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Wikberg, Fredrik; Ekholm, Anders

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LUND UNIVERSITY

PO Box 117  
221 00 Lund  
+46 46-222 00 00

## ARCHITECTURAL OBJECTS AND SYSTEMS BUILDING

FREDRIK WIKBERG, ANDERS EKHOLM

*Design Methodology, Department of Construction Sciences,  
Lund University, Faculty of Engineering*

**ABSTRACT:** In this paper we explore the concept of “architectural object” as a representation of a real “situation” involving people, behavior, experience and environment. The purpose is to define a selection of possible configurable architectural objects that reflect the variability of situations possible to achieve using an industrialized building system. The paper presents a theoretical foundation for organizing architectural objects in a level order of design in different levels. It is applied to configure building projects in a company with off site production of volume elements, and proposes how these objects could be developed into architectural objects.

**KEYWORDS:** Architectural object, situation, design, configuration, decision levels

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**ABSTRACT :** Dans cet article, nous explorons le concept d'« objet architectural » comme représentation d'une vraie « situation » impliquant gens, comportement, expérience et environnement. Le but est de définir une sélection d'objets architecturaux configurables qui reflètent la variabilité des situations réalisables avec un système industriel de construction. L'article présente une base théorique pour ordonner les objets architecturaux selon différents niveaux de design. Cela est appliqué à la configuration de projets de construction d'une entreprise ayant de la production de volume hors site afin de voir comment ces objets pourraient être développés en objets architecturaux..

**MOTS-CLÉS :** Objet architectural, situation, design, configuration, niveaux de décision

## **1. INTRODUCTION**

### **1.1. Demands for industrialization of the building industry**

The building industry, in Sweden and internationally, has not shown the same development in productivity and industrialization as the manufacturing industry and the sector has been criticized for quality failures and high costs (ECTP 2005; Egan 1998). An industrialization of the industry has been pointed at as a measure of meeting these problems (Bygghälsan 2002). Different strategies have been developed in order to make the industry more efficient (Lessing 2006). Off-site manufacturing and systems building has a long tradition (Gann 1996), while Strategic partnering (Miles 1996), Lean construction (Berthelsen 2004), and BIM (Eastman 1999) are recent developments with this purpose.

This study is specifically directed towards the development of BIM technology for architectural design in the context of systems building.

### **1.2. Background, problem, and objective**

The shift from drafting oriented CAD to object oriented CAD enables new ways of managing and structuring design information (Eastman 1999). The development supports not only 3D-visualization and production of drawings, but also BIM, Building Information Modelling, to be used for simulation, calculation, and information retrieval. The resulting building models are not only intended for use during the design phase, but also during production and facility management.

Modelling of buildings based on their constituent technical parts is supported by today's object oriented design tools. However, architectural design involves both user activities and the built environment (Ekholm 1987). Therefore it would be of interest to investigate the possibilities to include user activity modeling as part of BIM. In this article we discuss the possibility to represent real world use cases, or situations, as architectural objects in a BIM environment, specifically applied to configuration of house-building projects. Situations are socio-technical systems that emerge during man's use and experience the built environment. Architectural objects are representations of such situations in a software environment (Ekholm and Wikberg 2008). See also definitions in Section 2.

### **1.3. Aim of this paper**

This article deals with the theoretical foundations for the use of architectural objects in a BIM environment. It also presents a case study of building design using the Open House house-building system, analyzing the possible architectural object structure and how it may be applied to configure a building project. The study identifies the relations of parts of the building system to situ-

ations in different levels of the built environment. The chosen situations are used in normal architectural practice as design units for building design decisions.

The aim is to develop principles for a design tool where a designer may work with architectural objects rather than building elements as design units, but simultaneously adhering to the restrictions implied by the building system. The result would be similar to a configurator, i.e. an application where a product may be designed taking into account the construction and production restrictions for possible configurations of the product. However the user interface of this configurator would include spatial and phenomenal properties of the product, in this case the real situation intended to occur in the built environment.

#### **1.4. Research questions**

The specific research questions dealt with in this paper are:

- Could a designer use architectural objects as a foundation for design of buildings in the context of industrialized house-building based on a technical platform?
- How does architectural objects relate to parts of a technical platform and different levels of decision making in design?

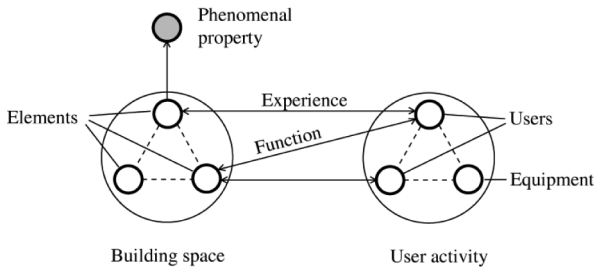
## **2. SITUATIONS AND ARCHITECTURAL OBJECTS**

### **2.1. Situations and Architectural objects**

In an earlier paper we have presented a theoretical background for our concept of “situation”, referring to a concrete system of man and environment which emerges during man’s use and experience of the built environment (Ekholm and Wikberg 2008). The concept builds on the idea of “behaviour setting” (Barker 1968), “pattern” (Alexander 1979) and “fabric” (Habraken 2005). A similar concept “sociotop” has been introduced in Stähle (2008), referring to a unit of place and users where the place has a specific meaning.

We hypothesize that architects design with such socio-technical systems or “situations” in mind. A situation can be described as human activity carried out in an environment with phenomenal values that support a specific mind-set and experiences during the activity.

In an object-oriented design context, an ‘architectural object’ refers to situations of people, behaviour, experience and environment as a unit. An architectural object is an architectural design unit that may support the design of certain activities and their related built environment. Object-oriented CAD-tools available today take as starting point objects representing building elements and spaces. In addition to that, an architectural object needs to include objects representing user activities and phenomenal properties (Figure 1).

**FIGURE 1.** CONSTITUENTS OF AN ARCHITECTURAL OBJECT.

## 2.2. The level order of design of the built environment

The built environment is generally thought of as organized in different levels of design or “intervention” (Habraken 1982, 1998; Ekholm 1987). The level order reflects both the artifacts’ size and other aspects, and the organization of social systems in different control levels. The idea is that a social system in a lower level may control activities and artifacts that do not interfere with social systems in higher levels. A social system in a higher level may control activities and artifacts that restrict the freedom of action and possible configuration of artifacts in a lower level. This leaves a relative freedom of decision making on lower levels within a framework set in higher levels.

Applied in the context of building design, the general idea is that design decisions concerning construction entities and building elements in higher levels of control constitute a framework that restricts the possible decisions about building elements in lower levels of control. For example, the possibilities to raise partitions in a building are restricted by the extension of its external walls and floors.

These physical restrictions are mirrored in the structure of social systems controlling the built environment. For example, a change of the apartment dividing walls in a multi-family house affects households on both sides of the wall, while a change of a non-loadbearing wall inside an apartment in principle only affects a single household. A decision about the apartment dividers must be taken at a social system level above the single household, e.g. at the building management level, perhaps by a housing cooperative board. And within a household the decision about partitions is taken at the household level, not at the individual member level.

The same principle holds in higher levels. For example in a city, a change in block size or street width can only be determined at the city authority level. Likewise a building’s extension is limited to the built zones determined at this level. There is a spatial extension order related to this socio-technical hierarchy where e.g. the extension of the building determines the possible extension of apartments, which limit the possible size of rooms which limit the possibilities of placing furniture.

The Swedish National Board of Public Building identified three levels of building parts according to their dependence on decisions in the related social system: society related, building related and organization related parts (Ahrbom 1980). The latter should be possible to change easily when a user organization needs a new space subdivision of the building based on change in the organization's activities. The building related parts on the other hand could be designed to remain unchanged throughout the life cycle of the building. The society related parts in principle should be able to outlive several generations of construction entities without need for change, e.g. the street pattern or sewer system and other servicing elements decided at the city authority level.

This subdivision has many similarities to the levels identified by the Dutch research foundation SAR who identified two levels of house-building parts, support and infill, corresponding to the above mentioned building related and organization related parts. SAR also coined the term "tissue" to refer to the pattern of streets and blocks determined at the level of town planning (Habraken *et al.* 1974).

A fourth level is of interest, i.e. mobile building elements or furniture, which are controlled at the Activity level, where an Activity is seen as the smallest relevant spatial planning unit in building design.

Situations in the built environment involve parts of the built environment and social activities that belong to socio-technical systems in different levels of complexity. Human actors play different roles which depend on the level of social system these roles belong to. For example, a chairman of the board in a housing cooperative takes decisions on the building level, and the same person in another role, e.g. as a member of a household takes decisions on the user activity level. Based on the analyses above, the level order of socio-technical systems that is related to control of the built environment in a building design context consists of four main control levels, the City level, the Building level, the User organization space level and the Activity space level. See Table 1.

**TABLE 1. LEVELS OF CONTROL, BUILT ELEMENTS, AND ACTORS IN THE SYSTEM MAN-BUILT ENVIRONMENT.**

CONTROL ACTOR	CONTROLLED BUILT ELEMENTS	CONTROL LEVEL
City authority	Infrastructure (streets, sewer, etc.)	City, neighborhood
Building management	Building related building elements	Building
Building user organization	Organization related building elements	User organization space
Building user	Activity related building elements	Activity space

The levels of control or decision making do not restrict the use of the built environment. An activity may involve parts of the built environment belonging to several different levels of control. A person may walk in the street, enter a shop, and perhaps try out the merchandise without being able to control or decide about the built elements that are involved. But once a person wants to do something that involves control he/she has to act within the determined and agreed limits.

### 2.3. Architectural objects and levels

As defined above, an architectural object represents a real situation where man uses and experiences the built environment in a significant way. Situations are socio-technical systems and may be related to the socio-technical control systems identified above.

Building design includes the determination of situations that are considered of interest to emerge during use and experience of the building. Every user activity involves human actors using some equipment or part of the built environment. The activity has a spatial extension and other properties that put requirements on the built environment where it takes place. User activities belong to the lowest level of situation and could be called *Activity space* situations.

A building in use is part of several situations, and using a building may involve several related situations. An office day may involve situations like: entering the building, visiting the reception desk, entering the office, or the desk in the open office space, working at the desk, visiting the rest rooms, socializing at the coffee table, etc. Taken together as one situation, e.g. the office situation, it puts requirements on the building's spaces, it may be called a *User organisation space* situation.

Different User organization space situations may occur in the same building, e.g. several dwellings are situated the same apartment building. Examples of parts used in common are staircases, elevators, entrance doors, roof, façade, etc. Therefore it may be relevant to consider also the combined use of the building as a *Building* situation in a higher level than the separate building situations.

Finally a similar argument may be applied to define situations in the city level, involving society controlled construction entities like roads, sewer system, parks etc. These may be called city or neighborhood situations. The built environment is part of situations in several levels and these correspond to the level order of socio-technical systems in the built environment.

### 2.4. Design involving different levels

A design process could be described as an iterative sequence involving several levels where decisions on one level, e.g. the building level involves analyses of possibilities and consequences in the neighborhood level and in the user orga-

nization space and activity space levels. For example, decisions concerning house geometry have implications for block size and for available space for user organizations as well as user activities. In a situation where the designers have control on all levels it is possible to optimize situations in different levels, while in a situation where a designer only controls decisions on a lower level, the higher level systems act as a given framework.

## **2.5. Architectural object structure in CAD applications**

Architectural objects to use for design with a technical building platform may be implemented in a CAD-application library together with the functionality of altering it's included parts. The objects may be parametric to the extent that this is made possible by the platform.

Activity space objects at the lowest level represent situations like dining with several optional choices concerning seating arrangements related furniture and communication. Such an object may include attributes that enable specification of requirements for window placement, lighting, and connections to other situations like cooking and general living-room activities. Attributes that allow representation of phenomenal properties are important to all architectural objects. In this case, attributes like: cosy, formal, stately, friendly are examples that should be possible to implement through choice of arrangements, materials, colours etc.

User organization space objects could, for example in case of an office design, have optional attributes for number of employees, required spatial extension, access to staircases and elevators, numbers of hygiene spaces, required open office space, number of enclosed office and meeting rooms etc. Social properties like sense of communality and interesting workdays may be achieved through open space office layout and integrative communication and gathering spaces.

Likewise, architectural objects on the Building level may have attributes to determine intended building geometry, length, height, number of stories, orientation, relation to open space, position of staircases or access balconies, architectural style, colour, etc.

Finally at the neighborhood level architectural objects representing e.g. a town situation, may state recommended population and block size, access to green areas, overall density, arrangements for security in pathways, etc.

## **2.6. Architectural objects and the technical platform**

A technical platform is designed to allow buildings of different kinds. Building elements belonging to a technical platform may be structured according to different control levels, e.g. the earlier identified building related elements, user organization related elements and user activity related elements. Design of



situations in different levels involves elements belonging to different levels of control. Activity space situations certainly include elements like furniture, but also put requirements on other elements both building related and user organization related, e.g. external walls and internal walls, access to lighting switches and water outlets, etc.

Likewise User organization space situations put requirements on overall building width, ceiling height, fire egress location etc. This means that design decisions involve building elements belonging to different levels of control. Technical platforms may therefore be characterized to have a larger or lesser degree of universality and flexibility with regard to the relative freedom to take design decisions in different situation levels. These properties depend on the structure of the technical platform. If e.g. the internal walls in an office building generally are loadbearing, the freedom on the user organization level to change the spatial layout of the building is strictly limited, but may still support various placements of openings.

### 3. CASE STUDY

#### 3.1. Introduction

The case study presented here aims at investigating the use of architectural objects for design of buildings with the Open House building system. It explores whether a design process based on architectural objects is feasible. The benefits would be a configuration methodology complying not only to a technical systems view, but also to meeting client objectives concerning use and experience. The case takes as presumption that an already realized block of 56 rental apartments is to be designed using architectural objects. An example of floor plans in this block is illustrated in Figure 2.

**FIGURE 2.** BLOCK LAYOUT AND EXAMPLE FLOOR PLANS FROM THE CASE STUDY.



### **3.2. Open House**

#### *3.2.1. The Open House system concept*

Open House Production AB is part of the Norwegian OBOS-group. During its 5 years operation about 1500 apartments have been finished. The Open House house-building system is based on lightweight steel and factory outfitted volume elements, inserted in a prefab steel frame on site. Other prefabricated parts are e.g. balconies, bathrooms and installation shafts. System details comprise standardized interfaces between system modules, frame, and installations as well as the sub-contractors' prefab completions. These predefined interfaces and limitations on system modules are considered being the system platform, still offering extensive freedom for architectural design.

#### *3.2.2. CAD-organisation*

In the investigated case, the company architects had a design and CAD coordinating role and were responsible for the project's BIM model developed in ArchiCad. A number of previous projects had resulted in an extensive library with preferred design solutions for system modules, compositional parts, and prefab units. These have been stored as reference files and library objects, and are forming a portfolio of reusable BIM objects. The studied project's design information was based on a mix of BIM objects or drawing primitives, either project designed or predefined in product library or object reference files. Executed designs were traditionally corresponding to separate construction entities and level of detail, but files were successively linked in order to constitute the project BIM model.

### **3.3. Case analysis study**

#### *3.3.1. Case study design*

A master plan and a general building program for the project was at hand, constituting the basic requirement for the design. The case study tries to back trace the executed design and simulate how it could have been achieved using architectural objects. Examples of decisions relevant to the design process are considered according to levels of design and sets of architectural objects used. On each level of control the client's building program and the industrial house-building system are guiding and restricting the design, but also the master plan and other stakeholders' interests may inflict on decision making.

Architectural objects should be implemented as library parts, they could be general or adapted to the specific building system, and may have inflicting relations to other objects. Available options should be reflected in the architectural objects at hand meeting different activity requirements. For an example,

see Figure 3, where the dining activity requires wheel chair access, connections to other activities, and different window options.

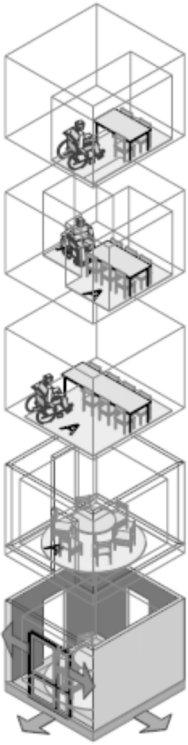
**FIGURE 3.** CONFIGURATION OF AN ARCHITECTURAL OBJECT AT THE ACTIVITY LEVEL.

Design decisions on the four main levels of situations and design decisions are discussed, the neighborhood, the building, the user organization space, and the activity space.

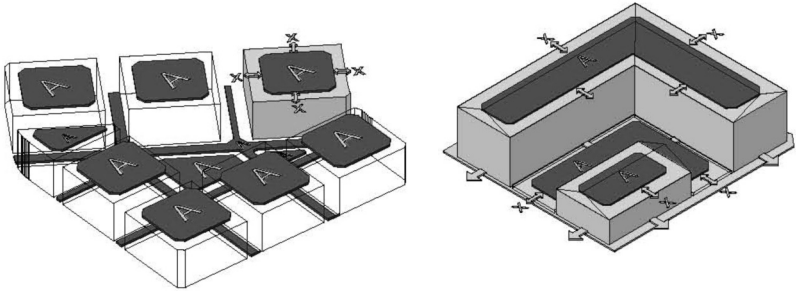
3.3.2. Design level – city authority

The overall use of the neighborhood is stated in a city plan or master plan determined on the city authority level, prescribing use and other requirements for the design of a block or an area. In the OH-case the master plan includes two housing zones, of 2 and 4 stories respectively, and one for semi-public open space activities. A maximum height must not be exceeded. Of prime concern for a developer is the design freedom concerning the plot.

In an object based design application the block or area may be represented by an architectural object holding information about plot geometry and general usage or activities in the area, like dwelling, parking, and playground. Furthermore, relations to other activities, buildings, open space or streets may be defined, represented by arrows in Figure 4. The architectural objects at this point hold information about spatial limits, main activities, their relations and notes on design intents guiding the design at next level.



**FIGURE 4.** CITY LEVEL ARCHITECTURAL OBJECTS INCLUDING STREET NETWORK, BLOCKS, BUILT-OPEN SPACES. SYMBOLS: RED - ACTIVITY, GREY VOLUME – BUILDING, GREY ARROW – PARAMETRIC EXTENSION, YELLOW ARROW - RELATION, X – UNKNOWN EXTERNAL OBJECT.



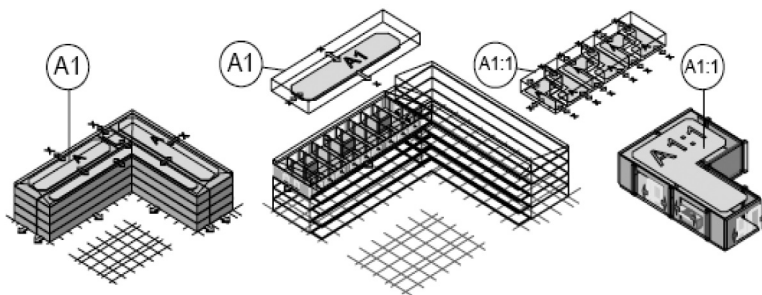
### 3.3.3. Design level - building management

Design decisions in the building level specify properties of the building as a whole and its subdivision into floors with possible apartments, common areas and technical systems like loadbearing parts, ducts, elevators etc. The building situation may be represented by an architectural object holding constraints from the city authority control level.

In order to determine the overall geometry of a building's floors the design procedure includes subdividing the building into general living and public space situations, see Figure 5. In the OH-case this results in separate architectural objects for buildings, access balconies and stair-cases, due to different use and different structural systems.

The building related elements in the OH-case, e.g. loadbearing structure, floors, roofs and façades with flexible openings, may be subject to parametric design and adaptable to different situations and part of several different architectural objects. Ducts may be added in a rule based manner securing predefined interfaces for HVAC, and later on, docking of prefab bathrooms and kitchen units.

**FIGURE 5.** BUILDING LEVEL ARCHITECTURAL OBJECTS, FROM BUILDING TO APARTMENTS.



The selected layout of the building structure and services determine the spatial limitations for each apartment, e.g. floors, ceilings, loadbearing walls with possible openings and main installations. The separate apartment situations are represented as architectural objects allowing various user activity scenarios. The OH-modules are also included in these objects.

A determined design on the building level is input to possible designs on the user organization control level, e.g. concerning user organization related building elements inside apartments.

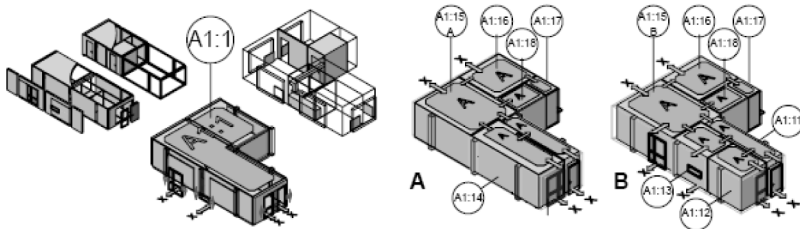
### 3.3.4. Design level – User organization

This level concerns among others layout inside apartments within the limitations set at the building level, e.g. the spatial dimensions, and positions of ducts

and staircases. In the OH-case, the general qualities of the apartments, e.g. daylight requirements for rooms, number of bathrooms, balcony etc. are partly determined at the building management level and expressed in the building program. Household activities and user organization related elements are open for design within the apartment's spatial limits. This means that different household constellations, with e.g. various spatial subdivision, alternative window placements, or extended kitchen facilities might be possible alternatives to the designer.

The spatial limitations of the two room apartment in the OH-case, illustrated in Figure 6 as an architectural object, only offer one placement of the prefab bathroom. Ducts and piping for the kitchen are also predetermined building management related parts. Exterior doors and most windows could however be altered within some limits and could then be considered belonging to the user organization control level. This also includes the option whether gable windows on the building level should be utilized or not.

**FIGURE 6.** USER ORGANIZATION LEVEL ARCHITECTURAL OBJECTS, ACTIVITIES AND MODULES.



Two spatial alternatives are at hand within these limitations. The illustrated apartment architectural object could accordingly be fitted with architectural activity objects representing eight separate situations and their relations. All have some inherited or shared building elements. Relations through possible openings, windows or doors are determined in the building program. Two of them have inherited use restrictions and pre-set fittings for kitchen and bathroom, the others could hold user activities like entrance, sleeping, storage, dining, and living/relax according to the program. Alternative situations and gable window options give in the case two alternative apartments, one subdividing an extra space for sleeping. The result of design decisions in the user organization control level is a spatial lay-out of the apartment.

### 3.3.5. Design level activity

The activities of a household occur within the apartment spaces. These situations are represented as predefined basic architectural objects, like sleeping, cooking, dining, relaxing, hygiene and moving around, see Figure 3. Most

objects must hold options for combining and altering to allow various spatial limits and mixed use. Each activity might hold a varying number of users and different furnishing and equipment alternatives requiring different amount of space. The case shows that architectural objects could be part of a predefined situation ensemble. They should possess well defined building parts and interfaces to support the configuration process. Still they could accommodate parametric options for walls, openings, doors, windows, services, finishing etc. within the industrialized context. This way it should be possible to reduce and control variation within the systems' buildings.

#### **4. ANALYSIS**

This case study has investigated the use of architectural objects in building design for an industrialised volume element building system. Different levels of design have been identified, representing control of elements of the built environment and activities in real situations. The case study has shown how the design process can use architectural objects as configuration units, representing and reflecting both client objectives and a building system's versatility. By defining requirements for different levels of design it's shown how client objectives concerning use and experience may be addressed concurrently with the building system's restrictions.

A noticed prerequisite is that architectural objects should be a result of previous product development, expressing the variability of represented building parts and possible user activities. In order to maximize the designer's freedom, design options within a specific level of control should be as wide as possible. The case project however shows that control level requirements and previous decisions taken in the design process might limit these options. If not fully covered by architectural objects for all situations, the methodology still shows a possible way of directing the design process according to a user-centered view. Separate design actions constituting or completing the product model may still be possible. The idea of architectural object is independent of the current case. Further studies will investigate the applicability with other building systems.

#### **5. CONCLUSIONS AND FUTURE DEVELOPMENT POSSIBILITIES**

By formalizing the concept architectural object and making it explicit, the related information concerning user activities and phenomenal properties, as required and designed, can be made accessible to all parties in the design, production and facilities management processes. The BIM information can be used to gain experience of the building in use, for simulation, as input to brief development, and other analyses of interest.

In a perspective of lean and industrialized house-building a methodology with architectural objects could have synergy effects on production planning and facility management. The possibility of directing production planning, cost estimates, quantity surveys, etc. in a subsequent way as the design process progresses could be investigated. It's also likely that the architectural object design methodology could support concurrent engineering and lean design, as the predefined architectural objects could focus product development work on systems solutions supporting client's user centered view of the building. The question how the functionality of architectural objects should be implemented in a software environment is not a part of this case study, but will get further attention in subsequent parts of the research project.

## ACKNOWLEDGEMENTS

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