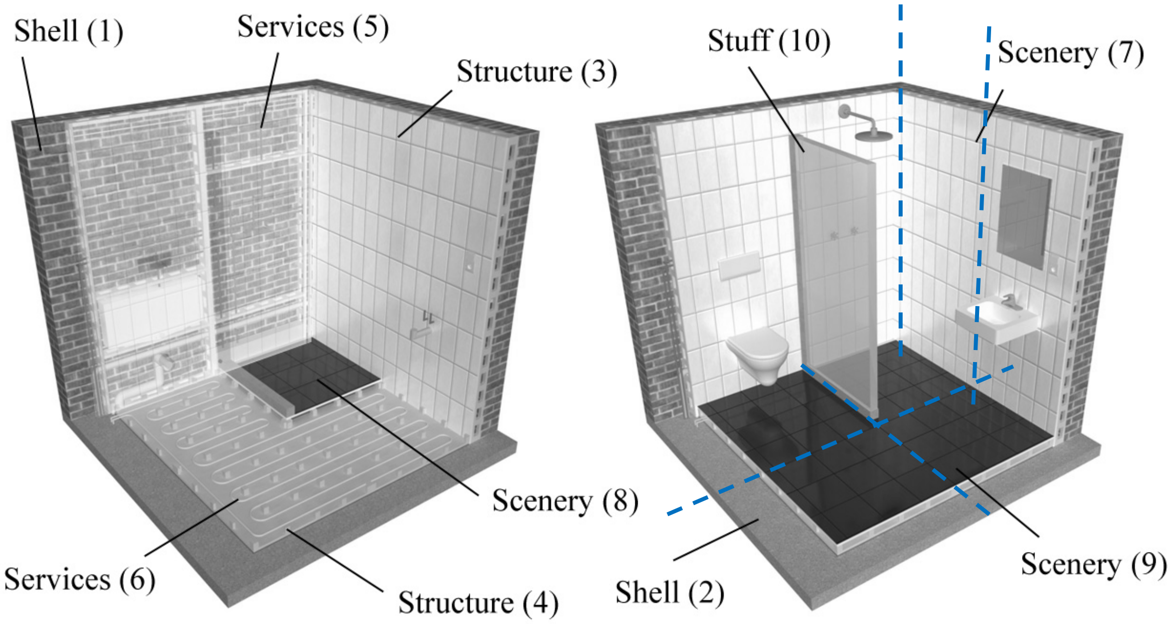

Figure 5: *The design of the sustainable and flexible bathroom of the pilot project (images by Guus Rammeloo)*

Modules & interfaces

The basis for the design is a combination of modules. This is shown in Figure 6. At the left, an exploded view of a wall module developed by an architectural firm in Amsterdam (4D Architects, 2009) and at the right a floor module that was designed during the pilot project (at the right), are shown. Again, the levels indicated in the figure. Both modules have fixed dimensions and can be seen as building blocks out of which a bathroom can be built. In the bathroom, four wall modules and four floor modules were used (see the dotted lines in Figure 5). Every wall module has space for one appliance (indicated by the level *stuff*). For every bathroom appliance, a wall module is available. By using demountable piping and applying a common height for *services*, it is possible to create a bathroom by placing several modules next to each other. In Figure 6 (at the right) it is shown how a floor module is composed. In this particular module, space is used for the drainage (the brown pipe) at the side of the module. Also, the blocks are shown that form the *structure* on which the floor tiles (*scenery*) lie. These floor tiles are prefabricated plates and can be demounted from the structure of the module. This demountability provides the opportunity to access the services later on, but without damaging the module.

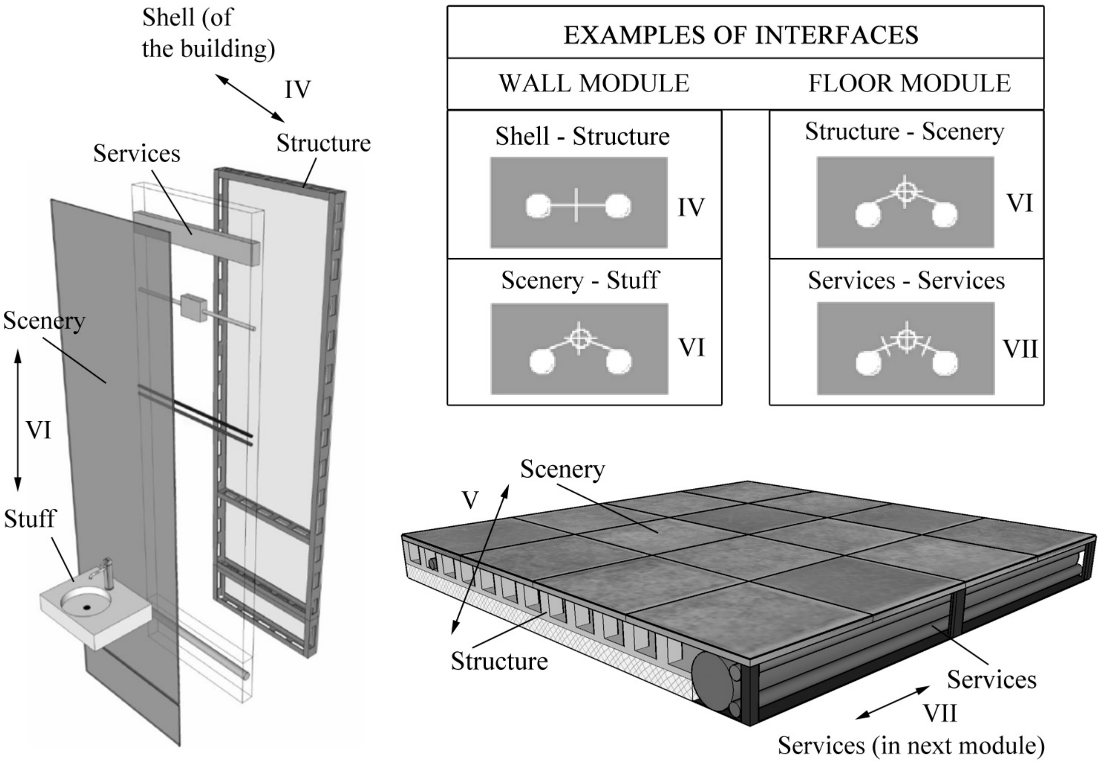

Figure 6: *The wall module at the left (4D Architects, 2009)and floor module (at the right) of the bathroom and examples of interfaces between levels of the modules (upper-right)*

The table at the top-right in Figure 6 shows several configurations of how different levels of the modules can be connected. Two examples are given for the wall module, as well as for the floor module. These examples indicate where the interfaces occur and how they can be applied. The illustrated interfaces are examples, but can also consist of other types of connections. They illustrate the importance of interfaces. The following examples of configurations are given:

- The *Shell* – *Structure* interface in the wall module consists of connection type IV from Figure 4. This is a direct connection with an additional fixing device such as a nut – bolt connection. Such a connection is sufficient because this interface will rarely be changed.
- The *Scenery* – *Stuff* interface in the wall module consists of a VI connection which is an indirect connection by using an independent third component such as a clamp or click connection. This offers the facility to detach/replace an appliance easily.
- The *Structure* – *Scenery* interface in the floor module is a VI connection which makes the floor tiles detachable from the structure. This facilitates access to the services.
- The *Services* – *Services* interface of the floor module is a VII connection; this is an indirect connection with an additional fixing device such as a “coupling part” for the piping. It offers changing elements so they can be re-used or recycled.

Water and energy saving

Although the main focus of the pilot project was to improve the adaptability of the bathroom, sustainability aspects regarding water and energy saving also played an important role. Reducing the amount of water was a key objective for the local water district of Waterschap

Regge en Dinkel. The sketch to the left of Figure 7 shows the design of a new product; a transparent shower wall that functions as a water-saving reservoir. At the right of Figure 7, the working of the product is shown: water coming out of the shower (1), which normally goes to waste down the drain, is filtered (2) and then saved in the shower wall reservoir (3). Next, the collected water can be re-used for flushing the toilet (4). Furthermore, the shower wall aims to make people more aware of their water use because they can see through the glass wall how much water has been used. This increase in awareness is expected to encourage people to save water. Water is also stored in the floor underneath the shower, which further increases the water storage capacity.

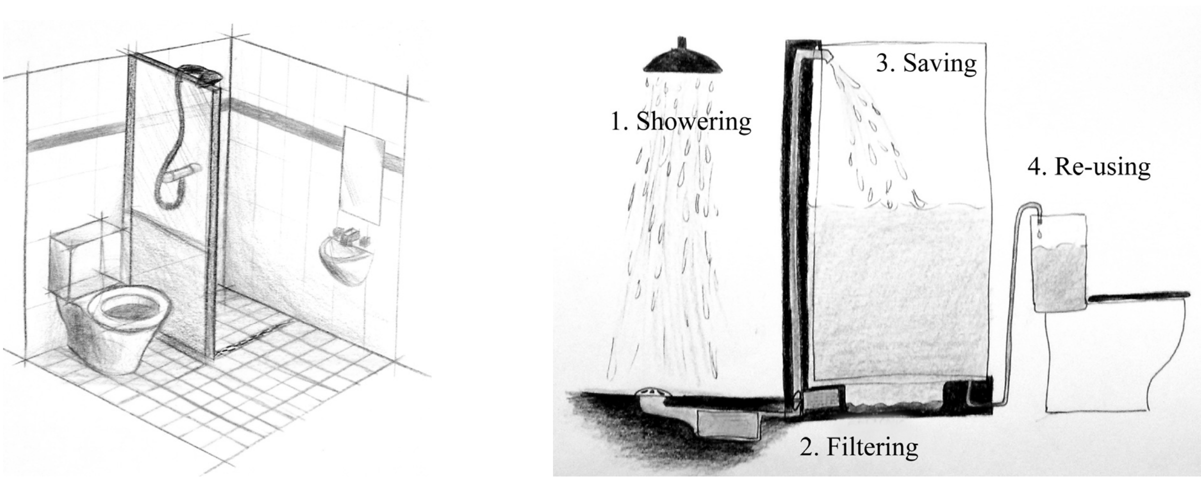

Figure 7: *The shower wall functions as a water saving reservoir (sketches by Eline Kolk)*

As well as saving water, the reduction in the required energy plays a role in the bathroom's design. This is acquired by applying a low-temperature floor heating system (as represented by the tubing in the floor in Figure 5). Furthermore, both water reservoirs in the shower wall and the floor will be filled with warm water from the shower. The residual heat in the water will then be transferred to the colder air in the bathroom, which leads to a further reduction in the energy required. Therefore, both water reservoirs function as a passive heating system.

CONCLUSION

The proposed PhD research described in this paper aims to design a typology of interfaces for the building industry that can be applied for IFD building and that will increase mass customization and industrialization of the building industry. If such a typology will be the result in the future, this will comply with Open and Sustainable Building by offering *stability* on one hand (the building consists of properly designed, strong connections) as well as *change* (the interfaces are flexible, so users can make alterations to the building). Furthermore, such a typology will increase the re-use and recycling of building parts, resulting in increased sustainability of the building process. The preliminary case study, in which a flexible and sustainable bathroom was designed, shows the importance of the interfaces between the various levels of the design of a structure. Also, it indicates how flexibility offers the potential to customize individual levels apart from each other; leading to improved opportunities for *mass customization*. In addition, the various levels can be manufactured and assembled in the factory, which makes the design *industrial*. Finally, the bathroom consists of systems and sub-systems that can be changed or removed with a minimum of interface difficulties due to the use of *demountable* connections. Undoubtedly, these properties will become increasingly important in the future of the construction industry.

FUTURE WORK

This paper has presented an overview of a PhD research project that will be executed over a four-year time span. Future work consists of conducting the research plan shown in Figure 1. Following the pilot project, future work is expected by cooperating with companies that showed an interest in the design of the bathroom. Improving the bathroom's design by specifying the flexible interface connections will be a first step. Next, the design can be tested in an experimental project.

ACKNOWLEDGEMENTS

We would like to thank Eline Kolk and Guus Rammeloo, students in Architectural Building Components Design & Engineering at the University of Twente, for their collaboration in designing the sustainable, flexible bathroom. Also we would like to thank the workplace IDF, Pioneering and Innovatie Platform Twente which make this research possible.

BIBLIOGRAPHY

- 4D Architects, IDF (Industrial Demountable Flexible) Bathroom design, Amsterdam, 2009.
- Brand, S., How buildings learn: What happens after they're built, Tennessee, Quebecor Printing, 1995.
- Brouwer, J. & Cuperus, Y., Capacity to Change, 1992.
- Cuperus, Y., De bouwknoop, 1998.
- Cuperus, Y., Mass Customization in Housing an Open Building/Lean Construction Study, Dense Living Urban Structures International Conference, Hong Kong, October 23-26, 2003.
- Duffy, F. & Myerson, J., Design for change: the architecture of DEGW, Birkhauser, 1998.
- Durmisevic, E., Transformable Building Structures: Design for disassembly as a way to introduce sustainable engineering to building design & construction, TU Delft, 2006.
- Habraken, N. J., Open Building as a condition for industrial construction, 20th International Symposium on Automation and Robotics in Construction, Eindhoven, the Netherlands, 2003.
- Halman, J. I. M., Hofer, A. P. & Van Vuuren, W., Platform-Driven Development of Product Families, Journal of Product Innovation Management, 20, (2)-149, 2003.
- Halman, J. I. M., Voordijk, J. T. & Reymen, I. M. M. J., Modular approaches in Dutch house building: an exploratory survey, Housing Studies, 23, 781-799, 2008.
- Hofman, E., Halman, J. I. M. & Ion, R. A., Variation in housing design: identifying customer preferences, Housing Studies, 21, 929-943, 2006.
- Kendall, S., Open building concepts, 2004.
- Kendall, S. & Teicher, J., Residential open building, Taylor & Francis, 2000.
- Olie, J. C. M., A Typology of Joints: Supporting sustainable development in building, Eindhoven, 1996.
- Scheublin, I. F., The drivers for adaptable building in the 21st century, 27-29, 2005.
- Van Gassel, F. J. M., Samenvatting symposium: IFD Bouwen, 2003.
- Van Randen, A., Oratie: De bouw zit in de knoop. Delft: Delftse Universitaire Pers, 1976.
- Veenstra, V. S., Halman, J. I. M. & Voordijk, J. T., A methodology for developing product platforms in the specific setting of the housebuilding industry, Research in engineering design, 17, 157-173, 2006.