THREE WAYS OF ASSEMBLING A HOUSE

part 1
STATE OF THE ART

part 2
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CINARK RESEARCH

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Three Ways of Assembling a House

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PREFACE

This report is the final result of the research project Architectural Quality, User Requirements and Mass Customisation in Industrialised Building Systems. The research was carried out by CINARK – Centre for Industrialised Architecture at the Royal Danish Academy of Fine Arts, School of Architecture in Copenhagen.

Preliminary studies and data collection were started in spring 2007 and the project was finished by the end of 2008. The research was funded by the French governmental secretariat for Planning, Urbanism, Construction and Architecture (PUCA) within the framework of the inter-European ERABUILD research programme. The task was at first to provide knowledge and an assessment of Scandinavian industrialised and prefabricated building systems applicable for multi-storey housing developments.
The report consists of two main parts. Part 1 is a preliminary State-of-the-art discussing the three main themes, Architectural Quality, User Involvement and Mass Customisation. This part was originally presented in November 2007. Part 2 is the main report *Three Ways of Assembling a House*. This part focuses attention on specific industrialised building systems and subassemblies and uses these examples as a framework for a conceptual discussion of industrialised building systems and assemblies.

Through the ERABUILD research programme, the present research has been connected to parallel projects carried out by The Technical University of Chalmers, Department of Architecture in Sweden and by the IPRAUS research unit at the Ecole Nationale Supérieure d'Architecture de Paris-Belleville in France. The exchange between the projects was realised through meetings, common excursions and company visits.

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EXECUTIVE SUMMARY

The report points at several critical questions when looking across the Danish construction industry from an architectural point of view. The following chapter forms an executive summary of the main observations, analyses and conclusions. Further discussions supplied with numerous examples from extensive interviews with significant stakeholders can be found in the full report. They underline the many different positions in the construction industry concerning the questions of: organisation and production systems, user aspects and quality.

Organisation and production systems

- The limitation of the production system solved by multiple suppliers

In turnkey projects, the general focus is primarily directed towards the production system of the main contractor when developing the project. If the traditional supply strategy (traditionally held by architects) is all about finding processes that spoil the architectural vision as little as possible, then the turnkey supply strategy (promoted by contractors) is all about finding a vision within the production system that reduces its capabilities as little as possible.

The architectural flexibility, as well as the transparency of the pricing structures of the turnkey projects are very limited. A healthy market structure based on such contractors can only exist, if there is a wide range of suppliers who cover a variety of qualities and designs. Optimising the various production systems to build anything can be one strategy, but it is neither technologically feasible nor very economical.

An architectural ideal, within the turnkey supply strategy, points at offering a wide range of systems, so the architectural schemes can vary from project to project and the investor can choose the right system optimised for his/her needs and preferences and for the end-users.

- Integrated product deliveries

Project based development is not efficient if know-how is not systematically collected and implemented in future projects. Part of the explanation for this is an outdated tender system that excludes the manufacturer from participation in the preliminary phases of a project where specific choices determine the final result. Fixed business partners on both sides in the value chain would be beneficial to the development of integrated product deliveries – an explicit strategy of *Altan.dk*.

Working with fixed partners who know what they want ensures stability in the production flow and allows room for innovation. One way of solving this dilemma is to split the design process into pre-contract and post-contract phases. The pre-contract work is mainly concerned with outline design, scheme design and detail design necessary

to determine the nature and position of all contractual interfaces and the product performance, but only the desired appearance of the visual ones.
Not all building projects can be based on integrated product deliveries. Also there might be a problem of possible overlap between them (no clear interfaces). A method of resolving this issue may be not to lock conventions on details – but to leave space for redefinition/reformulation of new interfaces and for future changes.

- Configuration management

The industrialised building composed by subassemblies can perhaps bridge the gap between the traditional project orientation and the industry's production orientation, thus resulting in unique projects based on composition and configuration of systemised products.
Given enough choices, the task of 'configuration management' could turn out to be one of endless opportunities.

User aspects

In what way and how far into the design processes are the users going to be involved? These are central and repeated questions throughout the interviews. Splitting up the building into different building assemblies that are manufactured and put on a market as products may seem over the top. However, it is not always completely clear how the product is defined and how the connection between product, production, technology and user should be understood. In the cases discussed, at least three quite different conceptions are expressed. What is actually the product? What do people buy? Who are the users/clients? It is therefore important to clarify aspects such as: Are the users to be involved at a general level in order to define a concept of living? Or are the users to be involved to specify materials and product qualities? In other words, are they to be regarded as visionary collaborators for mutual inspiration and specification of the projects? Or are they to be regarded as consumers being offered what they expect? A question left open for discussion is: Does having the choice give more value than the (high quality) standard solution? The answer might depend on what is left open and what is standardised.
Some aspects are important for the end-user, some for the client and others again for e.g. the architect, and often it is the financial and organisational setup rather than architectural experience that determines whether choices are left open for different stakeholders - and which ones.

Quality

Looking across the cases, architects are strikingly absent from industrial product development except

in one case (NCC-shaft). However, when focusing on e.g. integrated product delivery it also has obvious weaknesses. Strict definitions of qualitative properties of subassemblies cannot secure cohesion with the actual context. This will require products that have a certain openness and adaptability towards the context in a broad sense thus including the actual interface as well as technical aspects, aesthetics, functional schemes, economy, ecology, time, place and other values,[1] which all influence what we term the architectural quality.[2]
An important challenge for the architect – as an in-house or external consultant – will be to clarify the demands concerning quality performance openly defined, as well as pointing out relevant contextual aspects in order to provide the necessary coherence of subassemblies used in construction.

SCOPE OF THE RESEARCH

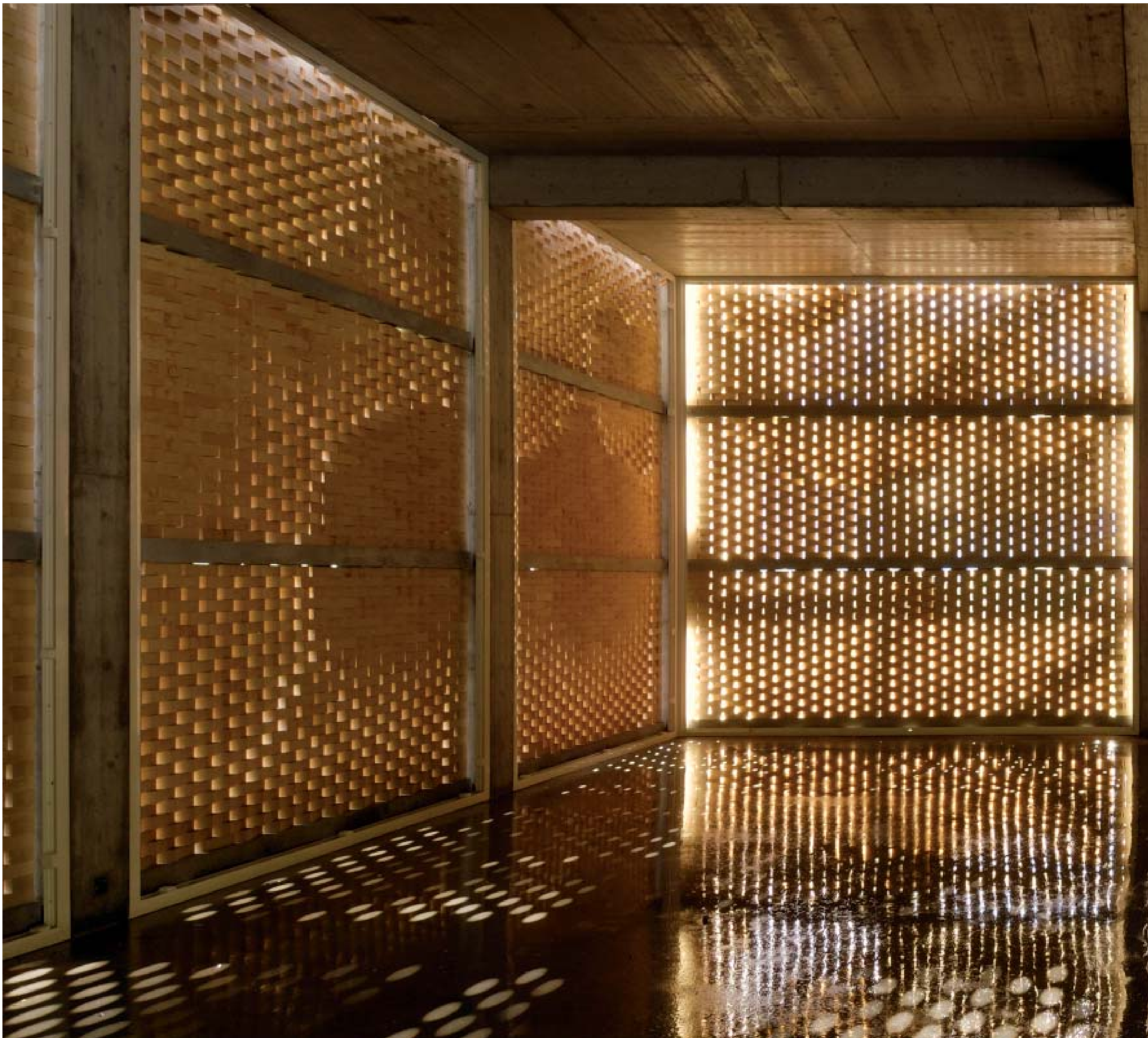
This research focuses on residential architecture. In the ongoing industrialisation of construction, many stakeholders are looking for ways to simplify, stan-dardise and rationalise the processes by means of systems at both product and process level. However, potential house buyers and users still want individually customised homes of architectural quality. These different attitudes are not always compatible. There is a risk that future housing will be cheap and unattractive at the expense of both architectural quality and sustainability. The present report aims at shedding light on highly industrialised Scandinavian building systems and concepts. By looking at the system itself, the way it is produced and the business model behind, the intention is to assess these systems and concepts in their broader organisational context and not just as physical manifestations of original clear-cut design intentions. Industrialisation is mainly about process – it is a means to an end, not a goal in itself.

[1] Beim, Anne and Jensen, Kasper Vibæk (2007); *Forming Core Elements for Strategic Design Management.* Article in: Architectural Engineering and Design Management. CIB
[2] The term, Architectural Quality, is discussed in, *State of the Art,* Part I of this project.

Acknowledging that there is more than one possible way of enhancing the application of industrialised solutions in construction and architecture, the present report introduces a framework of several different strategies for industrialisation. The strategies are not to be understood as scenarios where one excludes another. Rather, the framework can be seen as our interpretation of parallel tendencies found in contemporary Scandinavian practice – a way to conceptualise a motley or scattered reality in order to better understand the dynamics behind. Through case analyses focusing on both technological aspects and applied business models, the specific characteristics of different industrial *deliveries*, within construction, are sought clarified. A subsequent general discussion focuses on the constraints and potentials of the different systems and strategies reflected in the cases. It is our hope that this will help inspire the development of new industrialised solutions that go hand in hand with architectural ingenuity.

But why should we industrialise construction and the (process of) creation in architecture? From the point of view of an architect, this question may seem difficult to answer. With a huge collection of mostly bad references from the first wave of industrialisation in the 1960's and 1970's, such as monotonous building (systems), widespread and serious building defects and economical failure of all encompassing building systems, there are many reasons *not* to return to this path. However, the present scenario of not using industrialisation, or only using it sparsely is perhaps even worse: While the basic architectural challenge in construction remains rather constant, construction as a whole is getting ever more complex in order to comply with current legislation demands on e.g. safety, energy consumption, indoor environment and material recycling. This fact makes it ever more difficult to control the process and achieve the necessary architectural *coherence*.[3] But is it then simply a question of choosing the least mediocre among various poor alternatives? We think not: Used wisely, industrialisation can – through better control – perhaps become the essential tool in true architectural creation.

[3] For an explanation of the coherence concept see Beim, Vibæk & Jørgensen (2007)



part 1
STATE OF THE ART

Weingut Gantenbein, Bearth & Deplazes with Gramazio & Kohler, 2006. Photo: Ralph Feiner

CONDITIONS FOR ARCHITECTURAL QUALITY IN AN INDUSTRIALISED CONTEXT

- Moving towards architectural sustainability

Introduction

However essential it might be, architectural quality is an extremely difficult concept to grasp and describe in words and even more difficult – if not impossible – to measure in any meaningful way. As concluded in a recent PhD thesis: [...] *an abstract normative definition and operationalization of 'architectural quality' is neither appropriate nor practically possible.*[1] Still, almost everybody can agree on the importance of architectural quality being present in our everyday physical environment. Architectural quality is somehow created, perceived and acknowledged on the basis of tacit knowledge without any need for an underlying clear-cut definition.

This does not mean that it makes no sense to discuss architectural quality. Equally, it does not mean that this theme has not been debated before. In this paper, however, we are concerned with the implications on architectural quality when architectural creation and construction meets industrial production. In this context, the main question would be:

- What are the implications on architecture when construction moves from craftsmanship to industrial production?
- What happens to the design processes, strategies and the role of the architect?
- How is the contextuality and specificity of architecture taken into account?

Our stance is that certain circumstances change radically. This concerns both the goals to be reached and the means to reach them (the strategies). Certain aspects or parameters of quality become more preponderant while others recede when two different rationales meet, as we will argue. In very general terms, industrialisation brings a greater distance and more partakers between the creator, i.e. the architect or the end-user, and the result, i.e. the building. This would imply a loss of direct control and calls for new design strategies that can facilitate a process *making provision for what cannot be foreseen.*[2]

However, industrialisation is perhaps at the same time a way of bringing the architect and the end-user back in control through new tools that can streamline the repetitive and standardised tasks, e.g. quality control and documentation, thus leaving more space for creativity, personalisation and general thoughtfulness in order to attain architecturally sustainable solutions. Here, we refer to an earlier used definition where [...] *sustainable construction is defined as buildings of high architectural quality taking into consideration people, environment and resources – both concerning genesis, use and maintenance.*[3]

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1 Nygaard, Niels 2006 *Arkitektonisk Kvalitet* (Architectural Quality), PhD thesis at the Aarhus School of Architecture
2 Citation borrowed from Habraken 1999, *Supports*
3 Conversion flexibility

The chapter is a collection of recent research and thoughts within the framework of CINARK – Centre of Industrialised Architecture, the Royal Danish Academy of Fine Arts, School of Architecture. Hence, it should not be seen as an overview of research on architectural quality in general, nor can it be precluded that others may equally have treated the topic of architectural quality within an industrialised context. However, some references to related research will be integrated where this is found necessary or relevant. In the following sections we will:

- Briefly describe two different rationales that we find present in industrialised architecture and construction and whose mutual interplay influences how architectural quality occurs and can be conceptualised.
- Elaborate on the concept of architectural quality introducing three different levels of objectivity and generality.
- Present and discuss a collection of empirically founded parameters of quality, which are of particular interest in an industrialised context.
- Further elaborate on and discuss one – in our opinion – central quality parameter, i.e. flexibility.
- Draw up a final hypothesis on what we would term as architectural sustainability.

The final hypothesis proposes a search for a new production paradigm facilitating architectural quality in industrialised construction.

Two rationales

According to Rönn[4], a distinction should be drawn between notions of quality starting from a perspective of industrial production and notions of quality based on a point of view concerned with design, architecture or urban planning (architectural quality). The former originate from a wish to limit malfunction and deficiencies in a specific industrial production (*technical* quality), whereas the latter, the *architectural* quality, has the purpose of serving more general and cultural long-term objectives. Elaborating on this distinction, the two notions could be ascribed to two different rationales with general societal significance:

- A technical/business rationale concerned with rational optimisation, (short-term) business economy and 'that which is realistic'

and

- An ecological rationale concerned with values and qualities for the user, (long-term) macroeconomics and 'that which is desirable'.[5]

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3 Conversion flexibility
4 Rönn, Magnus (2001)
5 Ecology as a branch of biology deals with the relations between organisms and environment. Human ecology is the study of the relationship between people and their environment. Our use of the term is mostly related to the latter. See also Madsen, Ulrik Stylsvig (2007:3) *Arkitekturen som rum(me)lig struktur* (Architecture as spatial structure) on *ecology* and *affordance* as concepts for a discussion of how people interacting with their environment create meaning from the things/objects they come across.

Producing architecture within an industrialised context implies working within both rationales. One assumption is that these have certain overlaps; industrial production mainly operating within the technical/business rationale can in some respects facilitate and thus meet architectural creation which mainly works within the ecological rationale (synergetic effect). As mentioned in the introduction it can e.g. free resources by streamlining repetitive tasks and facilitating technical quality control. In other respects, though, the synergy between architectural creation and industrial production and their related rationales is less evident and the combination can even become problematic. It creates a tension. Industrialisation inherently aims at optimising a production of an existing product thus dealing rather with process innovation than with product innovation, which, in turn, is a hallmark of architectural creation. To us, it seems relevant to describe both synergy and tension in order be able – as architects (and end-users) – to impose clearer demands on the construction industry (industrial production) on the one hand, while on the other hand outlining appropriate procedural conditions, which should be taken into account when designing the physical environment (architectural creation). The intention here is to raise the level of consciousness and provide a common understanding and language for discussing architectural quality and value in this particular (industrialised) context. It is our hope to make more visible certain architectural parameters that seem to become particularly relevant when exposed to industrial processes and production. First, however, we need to elaborate a little on the framework for our discussion.

Three levels of architectural quality

In the following, we divide the notion of architectural quality into three general/main concepts: properties, coherence and value.[6]

The properties of a piece of architecture are qualities characterising different parts of the architectural work and their way of being and performing.[7] Properties thus refer to 'that which belongs to or characterises a thing by virtue of its nature or being'[8] and elsewhere: 'an essential or critical factor for […] a thing's way of being or functioning'. [9]A piece of architecture possesses a number of predicative as well as performative properties – *it consists* of and *has the ability* to do this and that. In this definition, the architectural property exists in the (architectural) work/object itself and therefore has seemingly objective characteristics, which can be understood/perceived outside the immediate context. Even so, the property is rooted in the cultural setting and

[6] This division was first presented in Beim, Vibæk & Jørgensen (2007) *Arkitektonisk kvalitet og industrielle byggesystemer* (Architectural Quality and Industrialised Building Systems). – The section is partly a translation from this publication.

[7] Static properties, tectonic properties, acoustic properties, thermal properties, material properties, sensorial properties, properties related to damp or fire safety, properties of use (with all its sub-properties) etc.

[8] Own translation from *Politikens Filosofi Leksikon*.

[9] Own translation from *Politikens Nudansk Ordbog med Etymologi*.

practice of which it forms part and consequently does not have completely universal characteristics. However, within a specific culture/community, it will possess such a high degree of inter-subjectivity that it could be classified as a *collective subjectivity*, which in practice works as if though it were objective. It may be worth stressing here that we are trying to outline *architectural* properties and not just properties in general.

The coherence of an architectural work is an all-embracing quality that works by holding the work together in a composition where the different parts and their properties (see above) relate to each other and work together on a higher level.[10] Talking about coherence here, we thus refer to a definition that goes beyond the purely aesthetical composition by drawing on a much broader exchange between the different properties as aesthetical as well as functional, technical, economical, ecological, related to time and context etc.[11] Securing the coherence of an architectural work takes the special skill of an architect - it is hardly a task that can be taken over by other professions. Coherence is *distinguished* from property by working in the relational play between different elements inside and outside the specific work of architecture. Coherence is relational whereas property, as mentioned above, can be perceived separately, although through coherence, they (the properties) can lift each other to a higher level and ideally meet at the highest level i.e. the work in its entirety.[12]
Coherence *share* a certain objectivity with the notion of property – it is *in* the object/the work but works on a more complex level through internal as well as external (contextual) relations thus blurring the boundaries between object and surroundings and calling into question the object nature of a work.[13]

The value of a piece of architecture is assigned by the user interacting with the object and will therefore always have subjective characteristics due to his/her historical, cultural, social and economical position, actions and endeavours. An architectural object will have some properties and certain coherence and if these fulfil the needs, aspirations and affections of the user, a possible value can be ascribed to the work which the user is encouraged to realise e.g. as utility value, social value, sentimental value, economical value and other perhaps more culturally based values such as identity, beauty or aesthetical value. Values exist by virtue of the properties and the coherence in the architectural object but can only be attributed by the user or a group of users sharing a common perception. As a consequence, value in our definition is something much more subjective and volatile than properties and coherence although it

10 "The notion of architecture is here understood as the coherence that emerges by the elaboration of general concepts, principles, stories or intentions, through the shaping, proportioning and composition of the different building elements". (Own translation from Mikkelsen, Beim, Hvam and Tølle (2005:9) *Systemleverancer i Byggeriet* (System Delivery in Construction).

11 Jensen, Kasper Vibæk and Beim Anne (2006:192-200) *Kvalitetsmål i den Arkitektoniske Designproces* (Goals and Strategies in the Process of Architectural Design).

12 An example of a higher level could be the combination of kitchen and dining room, where the possibilities of conversation and preparation coexist as an extra quality dimension.

13 The surroundings of an architectural object can not just be defined as the close physical context. It is a much more complex network of cultural, mental and programmatic relations of which the work forms part – and of which the boundary is impossible to determine.

still relates to these qualities within the work. Still, a strict market value (capitalisation) definition would be too narrow; architectural value is, in our opinion, broader in the sense that it represents something useful, important or demanded by the user(s). According to the encyclopedia of philosophy, value is 'often (or perhaps always) [...] related to some sort of action [and thus becomes] something that, in a positive or negative way, controls or ought to control human endeavours'.[14] One could say: This house is of value to me because its properties and coherence, i.e. layout, appearance, structure, functional organisation etc. are useful to me (or give me pleasure) due to my specific situation here and now (what I do or want to do = action). Properties and coherence can hardly change from one day to the next unless something in the architectural object itself is changed that deprives it of certain qualities. In contrast, the value can change suddenly due to external factors or changed attitudes. Properties, coherence and value must all be observed in a specific time and cultural context, but value can, as opposed to properties and coherence, be directly compared and weighed (although essentially in a subjective way) in relation to something else.[15]

Parameters of architectural quality

The following is a presentation of a collection of parameters based on empirical qualitative research interviews in a professional architectural environment.[16] The aim of the research carried out was not to develop a tool of measurement for *judging* the presence of architectural quality in specific environments or physical settings but, as mentioned, rather to provide a common understanding professionally as well as among laymen by contributing to a linguification of the field – especially within the current context of (new) industrialisation.

Industrial production, which is mainly governed by the technical/business rationale (see above), demands strict linear planning and early decision making, whereas a creative design process (architectural creation) governed by the ecological rationale often calls for open scanning of solution space and iterative decision making. The research question behind the quoted project intended to clarify: "whether it is possible to work with precise goals of quality in a design process which by nature is abductive?"[17] The empirical results indicate a collection of parameters that should not be understood as an exhaustive nor universal list but which at least seems to represent the prevalent

[14] Own translation from *Politikens Filosofi Leksikon*.
[15] For a similar distinction between architectural value and architectural quality, see Sällström (2002:9).
[16] Interviews were carried out in architectural offices as well as in housing production companies during autumn 2004.
[17] Jensen & Beim (2006).

concerns among professional architects when dealing with industrialised architecture (industrially produced). With reference to the two rationales mentioned above, the intention in the current section is to exemplify how some of these parameters (of architectural quality) actually work fine within both rationales (synergetic effect) while others seem more likely to produce tension when clashing with the technical/business rationale. Others again seem more ambiguous.

Parameters

Among the most specific parameters mentioned among professionals is a focus on **materials** and their appearance, inflow of **light** and the **view** are often mentioned. **Detailing** is an important and in the industrialised context extremely sensible field, while the **technical quality** and **environmentally sustainable** solutions are also emphasised. **Economy**, although perhaps in itself hardly an architectural parameter, inevitably has an effect on the architectural outcome. Among the slightly more abstract parameters, goals about **scale** and **proportioning** as well as **sensation of place** (genus loci) are repeated. Among the most abstract parameters, we find **artistic originality** and **entirety/whole** as something more than just the sum of the single elements. Many professionals discuss the question of architectural **honesty** and **readability**. Finally, **flexibility** concerning both professional latitude and user requirements is often mentioned. The parameters mentioned have many overlaps and can even be sub-parameters for one another. Moreover, the list is – as mentioned above – neither exhaustive nor universal. Still it *does* represent a linguification among professionals, which can point out some general concerns within the present field of architecture (and the ecological rationale), which perhaps – perhaps not – clashes with the technical/business rationale which predominates within the field of construction as a whole and in industrial production specifically. We will now look further into these potential conflicts.

Easily compatible parameters

Although mentioned among professionals in a discussion related to architectural quality (ecological rationale), some of the parameters could equally have been the outcome of another discussion with point of departure in industrial production thus representing concerns within the technical/business rationale as defined above.

Technical quality

Technical quality is obviously an important parameter, also within industrial production and in the interviews it is also stressed more elaborately among the producers than among the architects. However, even here, in relation to the question of architectural quality, the parameter seems to gain a broader meaning than merely a specification of measurable technical properties; the interviews point towards a definition related to architectural sustainability – as sketched above – where technical, functional and aesthetical properties are all integrated in a common assessment of quality. In this broader definition, more attention is invested in the mutual coherence between multiple properties (technical, functional and aesthetical). Even so, the strictly technical properties of an architectural work – perhaps as a sub-parameter of the broader architectural sustainability – seem to be one of the most 'numeric' parameters which canconsequently relatively easy be fitted into and controlled within an industrial production paradigm through the performing of e.g. quantitative quality control. Industrialisation thus becomes the means of controlling technical quality.

Sustainability

In its broader definition – as architectural sustainability – another of the parameters concerned with environmentally sustainable solutions comes out as a sub-parameter, which in many ways also seems to fit easily into an industrial production paradigm if this is understood as a means of e.g. reducing waste, resources and energy consumption during the production of an architectural work as well as a way of controlling the life cycle aspects.[18] Traditionally, industrial production has had an image of being opposed to environmental responsibility, – partly due to its scale compared to handicraft production – but this seems about to change through IT supported systematic knowledge building, monitoring and control of the environmental consequences of specific design solutions. Industrialisation makes it easier to control environmentally sustainable solutions.

Light

The significance of light is a classical architectural parameter. Some even call architecture 'building with light'[19] or attributes it properties as though it were a material (substance) in itself. However, even if considered as substance, light has a reciprocal relation to everything else of (physical) substance, which cannot visually be perceived without the presence of light, whilst the other way around, light cannot be perceived without the presence of physical matter/substance to catch it. In this way, questions of light are always related to the specific context brought into play. In the architectural sense light is much more than quantities of lux that make it possible to orientate oneself. Light has some technical aspects (physical properties) that can be measured, but even the more loosely defined *experience* of light can, by use of IT technology and CAD platforms, be *simulated* quite precisely in relation to architecture and thus be an integrated and fairly controlled part of an industrialised design

18 A related concept, *resource responsible architecture,* is used in Larsen and Sørensen (2006).
19 See e.g. Elwall, Robert (2004) *Building with light: An International History of Architectural Photography* or Hjort, Anne (1999) *At bygge med lys* (to build with light) – Documentary Film.

process. As a twin to the inflow of light, the **view** as an architectural parameter of quality is equally easier to simulate and check with modern information and simulation technologies. However, designing adequate solutions (by creating *coherence*) requires professional judgement – and it seems improbable that this judgement can be specified through rules or mathematical algorithms.

Hardly compatible parameters

As mentioned, not all parameters of quality draw such evident parallels between industrialised and architectural production (between the technical/ business rationale and the ecological rationale). Some of the parameters repeated in the interviews seem to have particular difficulties in finding their way to an industrialised architecture.

Detailing

The Nordic tradition of architecture has a reputation of being especially concerned with detailing, and the interviewees do show a considerate preoccupation with this parameter when confronted with industrialised production on an even larger scale.[20] When the different elements become bigger and already consist of various components when they leave the factory, there is an increased risk of monotony in the final result. At the same time, the transition between these bigger elements becomes more dominant and consequently needs more attention, architecturally speaking. Different strategies are used in this context: one is simplification of the detail itself making the production easier to control and cheaper to manufacture, e.g. to paint a door frame instead of actually building it. Another strategy points precisely towards special emphasis on the transition between (large) elements by going beyond mere necessity and providing them with ornamental properties. In these strategies, industrialisation calls for another way of working with and defining the detail. Yet another different strategy would be to see industrial production as the means of gaining higher precision.
Systematically collected knowledge about physical properties of materials and their interplay could clear the way for more refined detailing even when

Prefabricated facade elements for the Horten Headquarters. 3xN photo: 3xN

[20] We will get back to the question of scale in a separate section.

large components are put together. Today, however, lack of such knowledge tends to confine good detailing to craftsmanship – which due to high labour costs is reserved for the few. (Nanotechnology is an example of extreme precision).

Artistic originality

Among the more abstract architectural parameters mentioned is the artistic originality. The parameter refers to the special twist, peculiarity or originality in a project which not only makes it different from other projects, but also contributes something new in an artistic/metaphysical sense and which cannot be derived from objective analytical activity. Others term it the atmosphere or feeling in a project. Architects somehow always refuse to copy specific solutions (their own or other's) even when conditions and context seem quite similar. Each project apparently needs to be led by its own concept, which is supposed to contribute to the coherence[21] of the project as a whole and among its different parts. The parameter thus seems to clash with the industrial demand for repetition and a thoroughly planned process with a predictable outcome even from project to project. However, systems and systematic approaches cannot be said to be opposed to concepts of artistic originality in architecture seen as a broad discipline; it can even form part of it and facilitate it. The degree of tension between the two rationales becomes a question of the balance between openness and closedness of applied systems (conceptual as well as physical). What is standardised and what is left open? 'Anything goes' is not artistic originality, and systems, i.e. rules and constraints, can facilitate creativity although perhaps not generate it themselves.[22] We will get back to this when discussing flexibility, which is seen as a crucial parameter of architectural quality in an industrialised context.

Place – site – topographical context

Sensation of place or Genus loci refers to statements about special project-specific conditions that will always have to be considered in a building project. The context – in the widest sense[23] – of two projects will never be exactly the same, and this has to be taken into account in each particular project. Again, the industrial demand for repetition and a thoroughly planned process with a predictable outcome apparently clashes with the need for adaptation to a given context. Standard and prefab solutions that are often partly or completely produced off-site often lack the quality of 'the exact fit'. The sensation of place can never be systematised or generalised, but – contrary to the artistic originality above – it can be uncovered through thorough analysis, which can be partly systematic at process level.

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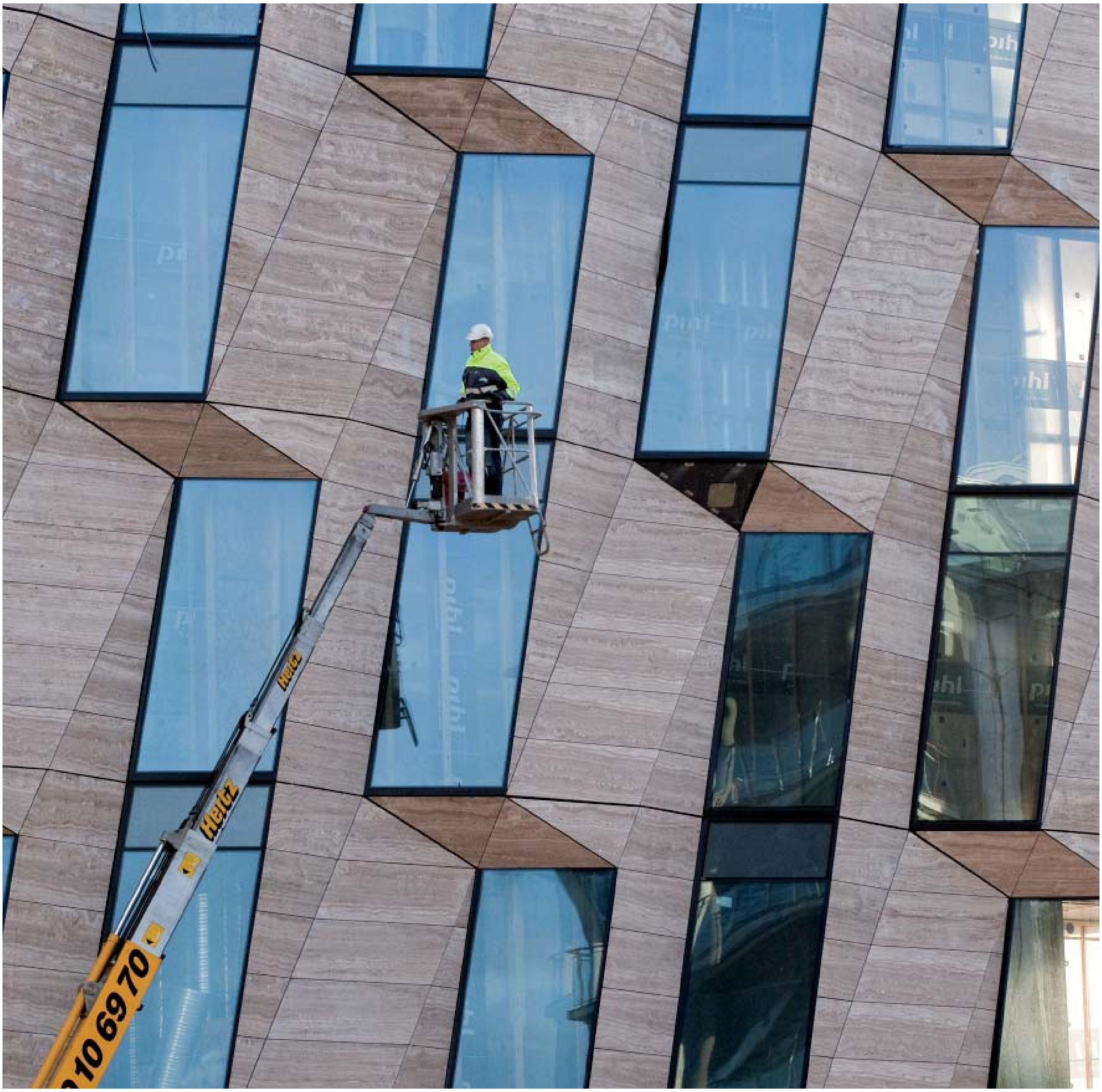
21 See definition above (properties, coherence and value).
22 A mini-conference entitled 'Creative Systems' held by CINARK in September 2007 dealt with this issue.
23 Here context refers not only to the physical setting but also the social, organisational, legislational and financial conditions etc. of a project.



Horten Headquarters. 3xN, 2008
Photo: Adam Mørk

Wholes and entities

Architectural projects are perceived or experienced as cohesive wholes/entities, which are more than just the sum of the different components, and which even have lines reaching outside the projects themselves as described under sensation of place. In industrial production concepts such as modularisation and production lines aim at reducing complexity by splitting up the different physical as well as processual parts of a product into well defined entities thus gaining control by looking on fewer parameters. There is, however, a risk that looking at these isolated entities without taking directly into account overall implications may result in local sub-optimisation. That has inconvenient consequenses for the whole especially when considering the contextual complexity of architecture. One strategy could be to have several matrices for the subdivision thus being able to make cross-checks. An example known from the naval industry is that a ship is split up by *zone* and by *system*[24] with each matrix encompassing all parts of a project. This consequently enables two perspectives while considering the whole: Do the physical (volumetric) elements form a coherent whole? And: do the different systems work together? By having (at least) two different 'languages' to describe a whole made of parts, the differences and overlaps of these in the particular project can be used as a quality check.

Ambiguous parameters

Material nature

The realisation of most architectural projects implies the use of physical substance or materials. In the present context, nature of materials as a parameter of architectural quality does not primarily refer to technical properties, e.g. durability or load capacity but rather to sensorial properties.[25] Apart from the former being evidently important for the life of a building, the latter properties are used by the architect in order to attain coherence as e.g. identity, experience and intensity. This could take the form of glossiness, texture, hardness, density, denseness, translucence, acoustics[26] or colour. The industrialisation within the building materials industry has led to an explosion in the diversity of building materials. This means more possibilities but also puts higher demands on the architect as to point out the most adequate combinations. What lacks is knowledge and experience about how the new materials behave over time and how they work together. The use of traditional building techniques and materials is based on experience over a long time (in some cases thousands of years), which without need for access to explicit documentation to some extent 'guarantees' a coherent building practice. This evolutionary[27] base is not present for new industrial materials and their (industrialised) combinations. This can lead to a lack of

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24 Zone refers to a cohesive spacial entity, while system is defined by a cohesive funciontion, e.g. structure, ventilation, electricity etc.
25 The specifically technical properties equal the earlier described parameter of technical quality.
26 This could ecually be a technical parameter, e.g. sound insulating properties, but how the material *sounds* would be more sensorial.
27 For a theoretical distinction between evolution and innovation see e.g. Beim & Vibæk Jensen 2007:33 *Forming Core Elements for Strategies Design Management*. In Schnier 2004, a distinction between intuitive and analytical design, respectively share certain characteristics.

VM Houses, Plot 2002, Photo: Johan Fowelin coherence not only concerning technical aspects (such as structural failure or building defects) but also when it comes to the sensorial aspects percieved as a poor or shabby look or vague expression/meaning. The industry excels in control though careful (conscious/analytical) planning, which could integrate systematic collection and use of knowledge concerning these latter material aspects as well. Industrialisation could then be a way of speeding up and impersonalising the 'embedding' of experience. However, the present situation does not offer adequate tools.

Scale – proportion

Questions of scale and proportion seem to become a particular focus among most of the interviewed when dealing with industrialised building. Industrialised building calls for work on a larger scale where buildings are made by larger (prefabricated) components or modules, which at the same time are repeated in order to obtain a rational production. It seems, though, that there is a critical limit in both scale and repetition of a given component or module – a certain balance between standard and special characteristics. Repetition as a basic principle in industrialisation is in itself not an unfamiliar concept in the architectural vocabulary (and rationale) related to similar concepts such as rhythm and seriality. It becomes the role of the architect to consciously use a certain degree of repetition while avoiding its leading to monotony. Refined use of repetition can break down the scale of large industrially produced elements.

Economy

In many ways economy seems to be the main parameter of western culture itself. The word economy comes from the cradle of our civilisation, ancient Greece, where *Oikonomía* meant household. Although today, economy can be of very different scale and scope as compared to the private household, it is still relatively small and separated (business) economies that control a great part of 'where things are going'. The same is the case not least within the field of construction and architecture where companies are actually small compared to other businesses. Of course (!) everything has to be economically viable first and foremost in order to be initiated. In that sense, all other quality parameters become sub-parameters of economy. Economy within the technical/business rationale as defined above determines what is possible and what merely remains a vision. Industrial production and its criteria of success are intrinsically economically driven as a means to reduce production expenditure concerning both time[28] and cost per unit, and investments normally have a relatively short period of profitability. Economy is the epitome of industrial production! Architectural quality and sustainability, however,

[28] Time becomes a sub-parameter of economy.

work within the ecological paradigm, and the investments made in architectural works call for a much longer period of profitability. The *coherence* characterising architecturally sustainable solutions can hardly be made up just in terms of short-term market value and sales price. It seems, though, that there is a clash between the two different rationales – and between architecture and industrial production – when speaking about economy. In terms of quality, it is much easier to argue for either specific architectural *properties* or specific values apparently created within a certain market segment than to point out future potentials through the interaction between a complex of more or less unpredictable factors that will only partly (or never) be realised, thus creating coherence and possibility of value.

However, after all, perhaps economy is not *always* the main parameter. In recent large public projects in Copenhagen (The Metro, The Øresund Bridge, DR Byen etc.) budget overrun rather seems to be the norm and studies show that this is not something new.[29] Although these prestige projects are criticised a lot in the media, they could be interpreted as a sign of something else brought into play that is placed on a higher level than short-term economical profitability. Still, this kind of projects are evidently of broad public interest. It is difficult to see how a private house-buyer's economy could endure exposure to such a principle, but even at this level, there will probably be a difference between investments made for direct sale (housing developers) oand personal investments made in order to get a better place to live.[30] In the former, the focus will often be placed on directly visible and perhaps more superficial (short-term) qualities e.g. fancy kitchen arrangements or 'designed' bathroom fixtures, whereas the latter will rather emphasise general spatial qualities (and quantities) and look into requirements and capacities over time. How can this dwelling satisfy my needs now and in the future? How can I make it my home? This leads to the parameter of flexibility, which in our opinion rather than economy must be considered one of the main parameters when discussing architectural quality in an industrialised context and within industrialised architectural systems in particular. Flexibility is a combination of freedom and constraint and thus in a way embraces both the technical/business rationale and the ecological rationale. Flexibility contributes particularly to what we have termed architectural sustainability enabling industrialised architectural systems to meet changing demands of time, space and culture. Below, we will try to unfold this central concept.

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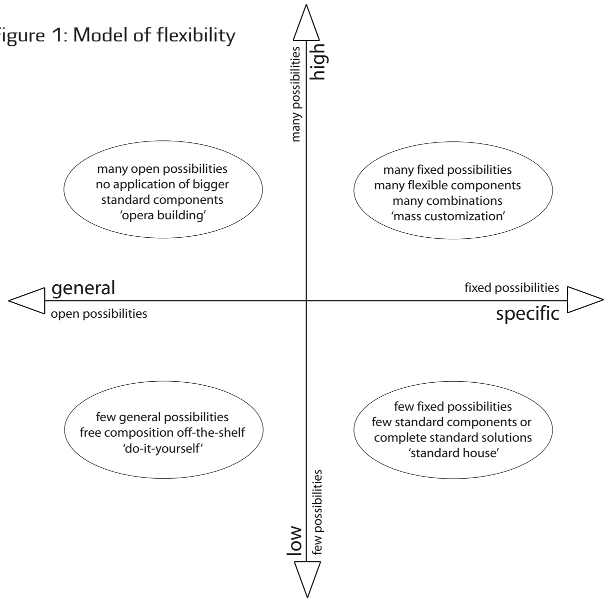
29 See e.g. Børsen (1999) *Store byggeprojekter løber altid af sporet* (Large building projects always get off track): *"A forthcoming thesis analysing 258. projects from all over the world reveals that large public construction projects almost always overrun the budget." www.borsen.dk/nyhed/12653/.*
30 The latter implies 'the natural relationship' mentioned in Habraken 1999 '*Supports*'.

Flexibility in architectural systems[31]

"Flexibility expresses freedom to choose among options or devise programs that fit individual needs and aspirations, whether for building, finance, ownership, or management. Beyond that, and usually for architects it describes the capacity designed onto buildings, building programs, or building technologies to ensure an initial good fit and to enable them to respond to subsequent change. Such designed capacity has come to influence the size and spatial configuration of built environments, services, and/or the technology of building components themselves."
(Hamdi, 1995:51, Housing Without Houses)

Figure 1: Model of flexibility



In many ways, industrialisation denies flexibility. Industrial (mass)production requires a level of systematic approach and standardisation that goes against the idea of leaving things undefined in order to maximise possibilities. However, the extent of flexibility – the appropriate balance between freedom and constraints – is decisive for genuine architectural potentials within an industrialised (production) system which is not the same as leaving anything open! The model below shows how the flexibility of an industrialised system can be conceptualised as two combined dichotomies (level and nature) spanning from little to much flexibility, respectively – from one solution to many possibilities – and from general to specific flexibility – from open to defined possibilities.[32]

A high degree of industrialisation and prefabrication traditionally calls for specificity (low specific flexibility). With the introduction of new information technology, huge amounts of customised data can now be handled in a standardised way thus opening for the concept of *mass customisation* – industrially produced 'unique' or individually customised solutions. This requires both specificity and a high amount of

31 This section is partly a restructuring of selected sections from the paper *'Flexible Solution Space'*, Vibæk (2007).
32 The original model was used to describe structural building systems, but can be generalised to apply to industrialised (architectural) systems. For a further presentation of the model, see Jørgensen, Vibæk & Beim (2007).

possibilities (high specific flexibility) in order to combine rational production with flexibility and create what we could term *flexible solution space,* which is neither totally standardised nor leaving every decision open.[33]
One of the differences in architecture and construction compared to other industrial products (e.g. cars, clothes, personal computers etc.) is that the platform – e.g. the structural building system – has to serve a much more complex and ambiguous functional schema – not least because of its great number of different users and its long lifespan. What is suited for standardisation is often quite arbitrary due to the complexity of the 'platform definition' combined with the small batch size.

Types of flexibility

A distinction between different types of flexibility that refers to the notion of time and of the user has been developed in former research. In the publication, *'Teknik & Arkitektur – mod en bedre Byggeskik'* (Technique and Architecture – towards an improved building practice),(Lundgaard et al 1995) three types of flexibility have been identified:

- **Design flexibility** refers to flexibility in the project design phase and is primarily applied by professionals.
- **Conversion flexibility** refers to the possibility of subsequent conversion or modification of the spatial organisation and is applied by professionals as well as 'inhabitants'.[34]
- **Flexibility of use** refers to a 'real time' flexibility build into a project by the designer/architect and applied by the end user.

The Design flexibility describes the freedom or choices the professionals will have while adapting e.g. a structural building system to a specific situation i.e. a building brief while the Conversion Flexibility describes unused built-in potentials or capacities that can be exploited later in a building's life cycle should the building brief change. Flexibility of use describes an interactive but fixed (specific) flexibility, e.g. moving or folding wall partitions, sliding doors etc. There is not necessarily any hierarchical relation between these types of flexibility; hence it is possible to have a high degree of design flexibility and use it for a building with low conversion flexibility or the other way around use a system with low design flexibility for e.g. apartment designs with high conversion flexibility and so on.

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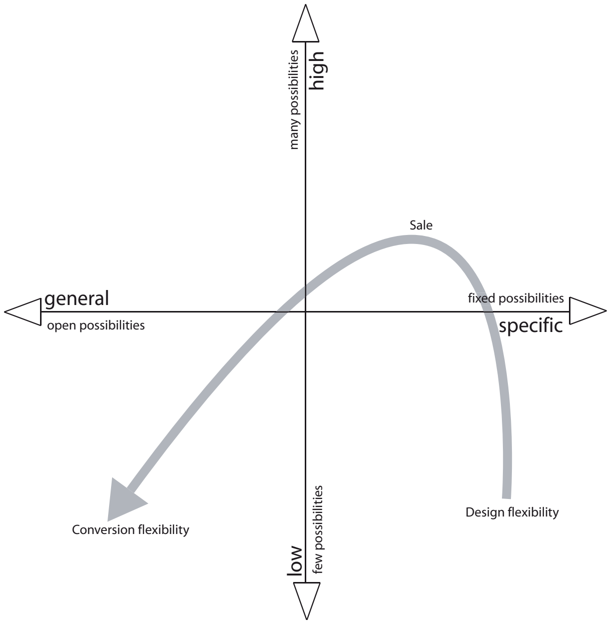
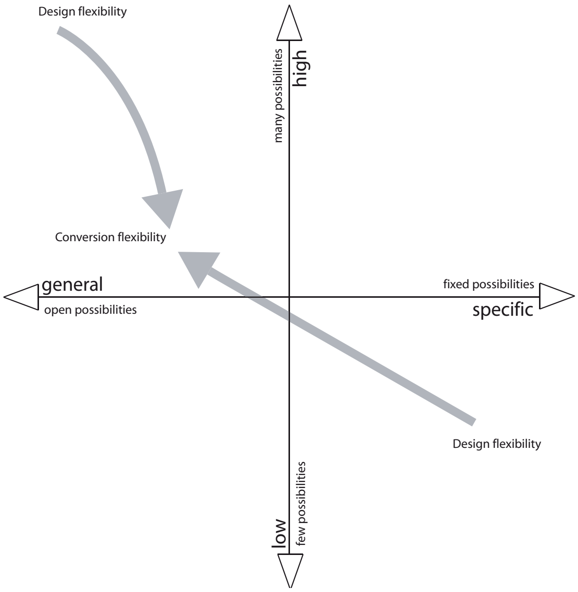
33 The concept of Flexible Solution Space is elaborated in Vibæk (2007) 'Flexible Solution Space'. This section is partly a restructuring of selected sections from this paper.
34 Inhabitants refers to end users of the building space.



Examples

The applied structural building system in VM-husene (the VM houses) by Plot has a fairly low and specific design flexibility, which nevertheless has been challenged intelligently offering a wide variety of plan solutions in the sales situation. However, this kind of customised diversity is rather fixed and thus subsequently leaves the end user with low and general conversion flexibility.

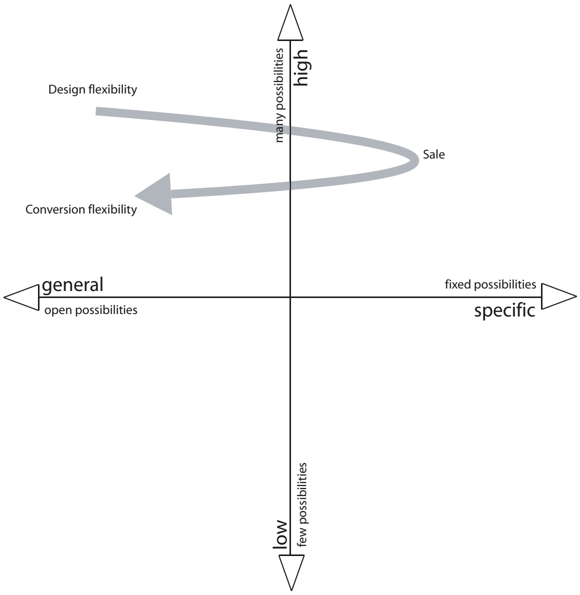
VM Houses, Plot 2002, Photo: Jens V. Nielsen

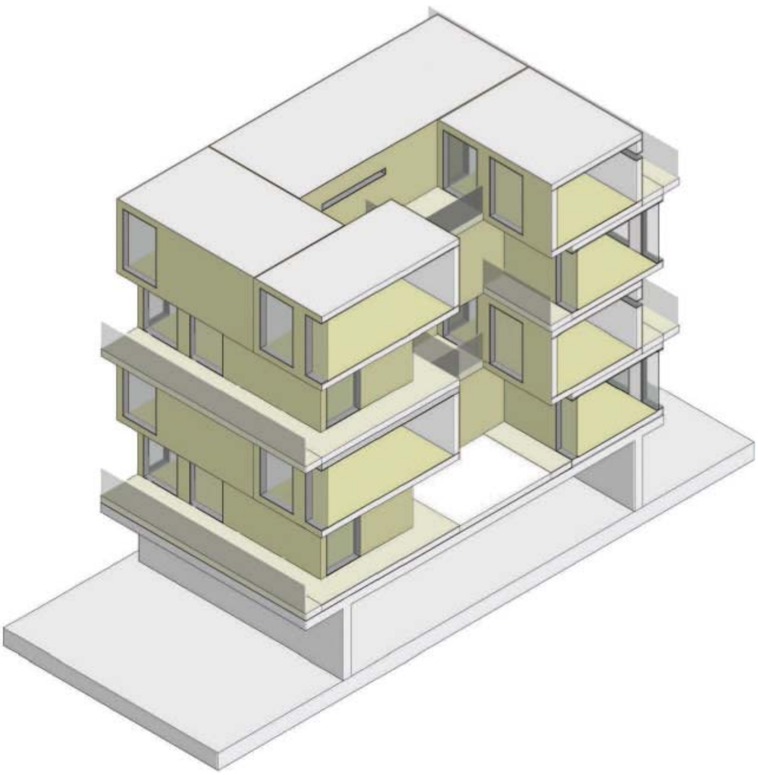


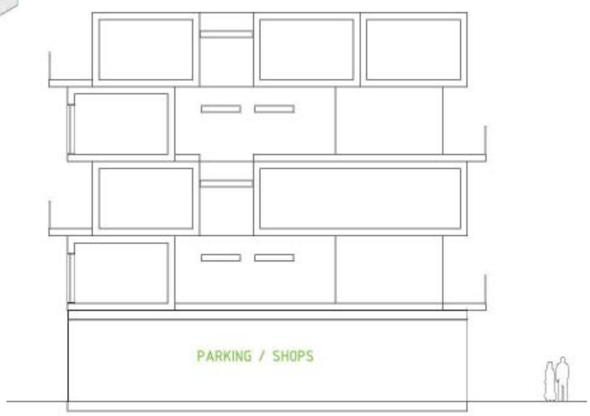
Det nye etagehus (The new/flexible multi-storey house) by Arkitema was developed – as a building system – in its original version to present a high and general flexibility in both design flexibility and conversion flexibility. In later versions, the design flexibility is reduced thus concentrating the conversion flexibility within each dwelling unit.

Latest version of The new/flexible multi-storey house, Arkitema. Photo: ThomasTolstrup

In Megastruktur (Megastructure), the aim is a general and high flexibility concerning both design and conversion. Like in the case of the *VM houses* the first version of the system will probably be sold pre-designed by the architect, thus having a high, but more specific flexibility holding a great number of choices for the first buyers. However, the conversion flexibility of the system remains general.







Megastructure. Illustrations: Gitte Juul Arkitekter

Different strategies for flexibility (and unique solutions)

But what is the general *quality* of flexibility? What needs does it grant? – A current 'trend' seems to be that people want to feel they have personal influence or choice when it comes to how they live. We do not accept standard solutions based on average needs or statistical evidence – as known from hard-core functionalism of the 1960's and 1970's – but demand variation and flexibility in order to be able to express personal identity e.g. through our homes. This is probably not something new but rather something lost. As advocated by Habraken (1999) *'dwelling is building'* (p. 25) – a constantly ongoing relationship between inhabitant and physical enviromment. This *'natural relationship'* (ibid) is sought restored through several strategies.

The expert user as a mediator

The current trend of offering individual and individually customised living solutions evidently has the inhabitant (end user) as a focal point. However, in our opinion ,dealing with e.g. industrialised structural building systems behind the specific solutions and considering the complexity of this platform makes it relevant to introduce the expert user as a necessary mediator in order to unfold the potential of flexibility in a building.

The synthesised knowledge applied in order to create a coherent whole of all relevant aspects can simply not be written into IT based parametrical product configurators or numerically calculable algorithms – or even less: be made accessible and sufficiently understandable for the ordinary 'customer'.
Furthermore, a direct customer-producer relation is a dubious solution when it comes to architecture that tends to modify common physical environments and thus mostly implies many secondary 'users' with many diverging needs, wishes and aspirations. If flexibility for the end user is maximised as a minimum, a mediator is needed in order to create a space for negotiating 'boundaries'.

The expert user, i.e. architect or engineer, and his/her possible decisions concerning customisable aspects at the Design flexibility level does not exclude that the end user (the inhabitant) can have direct influence at the level of Conversion flexibility or Flexibility of use (see above) concerning more tangible aspects, e.g. colour schemes, surface materials, certain accommodation aspects or even location of certain partition walls etc.

Flexible solution space

The point here is that all types of flexibility can coexist perfectly. Still it seems that there is a tendency to give priority to the end user orientated aspects of flexibility. These are immediately visible, but do perhaps not embrace the true demands of the very same end users thus resulting in poor architectural sustainability.

Research shows that the sense of freedom to choose not necessarily is in direct ratio to the actual number of possible choices. If you leave all the flexibility to the end user and maximise the freedom to choose, people apparently have a clear tendency towards one single or a very limited number of solutions.

If an overall intention of giving the end user freedom is to obtain variety physically as well as socially, perhaps the strategy should not be this general conversion flexibility.

Perhaps a combination where the expert user, i.e. architect or engineer, by use of structural building systems with relatively high and general design flexibility creates a moderate and more specific conversion flexibility, e.g. as a more fixed diversity in overall plan layout combined with a smaller amount of possible changes over time may be more relevant.

In this way, expert knowledge is used to create a certain resistance in the result, which ideally can help laymen to unfold built-in potentials in a personalised but still architecturally sustainable way. However, in our opinion, even the expert user needs much better tools to handle the complexity of industrialised construction and architecture. This requires systematised knowledge, specialisation and development of ‘intelligent’ systems and may result in a radical change in the role of the architect as well as concerning how architecture is produced. This points towards the search for a new production paradigm for architectural sustainability.

Hypothesis on architectural sustainability and a new production paradigm

Traditional production technology and terminology have the aim to optimise standardised product solutions with fixed *properties* produced for an unspecified market. The problem here is that the unspecified market is always limited and furthermore has a tendency to change over time, perhaps making the fixed properties inadequate (= not sustainable).

On the other hand, modern production terminology, which is only partly technology supported, i.e lean production, lean construction and mass customisation, is very customer centered and therefore has its main focus on the value level – what value does the product provide for the customer? This level is the least constant (most subjective) of the three levels (property, coherence and value) over time and thus forces industry to move ever faster in the hunt for market possibilities (= not sustainable).

What lacks within both production paradigms in order to provide architectural sustainability is *coherence,* which through the interplay of specific properties provides the architectural work with a sufficient degree of *potential value* in order to be able to meet changing user requirements (values). Coherence implies potentials rather than pointing out fixed values – and the degree of coherence determines the architectural sustainability of the architectural work.

Further research will be needed in order to test this proposal and elaborate on a future production paradigm for architectural sustainability within an industrialised context in the sense of assuring architectural quality over different times, spaces and cultures. The concept of affordance introduced by James J. Gibson dealing with […] *latent possibilities of meaning embedded in the physical surroundings*[35] seems related and could perhaps inspire our concept of *coherence* as a crucial level of architectural quality. Other Danish as well as international research environments have recently published work concerning a more general approach to architectural quality, which will also need to be considered in our context of industrialised architecture.[36] This work, however, has not been possible within the framework of the current project and this chapter.

35 Stylsvig (2007:6) *Arkitekturen som rum(me)lig struktur* (Architecture as spatial structure)
36 E.g. Two recent PhD theses from the Department of Architecture and Aesthetics at the Aarhus Shool of Architecture, projects from Building Design and Technology at University of Aalborg/Danish Building Research Institute and work from the CIB W096 group.

USER INVOLVEMENT

Introduction

With point of departure in the publication; *Brugerinddragelse – CINARK sætter focus* (*CINARK Focus – User Involvement*) this chapter unfolds the question of user involvement in architectural making – from design processes, over manufacturing and construction to post occupancy - concentrating in particular on housing projects. The focus and structure of this chapter are:

- User typologies – how are the users defined?
- User involvement – how are they involved and what is the role of the users?
- Examples of user involvement – specific examples of tools and processes
- User objectives – what are the objectives/ arguments of involving the users in various ways?

Questions that are particularly interesting in relation to these themes are: What are the motives for involving different sorts of users (cf. user typologies)? And, is user involvement particularly important when using industrialised construction procedures instead of conventional building practices? The final question might be shaped by the fact that the (end)users as well as expert users, i.e. architects and engineers, are usually secluded from industrialised manufacturing processes that take place in factories.

This mapping exercise or state of the art looks at the users primarily from an architectural perspective, however, principal theories and methodologies generated in other scientific fields will briefly be touched on, too.

Users in industrialised construction

The issue of users and user involvement in relation to architecture is no novelty! It has always been and always will be an essential part of architectural design processes and project practices/management. The needs and requirements of the future users have always been integrated into the architectural project. Even so, the architectural design is sometimes brought to an end, which the users could not have imagined themselves. Today, the phases of design, planning and construction have become increasingly rushed, complex and rationalised. This development calls for suitable methods and tools in order to involve the (end)users and their judgements in the processes. It has to be in the right mode and with the right timing in order to support the processes as well as qualifying the end result.

When construction is growing to become increasingly industrialised, (e.g. vast use of prefab solutions, systemised supply chains, and automated processes at the construction site), the question about (end)users and user involvement is equally becoming ever more important. This due to the fact that crucial decisions that influence the architectural quality are being made in the early phases of the project brief (the concept design) and often they are made outside the specific project scheme. One of the problems here is that in industrialised building processes, it may be difficult to involve the future users because often they are unidentified. Also, it can be contradictory to design architecture based on detailed user needs that has to appeal equally to wide-ranging groups of users and thereby fulfill general or societal needs. (e.g. client + (end)user + society).

The two rationales[1]

There is no doubt that construction business can benefit from optimised industrialised processes and products in order to become more economically efficient and productive. However, history shows that the industrial visions of the 1970's should not be replicated (as regards the poor social environments and technical results it fostered) – the movement of new-industrialization has to offer a high quality alternative both technologically, socially and architecturally.

The industrial (production) system and the technical/business rationale for the most part imply linear and planning procedures, strict logistics, fixed or systemised working routines and hierarchical decision making. This means that when you press the 'start button' for production – most of the (design)decisions, product properties and performance characteristics are defined and fixed. Involving the user in the decision making of the final design in industrialised construction then becomes a question of: When and how far into the process is it possible or sufficiently economical to integrate the user? And secondly: How can the ecological rationale and the architectural qualities be integrated into or managed beneficially in the manufacturing processes? Another important aspect that also influences the interchange of the two rationales is how to balance specific and subjective user needs and preferences with general and more standardised user needs.

Cultural and human dimensions are central parameters in this discussion. To exemplify: An important issue in the Danish Housing Programme; led by '*Fonden for Billigere boliger*', The Foundation of Affordable Housing, will be to humanise the volumetric elements (the 'boxes') – their physical features, their architectural design and assemblage, and finally to contextualise their scale – will be decisive for their success. As Mies van der Rohe has stated: "Architecture begins when two bricks are put carefully together".[2]

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1 This refers to the common definition in the chapter by Kasper Sánchez Vibæk on: *Conditions for architectural quality in an industrialised context.*
2 Carter, Peter (1961): Mies van der Rohe, *Architectural Design,* March 1961, p. 9

User typologies

When dealing with user involvement in industrialised construction, it is essential to clarify the wide range of users who can be identified in relation to decision making, design processes and evaluation etc. To define the potential users can be a very difficult task, due to the fact that the concept of 'the user' in relation to architecture and construction is defined in various ways, depending on which part of the professional environment you belong to.

Theory concerning property development uses the concept of 'the client', when speaking about the user. It is here taken for granted that one true client exists, i.e. the property purchaser. Here, the developer is the caretaker of this end user's need. However, it is evident that multiple types of clients and users exist.[3] Three primary categories can be defined as important, i.e. the citizen, the user and the consumer.

The citizen

Since the Middle Ages the concept of the citizen has been defined as a person who holds a number of duties and specific rights – among other things to take part in the democratic processes of society. The citizen belongs to a community and has the right to speak out and share his opinion with fellow citizens. The citizen will use this right when he feels motivated and in some cases he will promote his opinion alone to manifest his right to get involved. The citizen is sometimes elected to represent a larger group of people, and therefore, he is responsible for the overall solutions and for ensuring that different interests are being taken care of. In relation to e.g. urban planning, new housing projects and the construction business, the citizen is often a member of an association, or he is a politician who relies on networking and knows the political game. He often focuses more on the general and long-term aspects and less on the specific project.

Collage of user typologies related to architecture and construction business, Anne Beim/Natalie Mossin 2006

3 Kristensen, Tore (2006); Det komplekse Brugervalg, IN: Lund, Lene Dammand ed. (2006), *Brugerinddragelse (User Involvement)*, CINARK sætter fokus, Kunstakademiets Arkitektskole, Copenhagen, p. 27

The user

The user can be identified in different ways. He might not be particularly interested in the long-term aspects of a housing developing project, but is rather concerned with specific and real improvements. This group of committed people is not concerned with the political processes, but rather with supporting the development and realization of the contents of a certain project. Where the citizen represents a larger group of people, the user represents himself. Their incentive is usually generated because they are future occupants or they have special professional knowledge that can support the project development.

The consumer

The consumer represent a group of users who engages in a specific project due to an understanding: "What does this project offer me that I cannot get cheaper or in a higher quality elsewhere"? The concerns of this group of consuming users are to ask for particular solutions or services. If these are not satisfactory, they will shop for better offers somewhere else. Patience and negotiation are not part of the consumer's identity.

The figure below sums up the various characteristics of the primary users se the figure below.[4]

User type	Citizen	User	Consumer
Defined by	Rights	Actions	Consumption
Primary resources	Relational	Specialised knowledge	Preferences
Primary values	Entity	Value in use/performance	Value/Price
Primary motivation	Participation	Improved end result	Curiosity
Awarding	Network	Ownership	Optimal 'purchase'
Primary activity	Negotiation	Contribution	Valuation
Focus on	Processes	Facilities	'Goods'
Responsible for	The entity	The end result	Not responsible
Democratic concept	Executive board	Participation	Supermarket
Community concept	Narrow	Extensive	None

[4] Overgaard, Flemming (2006), inspired by; Jensen, Kirkegaard and Pedersen (1999): The characteristics of the Citizen, the User and the Consumer.

The professional user

Finally, we have the professional users as a special category of advisors or consultants within the construction industry. They are users of software technology, communication technology or similar facilitating tools. They are also users of the construction industry who can shop and choose products or goods in accordance with the architectural/structural intentions of a given project. The professional users are architects, engineers, contractors, developers and the industry. It is important to differentiate between (end)users and professional users when dealing with integrating design processes, mass customisation or user driven innovation.

Lead users – extreme users

When it comes to developing high-end technological industrial products the leading industries and design firms have experienced that the products can only be brought to maturity in cooperation with so called 'lead users' or 'extreme users'. These users seek the essential values of a given product. This phenomenon was described back in 1962 by Everett Rogers, who proved that only 2.5 % of a population can be characterised as innovators who are able to develop new solutions and who can see the value of these.[5]

User behavior

Another classification of users has been used in studies on user behavior in the construction industry and are very different from similar studies in more traditional product industries.[6] Existing theory and models concerning research in consumer behavior look at the user as a 'trend shopper'. To end up with such narrow conclusions requires that it must be possible to identify who the users are and how they behave when presented with different solutions or products. Such analyses are usually much easier when it concerns design of new computers or mobile phones. However, when the 'product' happens to be a complex and long-term investment, such as a house or an apartment, then we are dealing with a great number of different stakeholders or users, who also happen to behave in different ways.

Architect Bjarke Ingels explains a housing project to a group of clients

[5] Everett, Roger (1995), *Diffusion of Innovations,* 4th edition (first edition 1962, The Free Press, New York. And Overgaard, Flemming (2006), p. 95
[6] Kristensen, Tore (2006): Det komplekse Brugervalg, IN: Lund, Lene Dammand ed. (2006), *Brugerinddragelse (User Involvement)*, CINARK sætter fokus, Kunstakademiets Arkitektskole, Copenhagen, p.29. The definitions are elaborated from Tore Kristensen's essay.

Categories of user behavior:

A. ‘The tenant’. Many tenants are very happy to live in their house or flat – however, they might be frustrated about the fact that they do not play a part in the general capital growth in society since they do not benefit from any property investment. It might not be the actual flat that is the reason for a wish to move out but rather pure financial concerns.

B. ‘The housing investor’. This is the house owner who wants to modify his/her home, but who does not want to invest more resources than what can be gained. Real estate agents recommend that you do not invest in a new kitchen when you are planning to sell your flat; most often you only get one third back on your investment. The smart housing investor only invests a third of the money he/she initially planned to spend on housing improvements.

C. ‘The learning housing investor’. This is the cautious type who lives in his/her house or flat because it is attractive, but who is very experimental as to how the dwelling could be designed. They are the ones who think that the kitchen could actually be rotated in the plan.

D. ‘The value-seeking housing investor’. This is a variation of the above mentioned. He/she is concerned about the various values that the dwelling offers not only financially, but also and in particular socially, depending on the context, the concerns of the children etc.

E. ‘The dreamer’. This is a person who wishes to live in a lighthouse in Venice, but who gives up the idea after some years, when he finds a fine house in the suburbs of e.g. Copenhagen. The dreamer is able to load his new dwelling with the meaning of the lighthouse he always dreamed of.

Ørestad city workshop, Mutopia Arkitekter. Photo: Mutopia Arkitekter

To conclude this part – we could claim that the citizen is a potential user and the user is a potential consumer. What defines their different nature is their individual idea of their particular role in the development of a building project and the resources with which they contribute. It can be very useful to involve citizens, users, consumers as well as professional users in the development of a project due to the numerous interests and approaches they offer. When planning innovative project processes where users are to be integrated, it is important to clarify their specific responsibilities and resources, in order to assess how they can contribute to the process. Here, it can be inspiring to ask the participating users to change their role in the project. This could be in ways of looking at the project with the eyes of another generation, the children or the senior citizen – generating the empathy of their special needs or values. That way they experience and get a better understanding of their personal approach and working methods as well as of other users' ideas and practices.[7]

User involvement

It now seems evident that we can point out various types of users with each their characteristics and potentials to contribute to architecture and construction in innovative ways. It is therefore tempting to ask wether the user per definition is innovative – wether the user is able to clarify his/her needs without having a predestined picture of possible solutions. The correlation between needs and solutions and the supply of new knowledge seem to be crucial aspects in developing (industrialised) architecture.
Involving the users in the development of buildings or dwellings is a well-known practice. However whereas the democratic dimension was essential in the 1960's and 1970s, today the focus has shifted to exploring the users' potentials as innovators for new spectacular solutions. Yet, it is still common to involve the users in a building project in order to generate solutions that fulfill most human needs at present as well as in the future and in order to achieve enthusiasm and general support for the project.

[7] Overgaard, Flemming, (2006) IN: Lund, Lene Dammand ed. (2006), *Brugerinddragelse (User Involvement)*, CINARK sætter fokus, Kunstakademiets Arkitektskole, Copenhagen, pp. 98-99.

Design process and user demands

Incorporation of user demands in architectural design processes or product design concerns the question: How can specific quality standards asked for by consumers or users be achieved or retained in the development of design and building products, as well as in entire building projects?
With point of departure in this question, the report *Design process and user demands* presents the results from one of the first research projects of its kind at the Danish Building Research Institute/ Aalborg University.

The project was executed in 2003-04 and attempted to investigate the design process, focusing on added value and improvement of (architectural) quality in construction. Based on eight interviews with key persons from prominent design and production firms, the report describes different approaches to the design process. The selected firms deal with design and development of products ranging from concepts for innovation, industrial design and building components to entire building complexes.

The main focus of the project was to examine the design culture of various firms and the ways in which user demands could be incorporated into the design process (directly/indirectly). Research questions were concentrated on how firms develop methods, key tools and structures in order to expose their processes to user aspirations and demands.
The purpose of the project was to exemplify how user demands can be successfully integrated as a parameter in a design process by exposing and calling attention to the methods, principles and design cultures of the various firms that are essential for successful design solutions. Major conclusions that can be drawn from the analysis of the eight interviews are:

• The design process has vital importance in relation to subsequent project procedure, use of resources and costs. It conditions the quality and value of the end result.

• The design process is not only essential for the development of products within the actual project. It is also central to the general development of skills across various projects and firms. This concerns accumulation of experience and knowledge among the individual employees, as well as exchange of professional knowledge between firms in relation to cooperation on different projects.

• As part of project planning and programming, the design process is of vital importance as regards integration of user demands. It is possible to specify, absorb and target the input of the user in relation to the product so that it will benefit the end user/ costumer the best way.

The research report contains several important conclusions that are related to specific methods, key tools and types of processes. These are described roughly in the chapter *Results*, but each interview provides a range of distinct details. By referring to a sort of 'best practice', it is the intention that the report should serve as inspiration for the improvement of design processes involving users, which are applied in design- and architectural firms – firms that work with product and process development par excellence within the construction industry. This in order to form a basis for processes, that to a higher degree meet specific user demands and that lead to solutions and products of high quality that in the long term will lead to greater user satisfaction in relation to building products and architectural solutions.[8]
This argument also relates to the definition of architectural sustainability mentioned in the previous chapter: *Conditions for architectural quality in an industrialised context.*

Mass customization

In innovative circles of the construction industry, mass customization is proclaimed as the overall answer to the problems discussed when integrating the users in creating higher quality industrialisedproducts. Processes are typically fixed within mass customisation – users qualify product (e.g. by configuration).

This production and business concept unites rational manufacturing, quality control and management, long-term strategies for product and business development etc. with specified individual needs and context requirements. The user is regarded as a consumer – or a procurer – who designs his/her product goods on the basis of a predefined palette/catalogue with fixed options. This model seems to work well when dealing with specific or small design objects and retailing, such as cars, shoes or designer jeans etc.[9] However, when dealing with the construction industry – and most importantly with architecture – the identification of the users and their product preference or understanding of quality cannot be viewed this simply or unilaterally.[10]

User driven innovation

Involving the users in the conceptualisation and programming of an architectural design – or for the assessment of the end result (POE)[11] is a well-known strategy. However, involving users in relation to the planning of architecture, such as in the design and construction process are manifold. A new concept in Danish design industry that is now being transferred to the construction industry is user driven innovation. User driven innovation deals with methods (such as statistics, interviews, design tools etc.) that can supply companies in the construction industry with new knowledge about the users, which

[8] Beim, Anne; Natalie Mossin (2004) *Designproces og brugerkrav* (Design Process and User Needs), Research report, SBi, Hørsholm, p. 90
[9] Vibæk, Kasper Sánchez (2007) The translation of mass customisation models into the construction industry needs an overall and thorough analysis in relation to the question of architectural quality.
[10] Jensen, Kasper Vibæk (2006) "In industrially prefabricated houses, there are some limitations. In that framework it is about how to make the users' desire come true". p. 70
[11] *www.postoccupancyevaluation.com* (a commercial model for Post Occupancy Evaluation - POE)

can improve their products and services – in other word their business. The concept is that they can benefit from integrating knowledge about user preferences and needs. They can do this by collecting data about the users' needs and desires and by systematically developing products and services that respond to these requests.

Examples of user involvement

It is important to find out which type of user needs and user behaviors can be used to generate systematic knowledge and how we then can use this knowledge in a creative and critical way – as designers, architects, manufacturers etc.
Below is a collection of some specific examples of applied methods for user involvement.

Integrating design processes

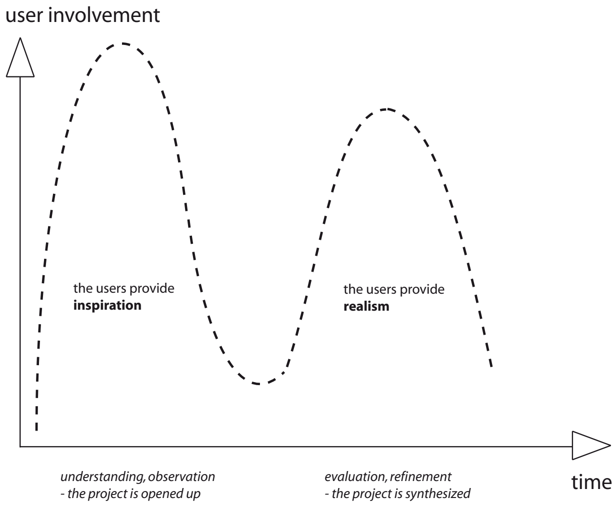
IDEO helps companies innovate. The key to their success as a design and innovation firm is the insights they derive from understanding people and their experiences, behavior, perceptions and needs. They have developed a commercial tool called *IDEO Method Cards: 51 Ways to Inspire Design*. The method cards are meant to keep people at the centre of a design brief. They suggest that as a designer or architect, you ask the users how to help; look at what the users do, and that you learn from the facts you gather.

Users and professionals using a drawing board. Photo: CINARK

IDEO has become a leader in design by keeping people at the centre of the design process.
The cards show some of the methods they use to inspire great design. Each card describes one method and includes a brief story about how and when to use it. This is not a 'how to' guide. It's a design tool meant to help designers/users explore new approaches and develop their own. The decks can be used to form a new view, to inspire creativity, to communicate with a design team or to turn a corner.[12]

IDEAs is a specific design tool that can help trusts and their architects and design consultants to develop their briefs and design ideas. IDEAs is intended to help create aspirations towards good design from the beginning of the process and direct

[12] *www.ideo.com*



IDEO sees relevance in a close contact with users during the whole design process, but the user involvement peaks at the beginning and at the end of the design process/product development

attention towards qualities that otherwise are often lost in highly technical health care environments. IDEAs has three main elements to help us understand 'what people do' and therefore 'what the design should do' to respond to these needs. IDEAs discusses two main sets of issues: CHALLENGES: what people need to do; their activities – and CONSIDERATIONS: what these challenges mean to a design[13]

Process assessment

The British *Design Quality Indicator* (DQI) is a pioneering process for evaluating the design quality of buildings; it can be used by everyone involved in the development process to contribute to improving the quality of our built environment. DQI is a generic toolkit, which can be used in relation to all types of building. There is also a version specifically aimed at school buildings, the DQI for Schools. There are four versions of DQI relevant to different phases of the project that is being assessed:

- **The brief** version is used to help a group of key stakeholders form a consensus about priorities and ambitions for the design brief by defining what aspects are fundamental, what would add value, and what would achieve excellence in the completed building. This helps set priorities and answer questions such as, 'what do we want?', 'where do we want to spend the money?'

- **The Mid-design** version allows the client and design teams to check whether early aspirations have been met and make adjustments accordingly to focus and quality, and can be used throughout the design phase when it is not too late to change things.

- **The Ready for occupation** version is used to check whether the brief/original intent has been achieved immediately at occupation.

- **The In-use** version is used in order to receive feedback from the project team and the building users to help make improvements to this project and the next.[14]

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13 *www.design.dh.gov.uk/ideas/*
14 *www.dqi.org.uk*

Post assessment

The Housing Quality Indicator system (HQI) is a British measurement and assessment tool designed to allow housing schemes to be evaluated on the basis of quality rather than simply of cost. The HQI assesses the quality of a housing project using three main categories: location, design and performance. These are subdivided into ten sections – the Indicators. An HQI assessment generates separate scores for each Indicator producing a profile of the scheme, and an overall HQI score.
The system was developed by DEGW on behalf of the Department for Transport, Local Government and the Regions (now Communities and Local Government) and the Housing Corporation, United Kingdom.[15]

Post Occupancy Evaluation (POE) involves systematic evaluation of opinions about buildings in use, from the perspective of the people who use them. It assesses how well buildings match users' needs, and identifies ways to improve building design, performance and fitness for purpose.
Key features of Post Occupancy Evaluation:

- 'Building users' are all people with an interest in a building – including staff, managers, customers or clients, visitors, owners, design and maintenance teams, and particular interest groups such as the disabled.

- Post Occupancy Evaluation differs significantly from conventional surveys and market research. It uses the direct, unmediated experiences of building users as the basis for evaluating how a building works for its intended use.

- Post Occupancy Evaluation can be used for many purposes, including fine-tuning new buildings, developing new facilities and managing 'problem' buildings. Organisations also find it valuable when establishing maintenance, replacement, purchasing or supply policies preparing for refurbishment; or selecting accommodation for purchase or rent.[16]

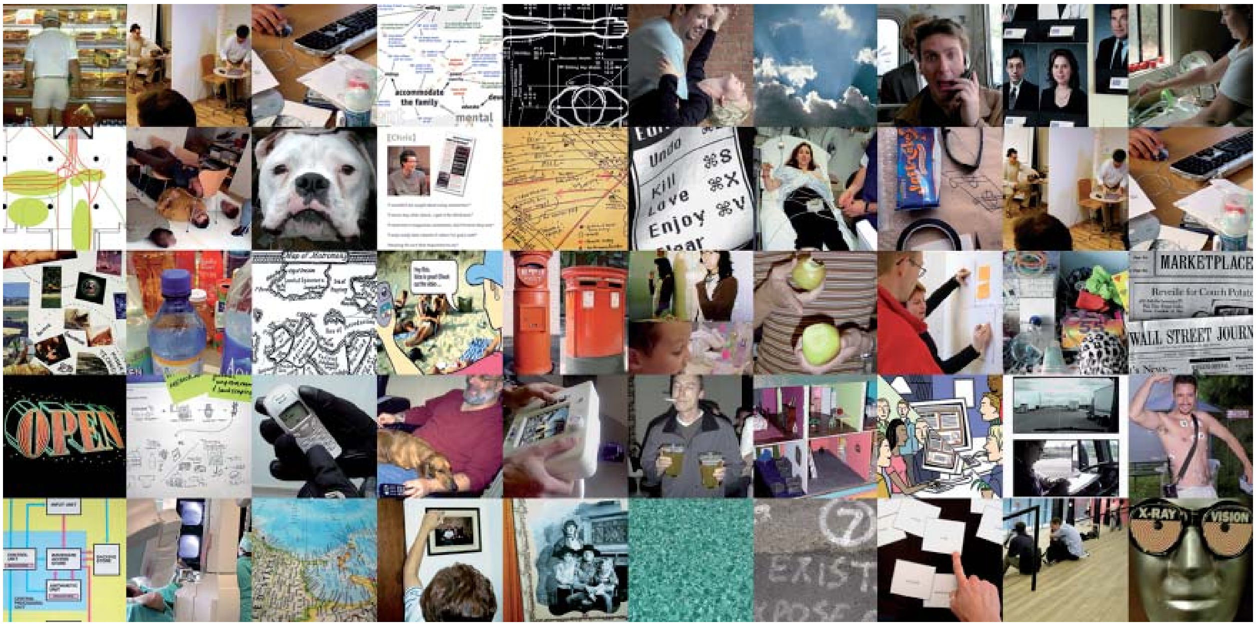
Facility Performance Evaluation (formerly Post-Occupancy Evaluation) – the Californian *Post-Occupancy Evaluation* (POE) programme name was changed in September 2002 to the *Facility Performance Evaluation* (FPE) programme. This name more accurately describes the programme. The goal of this programme is to improve DGS buildings, DGS and State building delivery processes, the responsiveness of DGS to customers and customers' perception of DGS service. It will incorporate a flexible, efficient evaluation process into the daily activities of the DGS. It will support all stages of the building delivery system such as the Five-Year Plan, facilities plans, Capital Outlay Budget Change Proposals, Budget Packages, design, construction and

[15] *www.communities.gov.uk/housing/decenthomes/publicationsaboutdecent/housingqualityindicators/*
[16] *www.postoccupancyevaluation.com*

operations. Major focuses of the programme will be to better understand the impact of early design delivery decisions on long-term efficiency and effectiveness of buildings and to better understand the impact of building delivery processes and decisions on customer response both initially and over the life cycle of the building. It will be broadly inclusive both within and outside DGS, partnering with customers as appropriate. It will start quickly and modestly and will include ongoing development and refinement.[17]

'Education' of the public client

CABE is the government's advisor on architecture, urban design and public space in the UK.
It is a public body that encourages policy makers to create places that work for people. CABE helps local planners apply national design policy and offer expert advice to developers and architects. They show public sector clients how to commission buildings that meet the needs of their users. And they seek to inspire the public to demand more from their buildings and spaces. Advising, influencing and inspiring – CABE works to create well-designed, welcoming places.[18]



IDEO method cards. Courtesy of IDEO

[17] *www.poe.dgs.ca.gov/default.htm*
[18] *www:cabe.org.uk*

User objectives – six arguments

In this chapter, we have discussed different concepts of the user, and how this user can be integrated or involved in the development and improvement of products in general and of architecture in particular. As mentioned in the introduction, the question of user involvement becomes more important in the industrialised context, which is today already a basic condition within the construction sector. As the rest of the processes related to construction become ever more specified and 'pre-engineered' (industrialised), the involvement of the user needs to follow the same track in order to be sufficiently taken into consideration.

But what is the overall purpose of involving the user? Is it always good, right, advantageous, profitable or facilitating? There is no simple answer to this question, but perhaps looking at six central arguments can help clear up the underlying purposes of user involvement when looking at particular cases.

- The economiy argument
- The management argument
- The participation argument
- The legitimising argument
- The knowledge argument
- The public argument.

Arguments for involving the users

In the discussion of involving the user in the innovative processes there are clear economic arguments. It is supposedly a win-win situation, where time and money are saved and products and services hold values that we can live off. This can also be a one-sided business perspective where the company tries to maximise the profits. Then there is the management argument. By way of example, if we are going to change the physical design of an office space, then it is a good idea to involve the employees in the discussions in order to form strategies for how to use the space.

As a third category, we have the aspect of participatory democracy. This is the true legitised human need; for instance to take part in decision making on how you want to live. This form of legitimisation is of great importance since it generates a sort of ownership for the various decisions and architectural solutions.

Then there is a fourth aspect, which is usually not very emphasised. User involvement can be seen as legitimising an intention. The users take part in some sort of story-telling that is going to help a project to be accepted. The project gets a 'democratic make-over', but basically the decisions are made before hand.

U_Build, software program. A gaming tool to improve and inspire communication with various user groups. Mutopia Arkitekter

There is also the argument of generating or gathering knowledge. I.e. exchange of knowledge between citizens and specific stakeholders. Here exists the dream that in e.g. workshops and seminars you can produce new knowledge that does not come from the citizens or architects alone, nor solely from the public/political authorities or the clients.

Finally, there is the public argument that concerns a political or governmental obligation to the public – or as Hegel stated 200 years ago: “If you want to realize the common/general then you have to put distance to the simply private”[19].

When involving the user according to the above mentioned arguments then the essential question will be: What sort of knowledge or innovation is demanded, and consequently, what sort of users and democracy models ought to be included in a current project? Of course there are combinations of implementation, innovation and evaluation projects, and the specific building project will always determine which sort of users and processes will suit the various phases of a given project.

This paper has tried to provide a map over a novel field of research within the construction industry and the architectural academic environment – i.e. user typologies, methods to gain knowledge about user needs and behaviours, and the implications of user involvement in building projects. Based on this work, we believe that three central hypotheses can be suggested as follows:

[19] Larsen, Steen Nepper (2006), *Borger, bruger, forbruger*, (Citizen, User, Consumer), IN Lund, Lene Dammand ed. (2006), Brugerinddragelse (User Involvement), CINARK sætter fokus, Kunstakademiets Arkitektskole, Copenhagen. p. 32

Hypotheses

a. User involvement makes best sense in the initial and final phases of a building project.

b. Only extreme or specialist users can provide the architectural design process with provokingly new knowledge or constraints that may inform the project with fruitful input that will result in a high-quality end result.

c. Users (laymen) assessing the architectural result may provide the designing architect with new knowledge and ensure quality in future building projects.

Thorough research into these key questions is still needed to be carried out since they have not been tried or analysed by architectural researchers – or building researchers in general. However, CINARK has the ambition to follow up on the initial work provided by the seminar and publication on; *User Involvement* (2006) by arguing for further financial resources from the Danish Ministry of Culture and similar research funding to elaborate on these issues.

MASS CUSTOMISATION AND THE PRODUCTION SYSTEM

– State-of-the–art in the construction industry

Mass customisation is often referred to as a strategy for creating increased value for the customer by adapting the product for the needs and expectations of the individual, but producing it by means of a standardised production system. This definition is clearly seen from the viewpoint of the mass producer, moving towards a higher degree of flexibility.

In architecture and the construction industry, the flexible (but by no means efficient) production system already exists and the products are mostly individually customised, not for the individual end user, but mostly for the individual client. In this industry, the notion of mass customisation is equally interesting, though. But where the manufacturers of consumer products seek to individualise the mass produced, the aim of the construction industry will be to mass produce the individualised.

In order to exploit the possibilities of mass customisation in construction, it is necessary to define a limited solution space and to make use of a production system that can automatically handle successive variations in stable processes. This necessitates the use of CIM, computer integrated manufacturing, or in the case of architecture, CIC, computer integrated construction.

Computer integrated construction aims at the integration of an automated production system over the entire value chain from user specification over construction, production, installation and use to maintenance and recycling. Systems incorporating the entire chain exist for the sales, production and maintenance of products like consumer electronics and clothing[1]. A fully computer integrated sequence of production implies an automated digital flow from initial decision/configuration process to manufacturing/delivery/assembly process.

"Configuration is a key concept in mass customization and is similar to the parametrics of CAD programs. Instead of having unlimited possibilities, configuration operates from a solution space limited by standards or parameters. This doesn't necessarily mean a limited number of solutions, as standards and parameters can have unlimited values, but in its pure form sets limits to, what is possible. By configuration, an individual solution is assembled for each order adapted from the parameters in the platform." [2]

A digitally automated manufacturing process is an engineered process, where the tools in operation are directly controlled by a parametric model and each of the resulting products thus can be different from the rest.

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1 *www.nikeid.com; www.dell.com*
2 Thomas Ryborg Jørgensen (own translation): *Architecture and mass customization*, CINARK 2007

The notion of configuration and digital, automated manufacturing can thus, in a simplified way be condensed to a read/write process or, in digital terms: scanning and printing. In most cases, the scanning or input of the user needs/decisions is done via the configurator, while for the printing or manufacturing some kind of digitally controlled process is needed in order to fully exploit the possibilities of an automated flow.

Within the construction industry, no fully automated configuration, production and installation system is in operation at present. Seen as a flow line from user specification to recycling, there are examples of systems handling different areas of the chain.

This chapter will show examples of CIC systems from the construction industry with their focus on configuration, engineering, manufacturing or installation. Although engineering in a fully industrialised line of thinking should be called product development and placed prior to configuration, in the contemporary design process it is still exercised as a construction process following the design phase. We will also show an example of a system from another industry (shipbuilding), which handles almost the entire value chain for a product, which in complexity is highly comparable to the construction industry.

Focus on configuration

The construction industry is, to a large extent, based on one-offs and can be characterised as an engineer-to-order environment. Considerable resources are used in the sales process. Manufacturers and suppliers of building components use their resources in several stages of the projects:

- (Architectural) Design stage
- Tender stage
- Construction stage

In the design stage of the project, the supplier will typically service the architect or contractor in terms of providing proposals and samples showing how their particular product can be incorporated into the project. The project team is at a research stage often without any clear overview of the project economy and the supplier has no way of knowing whether his product will survive the following tender stage, even if it meets the required specification.

At the tender stage, the supplier will use resources for calculation of the supply to the project. As products for the construction industry are often customised in one way or another, calculating projects often takes up a lot of time and the 'hit rate' can be depressing.

At the construction stage, the suppliers of more complex systems like cladding, ventilation, special interiors or shading systems will be expected to supply detailed design documentation of their delivery, something that often requires many engineering hours.

It is obvious that there are huge savings to be made in the automation of these processes. The design stages can be automated by the customer/architect using interactive tools for modelling proposals for testing the product in relation to a specific project. Tender stage calculations can be rationalised enabling the company to tender for a wider range of products, and the production of detailed design documents can be produced by means of a modular design and documentation approach.

One example of a configuration tool oriented towards the user/architect as a decision facilitating tool is the configurator developed for the roof light company Velux. The tool is based on relatively simple rules showing the possibilities of combining the company's products and the geometrical limitations. The configurator is not connected to the company's ordering or production system in any way, but is only meant as a guide to the customers (and thereby a way of saving time in the sales process). The tool has therefore been developed to be graphically realistic and with a self-explanatory interface. As the tool only handles the roof lights, there is no interaction with other parts ad the context-sensitiveness only works internally within similar parts.

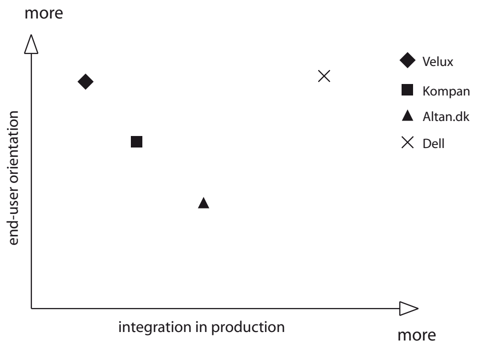
The company Kompan[3] on the other hand, has developed a configurator where the context sensitivity is far more developed. Kompan designs, produces and sells complete systems for playground installations. The individual parts of the installations could be quite different (swings, rope ladders, jungle gyms, slide etc.) They are all part of a modular system, but with a complex set of rules. Not all parts of the system can be combined, and to make things even harder to manage, only some configurations of one part can or must be connected to another. As an example, the steps up to a slide should be secured by a railing, but only if more than a certain number of steps are needed. The railing is automatically added by the configurator, ensuring that the final system is according to norms. Also distances between parts of

[3] *www.kompan.com*

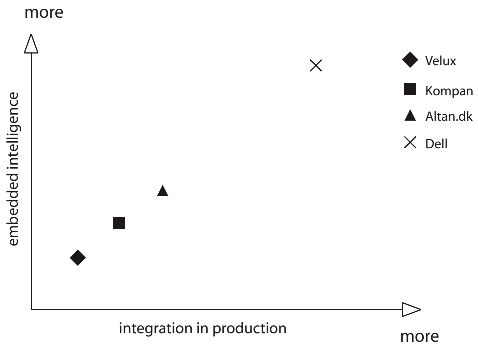
the installation are checked for security issues. This system is integrated within the order system of Kompan and therefore also saves resources in the ordering process. Due to the training needed, the configurator is operated by the sales person, and it is not integrated in the production process.

Further toward production integration, the configurator of the company altan.dk is found. The company is an example of a very computer integrated company, where the development of the IT systems has influenced the very nature of the product. The sales orders, generated from the configuration, which as in Kompan's case is done together with the customer, automatically create a production order, detailed down to the last bolt. The integration in the production system is more developed than at Kompan, although there is still no direct link between IT system and numerically controlled machines. The actual production still goes via paper documentation.

The correlation between direct customer interface and degree of choice on the one hand and production integration on the other is shown in the diagram below. For comparison, an example from the computer industry is plotted in as well:



The corresponding diagram comparing embedded intelligence in the configurator and production integration would look as follows:



As it is seen by comparing the two graphs, integrating the software from customer to production line is very demanding on the complexity of the software. The production integration is also far more demanding to implement for the company. A front-end application for marketing purposes can be outsourced to a web designer, whereas production integration sometimes means rearranging and rethinking the entire production setup.

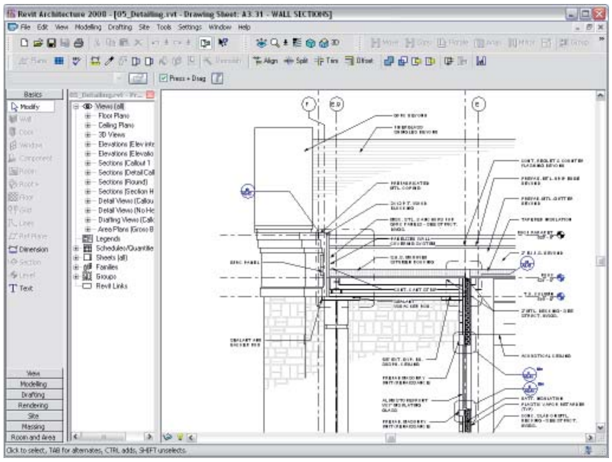
Focus on engineering

Engineering in industrialised construction is in a way self-contradictory. In an industrialised context, engineering is only used in the design and development of products and processes. Within a reasonable economy, the manufacturing of the individual product, whether it is one of a kind or one out of a series, cannot be designed or engineered, only configured on the basis of previous design or engineering. In the world of producing consumer products, it is unthinkable to use design or engineering time on the basis of one customer. As almost all architecture is (still) designed and engineered, we cannot (yet) speak of a fully industrialised construction industry.

The architectural/engineering community is working with software, which in time could be integrated in an industrialised construction process. The software used today falls into two groups:

- 2D/3D
- 3D parametric

The 2D/3D software is geometrically capable, but with no inherent knowledge of what the different geometrical elements represent. Typical examples are AutoCAD from Autodesk or MicroStation from Intergraph.



In 3D parametric software, properties can be attached to the individual elements, allowing them to interact with each other and also respond to context, such as position, orientation, size and proximity to other objects. The parametric software is similar to the software used in the user-oriented configurators above, but it is not dependent on a production system. Examples in architecture are Revit from Autodesk or Gehry Associates' use of Catia, software developed for use for and by the aerospace industry.

The use of parametric software is sometimes put forward as a fully integrated approach (as with Gehry Associates' use of Catia), but in order to be fully industrially integrated, the software will have to fulfil the following demands:

- A set of rules, only allowing choices to be made, that are according to norms and to the (economically viable) possibilities of the production system.
- The ability to develop continuously as a result of accumulation of knowledge.
- An un-interpreted digital dataflow from configuration to production order.

As this is in no way the case, the use of contemporary parametric design software can then in away be seen as a 'detached configurator' i.e. one, that has no direct connection with the manufacturing system and where 'illegal choices' are controlled by the knowledge of the designer, engineer or manufacturer. The digital output from the software is sometimes translated, sometimes interpreted and re-entered as digital information in a different format by the industry. Some offices have gone far in trying to implement a fully digital workflow. Gehry Associates 'digital project' developed on the basis of Catia is potentially capable of integrating rules and context-based reactions[4].

One of the major obstacles in implementing a fully computer integrated dataflow in the construction industry is the in-grown tradition of the tender process. Tendering for a 'package' on the basis of a set of construction drawings has its roots in the workmanship-related division of architectural construction into 'crafts'. The tender legislation was formed to ensure that the client, by choosing the lowest bidder, would pay the market price for a product. In an industrial environment, it does not work this way. "If the construction of a car was documented and tendered in this way, even among the present manufacturers, the price would be at least 10 times as much as it is today"[5]. The pricing mechanisms in the industry are based on uninterrupted dataflows and supply chains, gradual process optimisation, stable teams and colllection of knowledge.

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4 *www.gehrytechnologies.com/products-knowledge-expert. www.gehrytechnologies.com/products-knowledge-advisor.*
5 Kaare Groes Christiansen, Interviewed 14. Sept. 2007 by Jesper Nielsen.

Focus on manufacturing

In the general manufacturing of architectural components, R.-B. Richard identifies five degrees of industrialisation:

1. Prefabrication
2. Mechanisation
3. Automation
4. Robotics
5. Reproduction

"… prefabrication generally implies building in a factory) components or full modules very similar to the ones done on a traditional construction site, very often using the same processes and the same materials. For instance, most modular housing manufacturers are first building wood-framed panels quite similar to ones done at the site even when they use automated devices.
Still, for the following reasons, prefabrication does bring the construction cost down as much as 15 % when the plant is producing at full capacity (i.e. when mass production is obtained):

- climatic protection;
- rationalisation of the tasks along a production line;
- specialised tooling and handling equipment;
- semiskilled labour;
- better quality control; and
- bulk purchasing of raw material due to the single delivery point.

Mechanisation comes in whenever machinery is employed to ease the work of the labourers (power tools etc.). Usually, prefabrication will be accompanied by some level of mechanisation. For instance, the modular housing manufacturers will usepneumatic hammers, rolling bridges etc.

With automation, tooling is completely taking over the tasks performed by the labourers. A 'supervisor' is still around, although the industrial engineer and the programmer are the critical participants involved. A study about Swedish wood-framed panels assembled by automation indicates an economy up to 27 % compared with traditional construction methods; the quantity was there, as those manufacturers covered about 90 % of the single detached homes market in Sweden in the 1990's.

With robotics, the same tooling has the multi-axis flexibility to perform diversified tasks by itself. It is likely that the robot is too expensive to use for nailing wood studs or laying bricks. The future of the robot is related to computer-aided manufacturing (CAM): Generating complex forms that can be different from one unit to another, opening the way to individualisation within mass production, opening the way to 'mass customisation'.

…Reproduction is the introduction of an innovative technology capable of simplifying the "multiplication of complex goods. The purpose of reproduction is to shortcut the repetitive linear operations, which are the trademarks of the craftsmanship approach, like nailing wood studs, laying bricks etc.

Instead of investing straight into machinery, reproduction is first calling upon research and development for 'ideas' to generate a simplified process. Reproduction is not necessarily available as a downright option, it usually accompanies some of the other degrees of industrialization".[6]

Reproduction could be seen as a combination of mass production processes (for efficiency) with customisable processes (for flexibility). The art of printing invented by Gutenberg could be seen as 'the mother' of reproduction. R.-B. Richard also exemplifies this last level by the comparing it to the integrated circuit, which started as components soldered together with wires, then developed into the printed circuit and is now manufactured as integrated circuits.

There are many examples of industrialised manufacturing approaches in the construction industry, incorporating one or more of the above levels.

Prefabrication

Prefabrication in the construction industry refers to manufacturing in a controlled environment (i.e. a factory) instead of on the building site. There are examples of small one-family houses, produced in their final sizes and then transported to the building site, but as soon as the building exceeds the transportation limits (normally 2.5 m. in width), the building has to be split up in some way. There are several approaches to this, all being related to a particular product architecture (not to be confused with architectural design) and modular strategy.

In product development, one normally distinguishes between integral architectures and modular architectures. Integral product architecture implies a non-flexible, performance-driven, highly optimised product meant to be produced in large

6 Roger-Bruno Richard, Industrialised building systems: reproduction before automation and robotics, *Automation in Construction* 14 (2005) pp. 442-451

volumes. In the construction industry, these kinds of products are to be found as individual parts of technical systems (ventilation, lifts) and to some extent as singular design elements like doorknobs, toilets and water taps. Modular product architecture is when the product is split up into individual 'chunks' due to production or transport limits, platform design, supply chain issues or user adaptability.

Modular architectures comprise three types: slot, bus and sectional (Ulrich, 1995). Each type embodies a one-to-one mapping from functional elements to chunks and well-defined interfaces. The differences between these types lie in the way the interactions between chunks are organised:

- Slot-modular architecture: Each of the interfaces between chunks in a slot-modular architecture is of a different type to the others, so that the various chunks in the product cannot be interchanged.
  An automobile radio is an example of a chunk in a slot-modular architecture.
- Bus-modular architecture: In a bus-modular architecture, there is a common bus to which the other chunks connect via the same kind of interface. A common example of a chunk in a bus-modular architecture would be an expansion card for a personal computer.
- Sectional-modular architecture: In a sectional-modular architecture, all interfaces are of the same type, but there is no single element to which all the other chunks attach.
  The assembly is built up connecting the chunks to each other via identical interfaces. Many piping systems adhere to sectional-modular architecture, as do sectional sofas, office partitions, and some computer systems.[7]

Prefabrication is used by many housing manufacturers, who assemble wooden panels in the factory in order to control quality and cut down process time. More interesting are prefabricated units, some with installations already in place. These functional units tend to appear mostly within two certain areas of the building:

- Bathrooms[8]
- Facade cladding[9]

The bathrooms are made from concrete, steel and fibre-concrete or steel and FRP. The units are assembled in the factory with all surfaces and fittings finished. An opening is left on the outside of the unit for connection of wiring and plumbing. The units are sealed off when shipped and installed and are not opened again until the building is delivered to the user.

7 Ulrich and Eppinger, Product design and development, McGraw-Hill 2003.
8 EJ Badekabiner, Betonelement A/S
9 Permasteelisa

The bathroom units are an example of a slot-modular architecture. EJ Badekabiner notes the following advantages of the concept:

- Savings in design and construction (design work is lifted away from the architect and placed eith the manufacturer)
- Fewer defects in the product
- Reduced waste
- Improved user involvement
- Security on site
- Simple guarantees and responsibilities
- Shorter construction times[10]

The same advantages could be listed for unitised cladding systems. Where conventional curtain wall systems are 'stick-systems' installed in separate profiles and glass panes, the unitised systems of i.e. the Italian company Permasteelisa are based on the saparation of the cladding in a separate prefabricated delivery of transportable units. Unitised cladding systems are based on bus-modularity.

Other manufacturers take the 'sectional' approach. Instead of building walls around technically centralized units, they 'cut' the building into transportable slices similar to the practice in the shipbuilding industry, leaving gaps around the seams to connect wiring and plumbing before finishing the surfaces on site in these areas.

The 'BoKlok' Concept made in cooperation between Skanska and IKEA is based on this sectional modularity.

Ullerød syd, low energy and low-cost housing. Photo: ONV Arkitekter

"The buildings are erected by Skanska in modules, i.e. the individual dwelling is built from 2 to 4 parts. The modules weigh 6-10 tons and are transported to the site on lorries. The modules are manufactured indoors in a dry and warm environment in a Swedish factory. Simultaneously, the foundations are cast, and connections for wiring and plumbing are prepared on site. The modules are moved into place by means of cranes and the houses are finished for occupancy after 6 weeks. During this period, terraces and balconies are installed and the landscaping is finished."[11]
Skanska/IKEA claims to save on time, materials, energy and money, and that they increase security in production and on site.

10 *www-ej-badekabiner.dk*
11 *http://www.boklok.com/*

Photo: Danish Robot Asssociation, DIRA.

Automation

Automation implies repeating a process continuously for a considerable period of time and in the construction industry it is therefore mostly used for the manufacture of smaller generic components (screws, studs, standard windows). Also casting with demands for continuous reinforcement (sliding shuttering), calls for an automatic approach.

Robotics

Robotics is not yet widely used in the building component industry. A couple of years ago, the window manufacturer Frovin in Denmark experienced increased production times and the inability to expand due to a bottleneck in the manufacture. Frovin delivers windows with puttied glass for renovations, but puttying is only carried out by skilled craftsmen and the process is slow. A putty robot was developed on the basis of intense studies of the craftsmen at work. The result is a capability increase of 900 % in this process.

Of greater architectural interest are the processes, where the digitally controlled robot is influencing the experienced shape and structure of the building. CNC-controlled processes with an obvious potential in architecture are:

- Milling
- Laser-cutting
- Bending
- Contour crafting

It is important in this line of thinking to understand, that digitally (or CNC) controlled processes like milling are normally several times (or hundreds of times) more expensive than a mass producing process such as injection molding. The common belief among the missionaries of freeform architectures and one-off objects that unique parts are the same price as standards parts, is only true in case you are forced to use a customisable process like milling or laser-cutting due to low volumes or high demands as regards precision. In all other cases, the additional cost of CNC-controlled processes should be weighed up against customer value.

An interesting example of CNC-milling opening new architectonical possibilities is the robotics in the company KLH in Austria, which manufactures laminated wooden panels.

KLH laminates panels up to 4.5 x 10 m. which can be used for exterior and interior walls, slabs and roofs. The panels are treated structurally like prefabricated concrete elements, but they are lighter, more insulating and with a very pleasing surface, that can be used internally without further treatment and thus no use of paint or other chemicals on the building site.

The panels are manufactured in rectangular shapes, but are milled by means of CNC-milling machines to exact free-formed shapes according to customer specification. The milling is done straight from CAD files by the architect or engineer. On the project 'Impulsezentrum' in Graz, Austria, the panels were assembled in the factory to lorry-sized units and moved into place by means of cranes, thus combining the concepts of pre-fabrication and robotics (CNC-milling).

Due to the simple nature of the panels, further automation of the unit assembly process by large scale robots could be imagined, and integration of installations could quite easily be done by laminating them in the process. It would also be an obvious step to develop a plug-in with the relevant construction rules for the CAD software of the architect.

Photo: KLH Massivholz GmbH

The CNC-milling of wooden sheets is restricted (unless excessive waste is allowed) to two-dimensional shapes, which could then be joined into facetted spaces, but most 3D software is capable of 'unfolding' complex shapes composed of single-curvature surfaces into flat sheets. This opens up for another approach, 'developable surfaces':

"Developable surfaces can thus be created from sheet material through simple bends, without stretching. Because of this, the technique is widely used in the shipbuilding and aerospace industries, and the method permits cost-effective creation of complex surfaces… In architecture, developable surfaces have lately become well known through the buildings of Frank Gehry, where the titanium cladding has been manufactured in this way."[12]

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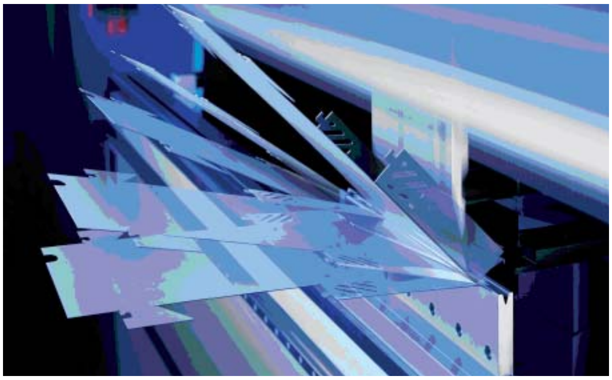
[12] Martin Tamke: Formative techniques, *Arkitekten* 6/2007.



Combined laser-cutting and CNC-bending.
Photo: courtesy of Trumpf corp.

The same approach can be applied to laser-cutting of metals. Laser-cutting is sometimes used in architecture for achieving customised patters in steel fittings like balcony railing or facade cladding panels, but the steel industry is gradually increasing their use of laser cutting instead of rolled profiles for construction members. This could potentially also open a new path for architectural design, as laser-cutting in connection with CNC-bending is a technology that is capable of creating structurally stable, but spatially interesting new shapes with only a fraction of the material needed in conventional construction.

Contour crafting

Where milling is a subtractive process and bending a formative process, the relatively new production method contour crafting is an additive process. The concept is very similar to the methods used in rapid prototyping, but where the SLA and SLS processes are based solely on layered fabrication, contour crafting is a *"layered fabrication method which combines ancient surface forming concepts with modern robotics technology"*.[13] The method has been developed and refined by Behrokh Khoshnevis at the University of Southern California.

Contour crafting is extremely flexible, as it can produce virtually any shape imaginable. The equipment is heavy and the finished structures not very strong. The process is based on the use of a gantry crane-like device for carrying the nozzle and is therefore also space consuming and difficult to erect.

In the future, smaller radially working and more flexible kind of robots could be used for the process, and reinforcement materials could be developed, making contour crafting a very interesting alternative to in-situ concrete casting.

Reproduction

A widely used example of reproduction in the construction industry is the development of extruded aluminium profiles. The commercial development of the extrusion process after World War II has been a major driver for the curtain-wall

[13] *www.contourcrafting.org*

market and besides the development of reinforced concrete in the late 19th century, one of the largest technical influences on contemporary architecture. The extrusion industry is highly flexible, and customised extrusions can be delivered at short notice and very low start-up costs.

With their Demonstration house in Tosu City, Riken Yamamoto & Field Shop show how an architect can work directly with the industry on a specific project by using aluminium extrusions. The house is built almost entirely from one X-shaped and one V-shaped extrusion, creating enclosing walls and structure at the same time.

Ecoms House, Yamamoto and Field Shop. Photo: Schinken chi ku-sha

"Riken Yamamoto & Field Shop's work takes the classic modular construction approach into modern day form; the team has developed a prototype – for a firm which produces special metal sections and aluminium-module furniture – for an industrial lightweight system. It is intended to make optimal use of the characteristics specific to aluminium, and to express an aesthetic identity which would not be possible with conventional, standard construction meterials, including steel."[14]

The architectural possibilities in 3-4 custom-made profiles have also been thoroughly explored by the English Architect Richard Horden.[15]

Among the processes for architectural 'reproduction', that could turn out to be of great future importance, is the pattern-making industry presently producing moulds and plugs for fibreglass boats and wind turbines. The huge milling machines grind down a polystyrene block to slightly smaller than the finished plug. A CNC-controlled paste nozzle distributes epoxy paste over the shape, and after the curing process, the milling machine grinds the plug into its final shape. After this process, the plug can be used for a large number of moldings of GRP. The process and raw material is still too expensive to use in the construction industry, but future investments in more automated versions of the process could make it very interesting indeed for the production of weather-resistant free-form surfaces.[16]

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14 Riken Yamamoto & Field Shop, Demonstration House in Tosu-City, *Detail*, #7/8 2006.
15 Richard Horden: *Boat House*, Poole, England.
16 El-Bo Productions A/S Kastanievænget 6, 8990 Fårup, DK.

Printing from CNC-milled moulds. Photo: EL-BO Production

Focus on installation

Automated installation on site is an almost unwritten chapter in the development of architectural construction. There have, though, mostly in Japan, been experiments with automated construction systems. The multi-national company Kajima (contractors on i.e. the Potsdamer Platz project in Berlin) is investing some research in the subject and has erected a few buildings based on the systems:

"Kajima has developed a fully automated building construction method, AMURAD (Automatic up-rising construction by advanced technique), where the top floor of a building is constructed first, then raised so that the next floor can be constructed beneath it.

This method is being used on the (tentatively named) Yokogawa Construction New Headquarters Project, scheduled for completion in September 1997. In January 1997, the 11th floor section, which is the top floor, was lifted up and secured into position.

By using this new construction method, which is radically different from the conventional method of constructing buildings from the ground up, workers can construct each floor of a building at ground level. Since everything from the lifting of each completed floor to the transport and assembly of materials, such as steel casting, is done automatically, construction time can be reduced 30%, and the number of workers needed and waste materials produced can be reduced 50 %".[17]

Automated construction systems inherently put restraints on flexibility of design, and the future in ever greater demand for individuality implies a limited future success for the concept on a large scale.
An interesting opportunity could evolve from the development of masonry robotics. According to Mette Jerl, CINARK, the architects Fabio Gramazio & Mathias Kohler at ETH's architecture department in Zürich have developed an industrial robot for masonry work.[18]

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[17] *www.kajima.co.jp/topics/news_notes/vol2/v2c.htm*
[18] Mette Jerl: The comeback of the weaved wall, *Arkitekten* 11/07.

The programmed wall, 2006. Gramazio & Kohler Architecture and Digital Fabrication, ETH Zürich

The robot is capable of doing bonds and patterns even more precisely than a craftsman. In the process adaptation for the robot, the mortar has been replaced by a polyester glue, and the bricks are made specially in order to accommodate the reduced tolerances of the robot compared to the human hand.

A classical bond is in principle an algorithm, i.e. a kind of recipe for solving a certain kind of problem. Written as a computer program, it enables the robot to do any kind of bond, and it depicts an image on the facade by means of small successive displacements of the brick…[19]

The latest example of the use of the robot is the cooperation between Gramazio & Kohler and the Swiss architects Bearth & Deplazes on a farm warehouse in eastern Switzerland near the town of Fläsch, where every facade element is manufactured in the ETH Zurich Architecture and Digital Fabrication laboratory and then transported to site.

The robot has its limitations. So far, it can only operate within a frame of 3 x 5 m, but it might invoke a new ability for the architect and craftsman to imagine architecture on the brick's terms and again think of the brick as a component, that can weave around new solutions and joints.

19 Mette Jerl: The comeback of the weaved wall, *Arkitekten* 11/07

Jerl clearly sees the robot as a tool for prefabricated units, but the possible implications for on-site automated construction systems are equally interesting and it seems to be a more rigid and tactile alternative to contour crafting.

Comparable industries

In order to show the potential level of industrialisation in the construction industry, the automotive industry is often put forward as an example and a benchmark. For a century, car manufacturing has been the main driver for innovation in product design, development, engineering and management as well as marketing. But a car is a truly mass produced item. Architecture is not.

We will compare with a different industry, shipbuilding, and see how configuration, engineering and manufacture have reached far higher levels of industrialisation than architecture, despite the similarities in complexity and similar need for customisation.

In 1998, the Danish Lindø Shipyard launched the most ambitious IT projects ever undertaken by a Danish company. The shipyard was running its production on an ageing CAD system, which was immensely expensive to keep updated to follow the demands of the ever more automated production facilities. In order to keep up with the ever increasing productivity of shipyards in the east, Lindø started up a consortium with Japanese Hitachi, Korean Samsung and American Newport News in order to develop an entirely new IT platform for shipbuilding.

The technical content of the new platform is built on the assumption, that a large part of the design/ engineering work in project-related companies can be industrialised, meaning that the design and engineering rules can be modelled and built into the CAD systems, so that the design work can be automated, i.e. transformed from craft to industry. It is expected, that more than half the output for the production can be generated automatically.[20]

[20] From the folder: Konsulentprisen 2007.

This means, that the creative design work is moved forward in the process, to the preparing of rules and solutions imbedded in the software instead of applied to the individual project. The main features of the software are:

- Design rules
- Interference checking.
- Component and detailing catalogues
- Automation of routine tasks
- Total integration with manufacturing equipment

"….with intelliShip the shipyard is using fewer hours to make a better product. If a designer pulls a tube through a wall, the software automatically adds the right flange, depending on the nature of both the wall and the adjoining spaces."[21]

"With intelliShip Lindø can design a ship in much shorter time than with our old system. It improves our competitiveness radically, as it is a much better system for making decisions, when we tender for new orders."[22]

According to Kåre Groes Christiansen, Project Leader of the intelliShip project, this approach could be used in architectural construction as well. The platform for the intelliShip software is the same as that which is used for "SmartPlant" by Intergraph, but with a new series of plug-ins related to shipbuilding. The system is also open to third-party plug-ins. As an example, using theri own plug-in the shipping classification authorities can verify that the design fulfils the required norms. For use in architectural construction, new plug-ins would have to be developed, but others could be re-used.

However, no software is better than the processes it supports. In order to take full advantage of the potential of Computer Integrated Construction processes, it is necessary to begin to understand (most) architectural artefacts as products and to move towards a more industrial approach. As long as architecture is conceived and produced in separated systems, an optimised construction process is very far away, but incorporating precise technical evaluations, process sketching and supply chain evaluations in the design phase would be a good start.

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21 *Børsens Nyhedsmagasin*, #9 2007
22 *Børsens Nyhedsmagasin,* #9 2007

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part 2

THREE WAYS OF ASSEMBLING A HOUSE

Kvistgård, Tegnestuen Vandkunsten, 2008. Photo: Adam Mørk

CASES

– building assemblies

CASES

– all-encompassing building systems

CRAFT AND ORGANISATION

– the product architecture of a building

All architectural creations of considerable size have been related to the concept of differentiated crafts – provided that they have been made from more than a single material (e.g. adobe structures or the wooden hut). Skills, professional experience and tools related to a certain material or process have separate communities of artisans or craftsmen, each refining their knowledge and passing it on through generations. The components of the building have been a factor, to some degree, in defining these crafts (floors and roofs have been made by the carpenter, walls by the brick mason), but by far the most determining factors in the distillation of the crafts are the tools and materials. The involvement of the blacksmith in construction, for instance, was related to many different stages of the building process: structural anchors, reinforcement of masonry and production of locks and hinges.

Wall building robot. Gramazio & Kohler ETH Zurich

Up until the massive industrialisation of building in the 1960's, the division between the craft and profession on the one hand and the modularisation of architectural construction on the other was always identical. The building crafts could be seen as independent modules with clearly defined interfaces. Construction specifications (drawings) had a substantial set of conventions, allowing a few instructions to be clearly comprehended due to a large amount of implicit knowledge. The dimensions of the windows on the plan of a masonry building, for instance, is known to refer to the window sills, not to the sides of the actual carpentry. The carpenter knows that he has to subtract the size of the joint (for which he has responsibility). It is thus not necessary for the architect as a 'specifier' to design this specific interface, only to define where it is. If the architect wants to control the appearance of the detail, he can supply a drawing. If he does not, the craftsman's default solution will be used, still with a high-quality result, as this detail will seem coherent in the particular building – always embedded in the implicit building tradition applied by the craftsman.

Today, the crafts and construction skills have almost disappeared from the construction industry in their traditional form due to increased technical and economical demands in architecture. Large standardised quantities, extreme precision on the technical side and a need for increased productivity with less manpower on the economic side, dissolve the essentials of the traditional manual workshop production and on-site adaptation. At the same time, the explosion in the number of choices within the building material industry has made it impossible for anyone to cope with all possible combinations in a traditional non-explicit (tacit) manner. Today, industrialisation is a condition, not an option. However, the organisation of the building sector does not reflect this fact. One of the results is that there is no self-evident product structure, and in contemporary architectural construction, no clear interfaces. Neither does it have possibilities of fair competition, it has no incentives for product development or innovation with the suppliers and no environment for the development of larger, more optimised industries in the sector, which could drive the productivity and quality requirements forward. The construction sector has ended up in what has for some time been called a 'lock-in' situation, which is impossible to break by one single or a few actors.[1] Industrialisation as seen in the product industry is thus far from reality, but is it a fruitful strategy to pursue in the construction industry? Or are the natures of production and construction fundamentally different from each other?

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1 See e.g. The Danish Agency for Trade and Industry (2000), *Byggeriets Fremtid – fra tradition til innovation* (The future of construction – from tradition to innovation), The Danish Agency for Trade and Industry, Copenhagen. Section 1.4 and 1.5 (http://www.ebst.dk/publikationer/rapporter/byg_frem/index.html)

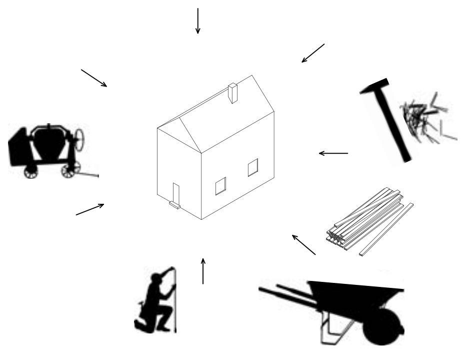
Taking a closer look at the construction industry, strategies used by industrially oriented manufacturers can be divided into three different main strategies:

A. Traditional product delivery – Supplying simple building materials or small components around the remaining, but faint (craft-founded) interfaces, which still exist in the industry and focusing on the processes.

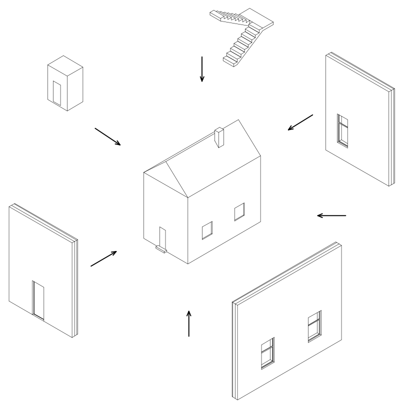
B. Integrated product delivery – Organising and developing their product as sub-suppliers of building assemblies with clear interfaces.

C. Turnkey delivery – Taking control of the entire supply chain, process and value chain by developing all-encompassing building systems.

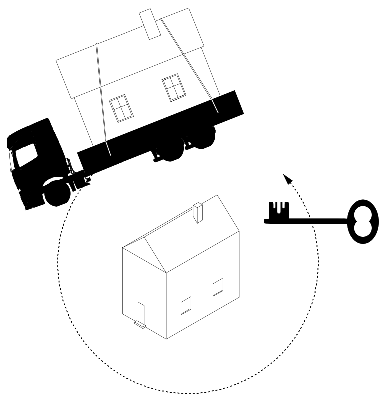
The strategies are theoretical and in their plain form do not represent any specific manufacturers. In most cases, reality will show different mixes between two or all three strategies.



Strategy A



Strategy B



Strategy C

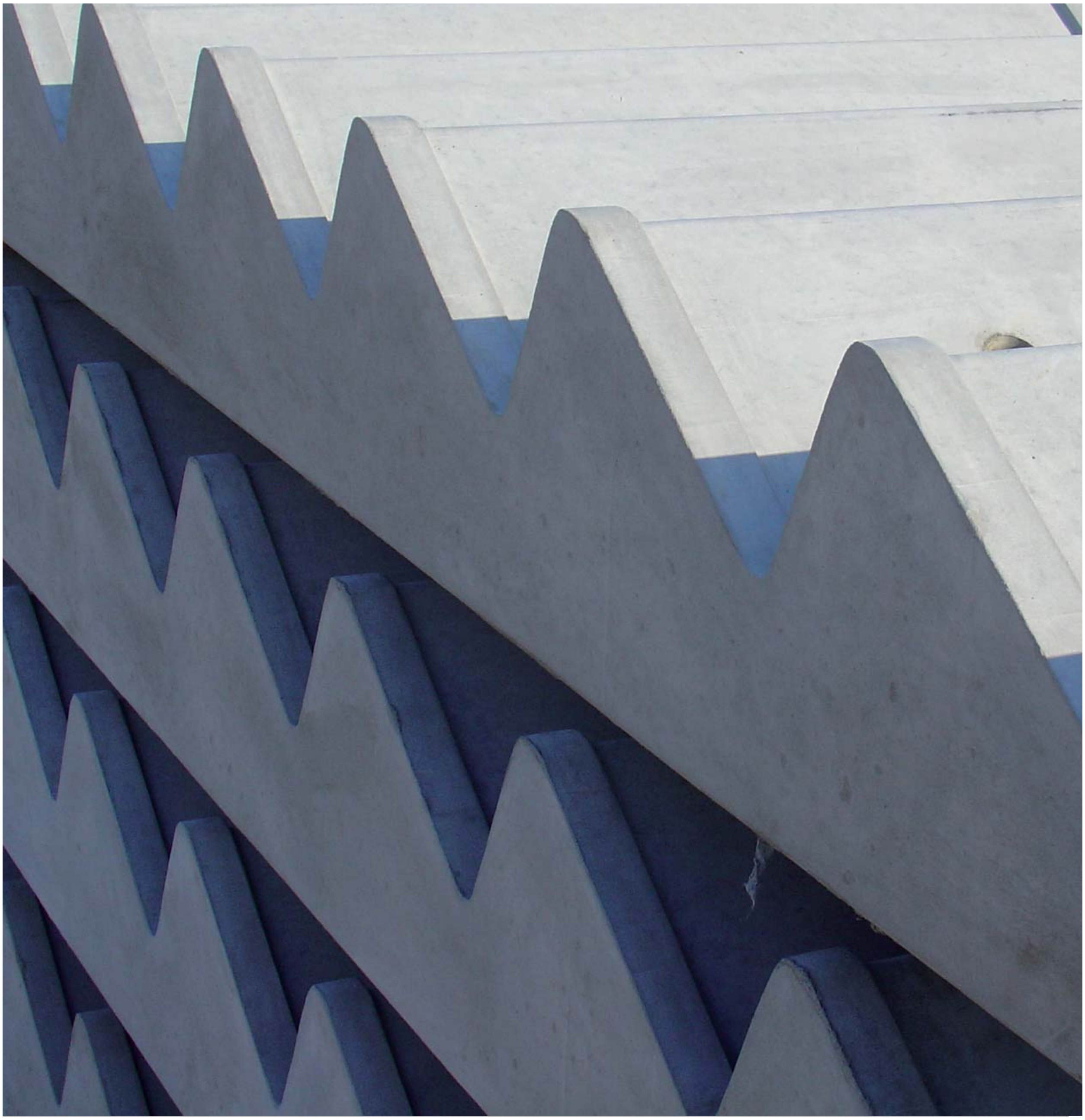
PREVAILING STRATEGIES IN ARCHITECTURAL CONSTRUCTION

– Product structures

Traditional product delivery: building by pieces

This first category refers to building systems relating to traditional crafts and construction processes. Although the strategy is called: *Traditional*, product examples of this first strategy can actually represent highly industrialised processes during production. Building materials as e.g. gypsum boards, bricks, flooring and even different kinds of mortar and filler are produced in factories with a high degree of automation, specific quality standards and efficient supply systems (= industrialised). However, in the current context of *industrialised building and industrialised architecture*, this strategy becomes more problematic: If buildings are to be composed directly by such products (as they are in general today!) it is almost impossible to control all interfaces and thus the final outcome in any industrialised way as defined above. The increasing amount of different building materials and the endless possibilities of combinations have eliminated the craftsman's default solution and blurred the link between craft and modularisation of the building by lack of embedment in an established building tradition. This makes the establishment or agreement of clear interfaces (almost) impossible.
Industrially produced building materials can be evident sub-deliveries of large elements or high levels of industrialised building and architecture, however, the industrial focus of building with materials and small components is mainly project oriented. It is primarily restricted to processes and to on-site construction in particular. The product structure therefore remains fragmented and is thus of less interest within the framework of this research. For further elaboration on this strategy, the concept and the theories of Lean Construction ought to be studied. They concentrate on *"project based production management in the design, engineering, and construction of capital facilities"*.[1]
The focus on products integrated in highly developed building systems is far more accentuated in the two other strategies described below: *The integrated product delivery* and *the turnkey delivery*. Substantiated by cases, this part will elaborate further on these two latter strategies and try to clarify their individual strengths, weaknesses and future prospects.

[1] See Lean Construction Institute, http://www.leanconstruction.org/.


Prefabricated staircases, Dalton A/S. Photo: CINARK

Integrated product delivery: building with assemblies

Within the strategy of integrated product delivery, the building as a whole is conceived as a total of sub-supplied industrialised building assemblies. Each manufacturer provides a clearly delimited product, which ideally has well-defined interfaces with other adjoining assemblies or fits into some kind of general standardised frame. The focus of product development within this strategy is the performance of the assembly according to technical demands as well as its capacity to adapt to specific conditions set by the context. A determining competitive factor will be the manufacturers' ability to sustain and maybe enhance these product architectures until they become best practice and eventually industry standards. Today, several examples of building assemblies can be found. Assemblies in our definition can have different scale and different degrees of physical/spatial integration with other assemblies or with the building as a whole. However, the idea of putting together a building or dwelling based completely on assemblies is so far not realisable – and perhaps not desirable, at least from an architectural point of view! However, by segregating certain parts of a building into integrated factory produced assemblies, it is possible to make use of both the technical and the economic advantages of a controlled production environment (prefabrication). This again opens new perspectives such as product guarantee, servicing and liability.

Units are transported to the building site on trucks. Photo: Tegnestuen Vandkunsten

Turnkey delivery: all-encompassing building systems

Within the strategy of turnkey delivery, it is usually a single company or a consortium that is in charge of a total solution comprising the whole process from sale over production to final delivery. In this sense, it might look like a conventional turnkey contract, but the main focus is a standardised ‘product’ and its entire value chain and not the single project, which is rather seen as a way to learn in order to improve later versions of the product. Furthermore, the turnkey delivery is usually characterised by a high degree of prefabrication. A brand is created with the product, which can have its own name different from the company itself. Questions of interfaces between elements or modules are solved internally within the product solution and the company. Although outsourced integrated product deliveries could be used as part of the solution, this is seldom the case. Due to the complexity of the final delivered solution, a determining competitive factor – despite the product focus – will be the manufacturer’s ability to create and sustain the brand through excellence, highly esteemed references and credibility at project level.

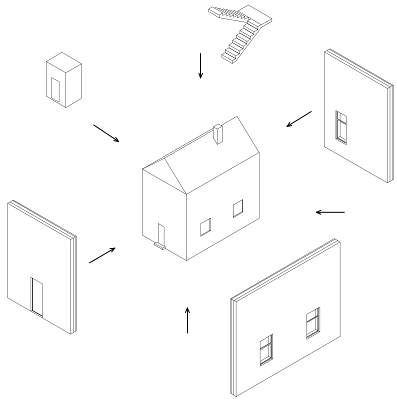
Most turnkey deliveries are based on a single base building system. Some concepts are highly standardised consisting of only one or a few types and low adaptation based on a specific physical appearance. Other concepts are more neutral and open, based on certain standardised structural principles and details, but are adaptable as regards the layout and appearance. As with the subassemblies, the high degree of control obtained through prefabrication facilitates quality check and product guarantee. Almost all all-encompassing systems are directed towards the single-family house market. However, more large-scale and multi-storey concepts are beginning to appear.

An example of an integrated product delivery from Altan.dk. Photo: Altan.dk

CASES

– building assemblies

In the following sections, five examples of integrated product delivery are presented. A first example of base building systems presents a general typology based on earlier research, while subsequent examples of pre-engineered bathrooms, balconies, installation shafts and a facade system are based on empirical data collected specifically for the present research.



Integrated product delivery

STRUCTURAL BUILDING SYSTEMS

– Structural typologies

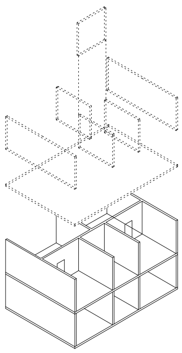
Although being fundamental and therefore in some aspects primary for the erection of a building, the structural system can be considered as a sub-delivery among others in order to provide the complete building.

Drawing on an earlier elaborated classification,[1] structural building systems (or principles) can be divided into 6 main categories.

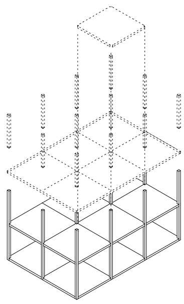
Pros and cons[2]

Pillar/slab systems and frame systems (type 2 and 3) are characterised by a distinction between the load-bearing and the dividing parts of the building, where the latter become a later finishing (fit-out). However, extensive technical (legislational) demands for this finishing (e.g. concerning fire safety, acoustics, insulation and pressure) seem to limit the potential capacity of opening and closing partitions independently from the load-bearing structure, thus gaining more flexibility. Flexibility is here understood both as design flexibility and (later) as conversion flexibility.[3]

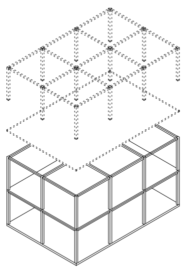
Structural building system typology



1. Load-bearing partition wall system – mostly transverse walls placed in dwelling divisions but also supplemented by stabilising longitudinal walls.



2. Pillar/slab system – typically circular or square columns in a grid combined with a floor structure (slabs).



3. Frame system (pillar/beam) – system of columns and beams often with structurally fixed columns or as rigid frames.

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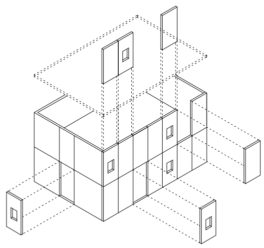
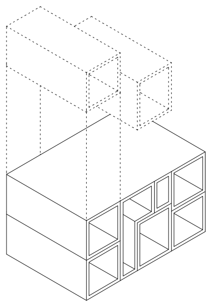
1 Beim, Vibæk & Jørgensen 2007:35f, *Arkitektonisk kvalitet & industrielle byggesystemer* (Architectural quality and industrial building systems).
2 Strongly inspired by Beim, Vibæk & Jørgensen 2007:117f.
3 Vibæk 2007: *Flexible Solution Space*.

These high technical demands simultaneously lead to a higher price, which is not necessarily competitive when compared to standard structural concrete panels. On the other hand, if concrete panels are used as partitions they will often equally make sense as structural walls.

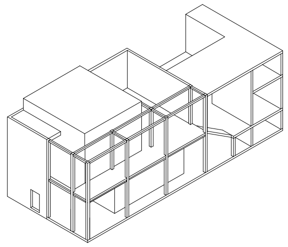
In Denmark, concrete based construction systems that combine the structural and the dividing parts (type 1 and 4) are the most common – primarily due to construction economy [4]. From an architectural point of view, however, this fact calls for a discussion on which capacities this choice include and exclude, respectively: Whereas the concrete based systems are mostly uni-directional, steel and timber systems are often variants of pillar/slab systems (type 2) or frame systems (type 3) and are non-directional or bi-directional. This enables transfer of forces in all directions. The concrete based alternative here is in-situ work which is not very common in Denmark due to high labour costs on-site [5] The development of new types of concrete is enhancing possibilities as e.g. FRC (Fibre Reinforced Concrete). However, a strong building culture and extensive knowledge about element construction among Danish contractors



4. Load-bearing facade system – System with bearing parts in the facades thus clearing interior floors.



5. Volumetric system – in its clear state characterised by a double bearing structure where volumes meet.



6. Hybrid system – different systems combined in the same building.

[4] Which is not the same as life cycle economy.
[5] A few examples of prefab-based bi-directional concrete systems can be found. See e.g Beim, Vibæk & Jørgensen, 2007, p. 39.

and structural engineers as well as the high prices of on-site concrete casting prevents it from constituting a realistic alternative to traditional concrete elements and present construction techniques (factor 10!).

By changing from pillar/slab or frame systems to panel based systems it is often possible to gain an extra floor in multi-storey buildings within the same building height. The extra height in the former system makes functional sense in office buildings in regard to hidden installations between the floors. This is not the case in dwellings where dismountable ceilings and floors are not commonly accepted – at least in a Danish context. However, increased floor heights and even exposed structural beams could be an architectural quality in itself.[6]

Volumetric systems (type 5) have lately become more applied in their light version– especially in residential buildings and even when dealing with multi-storey constructions. By nature based on bigger 3-dimensional assemblies, the volumetric systems considerably reduce the amount of interfaces coupled on site and increase the possibility of applying pre-fitted equipment in the buildings, thus leading to maximised prefabrication. In volumetric systems, each volume has its own structural sub-system, which theoretically can be any of the four prior types (1-4), although normally some kind of fixed joints or frames will be required to ensure stability during transportation. Examples of heavy volumetric systems exist but seem to fail due to excessive transportation costs, but even for light systems, the concept of transporting 'a lot of air' is problematic. Another constraint of volumetric systems is that usually they can only produce very limited space sizes.

An assumption could be that systems that combine structural and dividing parts create most value from a short-term investment point of view, whereas splitting up the two in separate sub-systems to a greater extent increases architectural value. Thus, both categories of building systems have their rationale and the choice of a specific building system rather becomes a question of the economic and organisational setup between the different stakeholders. As for the degree of prefabrication, it seems inversely proportional to rational transportation. Put into practice, however, it will always be a balancing of distance, fuel prices, road taxes and other road or shipping conditions versus production apparatus and wage levels.

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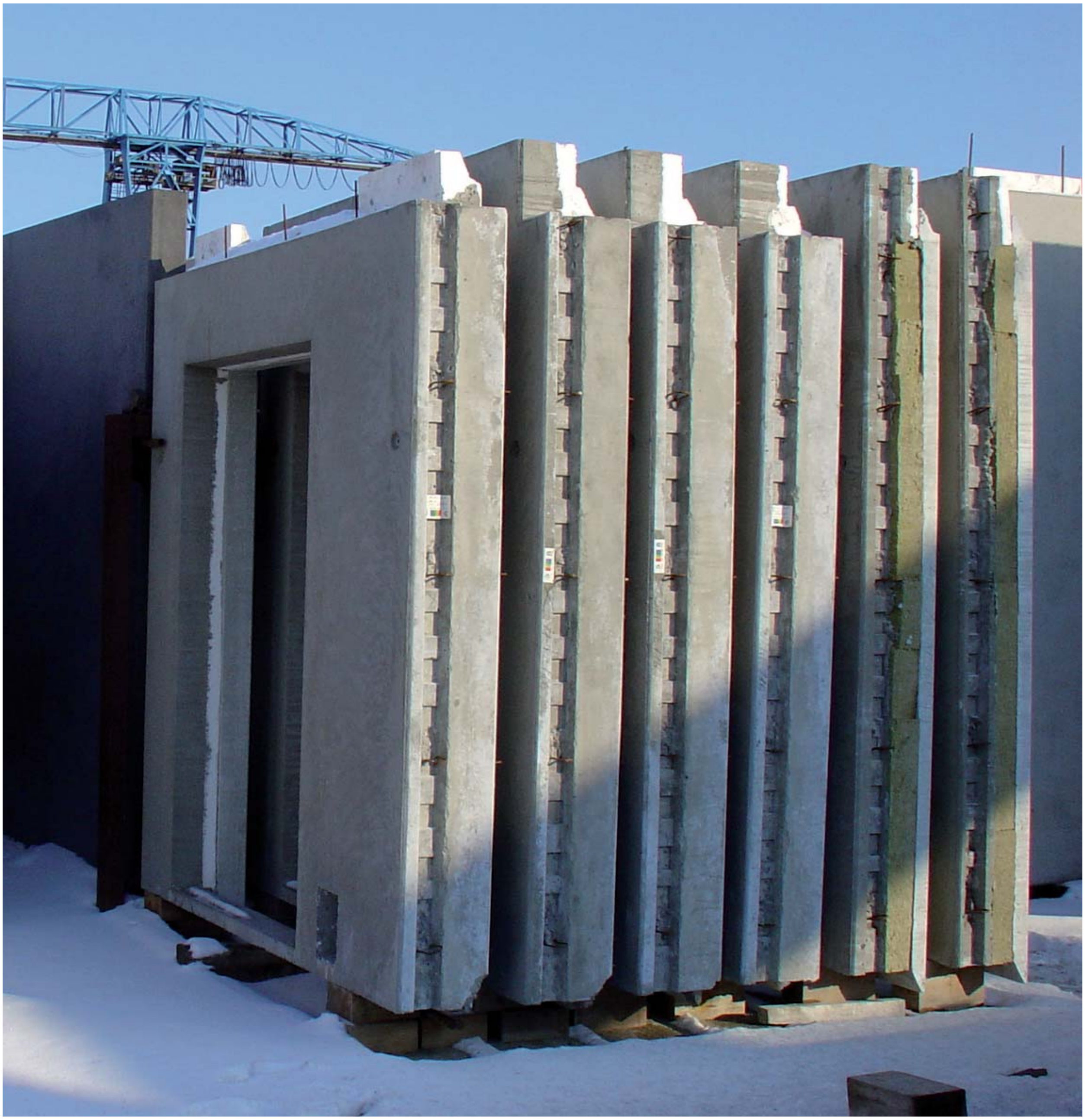
6 See e.g. Kim Utzon about visible TT decks with references to traditional oak timber beams in Beim, Vibæk & Jørgensen (2007), p. 91.



Facade components. Dalton A/S. Photo: CINARK

EJ BADEKABINER

– Pre-engineered bathroom pods

The bathroom of a dwelling gathers a collection of activities that usually call for certain privacy thus resulting in a shielded or closed area mostly of a rather limited size. Moreover, the bathroom requires conveying of a considerable amount of installations such as hot and cold water, sewer for both toilet, wash basin and bathtub/shower, ventilation, electricity and heating. This makes the bathroom a functionally and spatially well defined space or utility, while at the same time it represents some of the most expensive square metres of the dwelling. The combination of the limited size and the many crafts involved in completion often results in long production time, difficult coordination and a following high risk of errors and deficiencies. All the facts mentioned above make the bathroom an obvious target for industrialisation understood as separate prefabrication (of a pod), controlled production process and quality combined with optimised use of materials and manpower. The following analysis will primarily draw on data from a case study of *EJ Badekabiner* (EJB) – the largest manufacturer of pre-engineered bathrooms in Europe.

The information below is partly from an interview with Niels Sandahl, former CEO and present director of development at *EJ Badekabiner*.

Business concept and strategy

Strategy and goals

The business concept focuses on medium to large-scale construction projects – mostly dwellings, where all bathroom units are taken apart and standardised as much as possible for production in a factory. After production, the bathroom pods are delivered as finished units, which are installed on site and remain sealed until commissioning.

In order to secure business, the objective has been – within current building regulations – to produce whatever the client wants.[1] However, recently, the production volume has reached a level (approx. 10,000 units per year), where it seems plausible to divide the production into two different tracks: 1) a more standardised version with a lower price, and 2) a more flexible, but also more expensive luxury solution. This situation has made the vision of an

Company profile

EJ Badekabiner was established in 1963 with basis in an old company manufacturing fittings for plumbing. In 1969, the production of the bathroom pods was separated as an autonomous company focusing on the further development of this product. Today, EJB has two production facilities – one in Denmark and another in the UK.

[1] The client is not the end user of the product.

integrated IT management system, more realistic.[2] Within the current production system it is difficult to prove a cheaper standard solution than the present customised solutions at traditional project level. Although EJB is probably one of the world's largest manufacturers of bathroom pods, the company is still of a very limited size compared to both the sub-suppliers in the early part of the value chain[3] and the contractors (clients) who enter later in the value chain. One of the big contractors in Europe could easily absorb the entire production from the two factories. An explicit strategy has been to expand in order to have more influence on the development of the product and the market. According to Niels Sandahl, there is no need to expand the product itself – the market is huge. In some projects, an installation shaft has been integrated but it is difficult to prove efficiency.

Organisation

At EBJ, all staff are employed and organised as semi-skilled workers independently of training and trade. However, some workers do have the necessary authorisations for plumbing and electricity. This gives higher flexibility among the staff than on the building site where the traditional trade divisions often result in serious logistics, coordination and risk of problems. EJB has internal and fixed piece rate systems for all operations.[4] The production price of a specific solution can thus easily be calculated.

Most clients today contact EJB early in the project and get useful input about what to take into consideration in order to make a better fit between design and production system. The earlier EJB is involved, the better the fit – and consequently, both the price and the quality – without necessarily compromising the design flexibility. In that sense, the bathroom pod is today a more mature (industrial) product than e.g. installation shafts or integrated facade systems, which are often more difficult to clearly separate as independent units as will be discussed in later chapters.

Transport/export/import

The UK factory produces almost exclusively to the British market (4-5,000 units/year), whereas the Danish factory exports to most European and some other international markets (4-5,000 units/year). This means that although EBJ is the primary manufacturer on the Danish market, the domestic sales only provide a minor part of the production. EJB has approvals on several markets. In Norway, the complete bathroom pod is approved as a single product (type approval), while in Denmark, this is so far unthinkable. Here, regulations are directed towards and intended for on-site construction, with a lot of different layers that do not make the same sense in an optimised factory production.

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2 http://www.ej-badekabiner.dk/undersideX.asp?ID=3&FF=2
3 i.e. Hans Grohe, Ifö etc.
4 As e.g. mounting tiles, painting ceilings, casting floors or preparing for transportation
Obviously, dimensions are also defined by national building codes prescribing e.g. minimum distances.

Product and production

Technology (and process)

EJB works with three to four different construction principles:

- **Light version –** with a concrete slab floor combined with steel frames and gypsum fibre boards on the walls.
- **Light lava concrete version** - which is placed on the concrete slabs of the structural building system.
- **Heavy reinforced concrete solution** - which can be stacked separately in multi-storey buildings.
- **Special version –** without floor slab where installations and components are mounted on the wall panels, which are placed directly on a main floor slab of the structural building system.

The *product* is in fact just a box, with different inlets and outlets, which is then finished according to the demands of the client. There are no standard measures or configurations. Each project requires new moulds, and within each project, considerable variation often leads to many different moulds, although one-offs are seldom found. Dimensions are often fixed according to selected tiles and fittings.[5] All installations are hidden. A complete average solution is often sold for about 40,000 DKK and with an on-site price around 40,000/m2, even small batches are cost-effective. The bathroom pods are installed either vertically by crane or sideways by trolley.

The production process has many players both in and outside EJB and the design is moderated several times before a final solution is found. The result is that the overall design cost constitutes a considerable part of the total price paid by the client. Final solutions are always redrawn at EJB for production and more standardised solutions would reduce this redrawing.

Configuration and web

No parametric design tools or computer integrated manufacturing has so far been implemented, although recently accomplished production volume – as mentioned – has made this vision more realistic. Neither does the company's website offer any specific information – apart from the principles above – about how a typical bathroom pod

[5] Obviously dimensions are *also* defined by national building codes prescribing e.g. minimum distances.

Prefabricated bathroom pods. EJ Badekabiner. Photo: CINARK is put together. According to Niels Sandahl, EJB is looking for adequate IT integration, but parametrical design and standardisation are complicated to apply due to different traditions as regards the cultural differences and individual legislation on the many different markets. Commercially speaking, the incentive for trimming the production is low because competition is low. [6]

Quality

EJB delivers bathroom pods to many different countries, and the local interpretations of what are good and bad solutions varies considerably when borders are crossed, e.g. wether light prefab solutions are preferred to heavy (concrete) solutions or the other way around. EJB has much experience in different solutions for different situations, but in the end it is the client who decides what solutions to choose, and EJB will make it that way as long as it complies with specific and local regulations at the final destination. In this sense, there are no minimum standards, whereas both flexibility and quality are important price parameters.[7] However, everything at the factory is done according to approved methods and using high quality materials. This means that, indirectly, some quality control will always be an integrated part of a delivery through the choice of materials and the prescribed way of putting them together. No architects work directly within the company, but specialised 'design staff' work specifically with the appropriate positioning of each component, i.e. tiles, sanitary units and installations. Normally, EJB gets a fairly precise description from the client, which enables fixed pricing. Other quality parameters are the elaborated documentation following the pod and the fact that there is only one single phone number to call in case of defects.

Sustainability

At present, EJB has no explicit strategy on sustainability, neither is it used as a marketing parameter. However, Niels Sandahl estimates that the current focus on sustainable solutions will become an advantage to companies like EJB, where most competition comes from traditional on-site alternatives.[8] Doing prefabricated

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6 In the analysis of balconies and Altan.dk, a distinction between blue and red ocean describes different market situations. In this terminology, EJB – just as Altan.dk – operates on the blue ocean with only little competition. However, in the case of Altan.dk this means space for development (see later discussion).

7 Whether flexibility in itself is also a parameter of quality is discussed in the *User Aspects* section of *Perspectives of the Different Delivery Strategies*.

8 As mentioned earlier, EJB is Europe's largest manufacturer of bathroom solutions. In Denmark, there are only two important manufacturers, and number two, Betonelement A/S is far from having the same production volume.

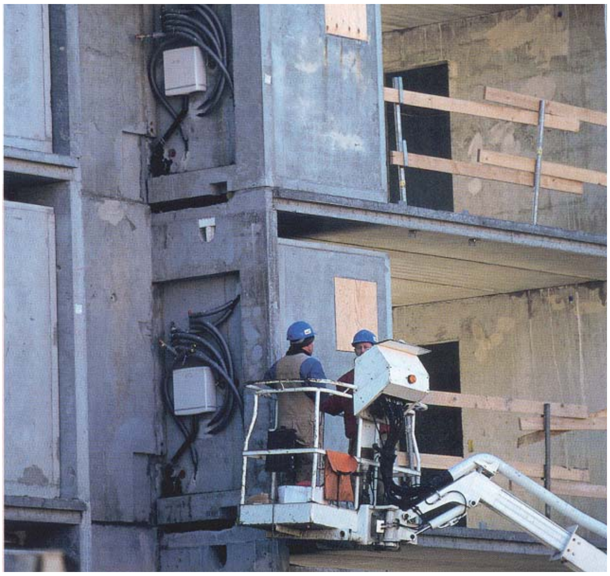
off-site construction gives completely different possibilities of controlling the whole process, thus performing better both concerning work environment and waste. The traditional building site is literally a mess and often represents a very unhealthy work environment, with heavy lifts, dust and shifting weather conditions. As the environmental demands become stricter, it will, according to Niels Sandahl, gradually become more difficult (troublesome and expensive) to construct on-site, and prefabrication will become a more viable alternative.

When it comes to the question of materials and waste, further emphasis on modularisation will enable better control with all components, thus facilitating dismantling and perhaps resulting in more recycling.

However, for EJB this is still a question that is primarily left to the client. If there is a market demand for more sustainable solutions, EJB will provide such solutions. Their product development is evidently a ‘pull’ situation rather than them ‘pushing’ new solutions for a future or different market.

User aspects

EJB has participated in some large projects where modifications and special adaptation was done on each single pod according to the demands of the



Pods are installed in a multi-storey building

The developer wanted individual choices integrated, but the administration of this freedom costs and the final result will either be more expensive or have a lower standard. According to Niels Sandahl, there is even the risk that poor (non-cohesive) individual solutions will have a bad branding effect on later phases of a big project. Free choices at the level of the end user do not seem to be a viable track – at least not within the current production system. Furthermore, the bathroom pods cannot be branded like other consumer goods e.g. Audi or Braun. The product is not visible in the same way to the end user. However, the production system is completely open to customised solutions at developer/contractor level. There are – as mentioned earlier – no special product standards. It is always an equation of volume, price and quality. It is consequently rather the developer that brands himself through specific choices in specific projects as e.g. by using Philip Stark components or Vola or Hans Grohe fixtures.

ALTAN.DK

– Configured balcony system

In Danish, two different words cover the English word *balcony*. The Danish analogue, *balkon*, refers to an outdoor area (floor) placed not on the top roof (as a roof terrace) but on the roof of a protruding closed building part like e.g. a bay window. Conversely, *altan* refers to an outdoor cantilevered area (floor), often with its own structural system or as a cantilevered extension of the main building structure. Whereas the former *balkon* although conceptually distinct can be structurally difficult to divide clearly from the main building as a separate system, the latter *altan* has a much clearer delimitation. It is the balcony in this latter sense that will be discussed below as an industrialised sub-assembly (an integrated product delivery), with the potential of defining clear interfaces with other surrounding main or sub-systems. The discussion will primarily draw on data from a case study of *Altan.dk (ADK)* – a recently established Danish company specialised in this type of balcony building system. Data is drawn partly from an interview with Nils Frederiksen, System Manager at Altan.dk, who also deals with the company's sales and product catalogues.

Business concept and strategy

Strategy and goals

The idea is to create a new company profile different from a traditional contractor inspired by the Harvard theory of the *blue ocean strategy*.[1] Shortly described – working within this strategy is about creating a completely new market, leaving the traditional competitive business situation, thus making it possible to concentrate on product development (customer value), rather than focusing on cost reduction (company value). Although a balcony evidently needs a physical expression, the market substance of the product is rather the *expectations, dreams and experiences* that can be realised through the use of a balcony. In this way, it is a goal of ADK to double the turnover within two years from start while simultaneously having a significantly flatter recruitment curve. This will be attained through systematisation, product adjustment, digitalisation, configuration, training, web 2.0 and innovation. Another important strategy is to narrow the focus thus choosing not to offer closed balconies, roof terraces or sunrooms, where other companies have

Company profile

Altan.dk was established in 2007, when the former midsize contractor *Ringsted Bygningsentreprise* (RBE) was split into two companies – one carrying the original name focusing on general exterior building improvements, and the other (ADK) specialising exclusively in balcony solutions as described above.

[1] Kim & Mauborgne (2005) Blue Ocean Strategy, Harvard Business School Press, Boston.
The metaphor of red and blue oceans describes the market universe. Red oceans are all the industries in existence today — the known market space. In the red oceans, industry boundaries are defined and accepted, and the competitive rules of the game are known. Here, companies try to outperform their rivals to grab a greater share of product or service demand. As the market space gets crowded, prospects for profits and growth are reduced. Products become commodities or niches, and cutthroat competition turns the red ocean bloody. Hence, the term red oceans. Blue oceans, in contrast, denote all the industries not in existence today — the unknown market space, untainted by competition. *(Continued on next page)*

special expertise. ADK does not do balconies for new projects either – only on existing buildings being renovated by replacement or with completely new balconies.

Organisation

From the very beginning, it has been the intention to trim the organisation, thus performing better with less need for labour (Lean). Furthermore, an attempt has been made to restructure professional divisions among the skills needed for the production[2] of a balcony. Traditional division of labour is one of the main obstacles within the building sector and seems to be further accentuated when dealing with products (and not just simple materials) instead of projects. New divisions have been underpinned by new job titles.

ADK is currently in the process of implementing digital site huts, which means that all communication and administration within a specific project is digitalised and furthermore decentralised to the local staff, thus cutting needs for central administration. An internal 'academy' for the training of staff has also been established.

ADK covers the whole service from the first customer contact and tender to the final delivery including authority approval.

Transport/export/import

So far ADK has not entered foreign markets, but there are present plans in this direction. The present manufacturer of the aluminium bases and railings – the Swedish *Weland group* – has suggested that ADK enters southern Sweden, but first, the new administration, tender and external communication systems etc. need to work properly on the Danish market.[3]

Product and production

Technology

The balconies arrive from different factories, basically in three parts: base, fixture and railing. The base is finished from the factory according to standardised principles, which means e.g. varied, but with standardised depth and with limitations such as max. free span of 5 metres or max. length 7 metres depending on the type. Bases are produced in aluminium, steel, reinforced concrete or FRC. The aluminium version covers around 70 % of the sale and the typical balcony size is about 3500 x 1500 mm. The fixture system is as external as possible – ideally with simple screw anchors fixing a vertical steel profile from which the base is hung like a shelf. In case of weak masonry or due to other architectural[4] reasons, different intruding/ anchored fixtures are used. Railings have different mixes of aluminium or steel frames combined with (perforated) sheets or glass plates. Handrails are

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In blue oceans, demand is created rather than fought over. There is ample opportunity for growth that is both profitable and rapid. In blue oceans, competition is irrelevant because the rules of the game are waiting to be set. Blue ocean is an analogy used to describe the wider, deeper potential of market space that is not yet explored. http://en.wikipedia.org/wiki/Blue_Ocean_Strategy.

2 For Altan.dk, production includes the planning, actual factory production, mounting and final delivery of a complete balcony solution.

3 Altan.dk takes approximately 25 % of the balcony production from Weland (www.weland.com).

4 By 'architectural' we refer to a broader definition than just the 'aesthetical' (cultural, historical, functional etc).

often made of wood. Prior to mounting windows are changed to balcony doors and indoor finish is completed.
ADK seeks to have fixed sub-suppliers in order to attain familiarity, mutual confidence and common procedures. Thus *Swedish Weland* delivers all aluminium solutions (base and railing), Kecon does all steel solutions including all fixtures, while windows, wooden handrails and flooring etc. mainly come from fixed suppliers.

Configuration and web

In order to kick-start the company, ADK initially participated in a development project supported by the Danish *Building Lab DK*.[5] The goal of the project was to develop a digital configurator for balconies. The vision was a three-dimensional digital tool for use in the direct sales situation with customers (typically housing cooperatives or house owners' associations) thus improving communication of possible solutions. Through real-time visualisation of choices and final result and a subsequent direct link with the internal order system, the risk of misunderstandings and failed delivery should be considerably reduced.
A new IT-based case management system has recently been implemented based on the specifications developed in the project. The digital configurator itself (the visual system), is not yet ready for use, but is to be linked directly to the specifications in the management system. The objective is that this link automatically generates tender drawings for authority approval, BIM model for production etc. Different stakeholders can then have direct access to relevant information through an extranet, which gives access either to directly changing the configuration[6] or simply generating customised reports from the management system. One of the original ideas was that the client, should be able to play directly with a downloadable or online configurator, before involving ADK, but ambitions were later scaled down. Alternatively, an upcoming web page contains a range of tools directed towards different stakeholders, thus ideally forming a kind of community. This encompasses the mentioned extranet, an intranet establishing contact with the digital site huts and closest partners, a marketplace with balcony accessories, blogs that can serve as

Various configurations of the balcony. Photos: Altan DK

[5] *'Building Lab DK cultivates innovation in construction. The goal is to help the industry to offer a higher quality and a greater value for money'* (www.buildinglab.dk). The development project was carried out as a consortium comprising Altan.dk, Weland, Kecon, Bascon, 3DFacto and Institute for Product development/Denmark's Technical University, (DTU).
[6] E.g. in the case of outsourced static calculations leading to modified design solution. Altan.dk currently uses outsourced engineering service.

information posts for specific projects, foras for design and development of new solutions, and an activity section for competitions or festivals. Furthermore, a couple of web-based mini configurators are planned: a service package configurator, an insurance configurator and a financing configurator.

Quality

As mentioned, ADK has deliberately chosen not to deliver balconies for new building projects. Although, this is where the major architectural development takes place, it is also a red ocean (see reference above) with a traditional organisational setup. Instead of competing in this market, Altan.dk tries to do their own more systematic product development, based on market research, research among professionals (e.g. architects) and by the establishment of a development committee in cooperation with Weland the main sub-supplier. The quality of the product is always a balance between what can be standardised, and what must be left open in order to adjust to specific desires and requirements of the specific projects. Through the possible combinations of the three different parts (base, railing and fixture), a considerable variety is possible. As mentioned above, in terms of strategy, the focus – and thus a quality parameter – is to meet dreams and create experiences for customers rather than to choose specific technical solutions. In this way, the different systems and techniques applied are constantly challenged and developed in order to make a better fit in this sense.

Sustainability

ADK has no overall focus on sustainability. However, especially the aluminium solutions are considered as having very low maintenance requirements, and all balconies are made of a few simple materials that can easily be disassembled and reused in case of demolition. No composites are used. Furthermore ADK is a member of FSC and only uses FSC certified wood.[7] The working environment for the staff is a primary concern and much effort has gone into making safe procedures and using harmless materials so that no special courses or protection equipment is needed during mounting.

User aspects

ADK follows a philosophy that allows openness towards constant input and critique. In particular the development project supported by Building Lab DK has systematically exposed different user groups to changes in the product and the business concept during the process and used feedback for further modifications. Furthermore, the fora of the planned web community should create space for different kinds of interactions between the company and the (potential) customers. Finally, statistics drawn from the case management system will create useful knowledge about trends concerning choice.

[7] FSC – Forest Stewardship Council: *'FSC supports the conservation of forests and helps people lead better lives'* www.fsc.org

NCC CONSTRUCTION, DK

'Skakten' – a prefabricated industrialised installation shaft

When building multi-storey buildings, and in particular dwellings, where each building volume is normally divided into several independent units (flats), the need for well-planned, coordinated installations become an important issue, in terms of both economy and quality of the final result.
Installations such as piping and wiring provide services like water, drainage, electricity, communication, ventilation, heating etc. Today, Danish legislation demands that the consumption of each dwelling unit can be measured and charged for independently. This has led to a vertical concentration of services in a limited number of shafts. Differently, the individual horizontal installations are then connected to the main routes through different gauges/meters. The building of shafts implies – as with the bathroom – many crafts working in a very limited space, often leading to very complex coordination of the work combined with unhealthy work postures and unforeseen (spatial) conflicts between the different installation systems. This situation has led to the vision of a prefabricated industrialised installation shaft segregated from the building structure as an independent unit. The following analysis draws primarily on an interview with Gert Jespersen, Design Manager at NCC Construction (NCC) and a report about the development of *prefabricated installation shafts for multi-storey dwellings*. [1]

Business concept and strategy

Strategy and goals

The concept of the installation shaft is primarily directed towards dwellings for reasons explained above. All vertical installation main routes are concentrated in a shaft, which is split horizontally into factory produced units corresponding to each floor. The units are then transported to the building site and are installed concurrently with the erection of the base building/main structure. Apart from solving the problems mentioned above and shortening construction time, this prefabricated solution will furthermore eliminate the need for interim installation during construction, where the final installations can provide service from the start. Each unit is organised in

Company profile

NCC Construction, DK was established in the late 1990's, as a part of the big Swedish contractor and developer NCC AB. NCC Construction deals with construction of buildings and surroundings – in particular with dwellings including development and sales.

[1] Published by Building Lab DK, Copenhagen, 2008

standardised modules for each installation system that can be put together in a number of different configurations. The goal is to be able to meet at least 80 % of the variety on the market, while the remaining 20 % special cases are left for traditional solutions.

At present, a prototype has been completed, and continuation of the project awaits acceptance from the NCC management board. Two strategies are in play: one – which will perhaps form a beginning – is to use the shaft in NCC's own projects alone, while the other is to introduce the shaft as a product on the market. Gert Jespersen does not see any problem in the fact that a contractor (NCC) goes into production and sells to other contractors. If price and quality are competitive, the product will sell. Products like the bathroom pod[2] have already prepared the market for assemblies, and within NCC's own organisation costs can easily be separated and compared to traditional on-site solutions.

Organisation

NCC Construction took the initiative to start up the project. In order to qualify the exploration of the possibilities, a consortium with three other partners was created including Building Lab.dk (innovation support), Valcon Innovation (management consulting) and RH Arkitekter (architectural office). After 18 months, the consortium ended its work in March 2008, with a prototype and a recommendation to the NCC management board to start production. The mix of different traditions and ways of thinking in the consortium group has challenged the way NCC works with construction development and changed the focus from project to product development. Whether NCC will create a new subsidiary company specialised in producing and selling shafts is not known at present.

Transport/export/import

The development project is based on the Danish building tradition of concentrating installations in a central shaft, which is not necessarily the case even on the closest international markets like Sweden or the UK. The construction industry is decidedly a home market business with considerable variation in how things are built in different countries. Legislation and standards within the building sector are national and often rooted in arbitrary historical facts rather than in any obvious or universal rationality. However, the general philosophy of having a modular technical unit (as the shaft) could easily work on other markets, but at present there are no plans to move to international markets.

[2] See analysis on EJ Badekabiner.

Product and production

Technology

The shaft is assembled like a steel frame with horizontal steel plates prepared with holes for the conveying of the different installation modules (water, heating, ventilation etc.). Besides positioning the pipes, one of the steel plates also serves as formwork, when the hole in the slab made for the shaft is cast and closed in order to protect against fire and noise. The different parts should be produced in an automated way e.g. using CNC-cutting and put together as floor-high assemblies in a factory. A slight over-dimensioning of the different modules limits the need for variations. All individual (horizontal) installations are made traditionally on-site and there are no current plans to develop an integrated solution. A similar but horizontal product could be developed for office buildings.

Configuration and web

The idea is that an open web-based configurator directed at architectural offices rapidly and early in the process can produce a possible shaft layout with correct dimensions, so that it does not at a later stage have to be squeezed into a finished design of a plan. The architect just needs to provide some basic information essential to the specific design e.g. number of floors, floor height, floor surface, number of bathrooms, separate toilets, heating source, number of rooms (living rooms and bedrooms) and whether the roof needs integrated drain.[3] This information can normally be provided by the architect early in the project. As an extra service, the architect can use the configurator as a parametric design tool for the bathroom(s) where all rules for dimensioning and distances are integrated and the shaft positioned. In this manner, the architect herself can generate the information he/she needs exactly when it is needed and will consequently not have to wait for feedback from an engineer, which is currently the case. The configurator assumes certain standard conditions to be present on the building site.

If a configurated solution is chosen for production, the configurator automatically produces documentation, which is evaluated by an engineer, who

[3] Jørgensen, Ola (2008:10)

The shaft is lifted into place, Photo: NCC Construction DK takes into consideration the actual building site – in 80 to 95 % percent of the cases, the dimensions proposed by the configurator will work and will be forwarded directly to production once they have been accepted by the customer. 3D documentation will automatically be generated. Whereas the latter 5-15 % of special cases today dictates the procedure for the rest 80 to 95 % the configurator turns this situation upside down.

Quality

An important aspect when it comes to quality is – according to Gert Jespersen – to 'exclude' human interference as much as possible during production and assembly. The computer file generated by the configurator should be used directly by the CNC cutter or other CAM equipment without any translation needed. It is the designer who needs to think of everything – not the man on the shop floor. Inspired by industry, the design should be foolproof in the way that the modules on site can be put together only the way they were meant to.

A vision of 'click' assembly, where the finished assemblies are simply lifted one on top of the other by means of a crane and joined together with a 'click', has so far been left as a wish-to-come-true – primarily due to missing documentation regarding the joints (like pressure tests etc.).

Sustainability

No specific initiatives have been taken in order to enhance the focus on sustainability – the use of materials follows the same standards as used in NCC's conventional projects. There are however, considerable savings to be made in the use of both materials and manpower if the production of shafts is moved to a factory, but so far sustainability has not been considered as a branding element – here the focus is rather: configuration, intelligent design, interim installation savings and quality control.

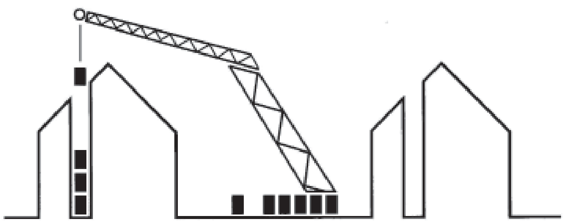

Illustration: Building Lab DK

User aspects

NCC has previously worked on standardising concepts for bathrooms, entrance doors etc. However, there is almost always a little twist such as a corner or a displacement that calls for small adjustments and thus inhibits the use of a strict standard.
Consequently, it does not make sense to have a standardised installation shaft. This is even more improbable when the installations are prepared after the spatial layout has been determined, as is the case today. By using the proposed web-based configurator, the architect is invited to supply information much earlier in the process, thus being better able to integrate possible solutions from the start.
The consortium involved in the development of the shaft included – as mentioned – an architectural office that has contributed to the shaft design and the list of information needed from the architect. These questions have later been tested on several architectural offices resulting in positive feedback. An open question is wether the configurator will work as an open web-based solution. The incentive for the architect should be the possibility of generating the necessary information automatically and without having to wait for expert feedback.

PERMASTEELISA

– Lightweight curtain-wall facade systems

The prefabricated curtain-wall facade together with the load-bearing structure in steel or concrete, is one of the few integrated product deliveries widely used in the design of buildings. Originally mostly driven by a desire to free the interior spaces from the straitjacket of the load-bearing facade, the curtain -wall was conceived as an entirely architectural feature. However, it very quickly became the answer to the need for a quickly-installed dry process facade element allowing maximum daylight into deep office spaces.

The first curtain-walls were made from steel and welded from the range of standard profiles. In order to ensure the tightness of the facade, all the connections were done on site. With the development of aluminium extrusions in the 1960's it was suddenly possible to shape very intricate profiles in relatively small batches. This opened up for a more individual design of the facade systems, but more importantly, it also opened up for the integration of rubber seals and thermally insulating elements. The integration of seals in the profiles allows the facade to be prefabricated in large modular elements, leaving only very simple and quick mounting operations on site. The facade industry today is thus split into company types based on the two main approaches:

• The 'stick systems' using smaller elements and more processing on site.

• The unitised systems using a high degree of prefabricated modules.

Where the 'stick system' contractors are normally small companies tendering for small to medium-size construction jobs, the unitised systems are the main choice for high-volume jobs and for high-rise. Both systems can again be categorized into standardised and customised systems. Most companies are characterised as working within one field or the other.

The connection between various contractual options (the procurement) and the overall structure of the industry (the supply chain) is demonstrated by Dvayne Vaz in a thesis work from 2007.[1] Vaz describes the options as follows:

Company profile

Permasteelisa's activities started in 1973. The company's growth and international expansion continued throughout the 1990's with the creation of numerous subsidiaries in different countries. With the acquisition of the Gartner Group, Permasteelisa became the largest company in the world in engineering, manufacturing and installation of architectural envelopes.

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1 Vaz, Dvayne (2007)

1. Traditional/lump sum

"In traditional general contracting, a prescriptive specification and fully detailed drawings are tendered with the main contractor having no design responsibility after winning the bid." [2] The process is purely based on competitive bidding from the subcontractors and there is no feedback to the specifiers. This approach allows no influence from the building material and component manufacturers and will normally result in a less advanced solution requiring longer lead times.

2. Design and build

"The project is tendered on a performance specification. Hence, the detailed design is carried out by the contractor post-tender. The contractor can use their preferred method of construction and favored suppliers allowing for maximum latitude and competitive pricing. The direct link between contractor and chosen suppliers enables free flow of design information since they have already been appointed to carry out the job." [3]

These two main approaches can be seen as extremes. Many construction projects will often have elements of both. Management contracting, construction management, two-stage tendering and partnering are other procurement strategies that incorporate some degree of control and influence between client/architect and contractor.

The design of these unitised facade systems is a highly specialised task and the final quality of the built systems depends on trade-specific or internal company-based specifications, which are not normally lucid or even accessible to the average architect or engineer. In the last 20 years, the main players in this industry have been struggling with unfair competition in the tenders from low quality competitors. 'Permasteelisa's strategy in this 'red ocean' is to go for the Design and Build option, to negotiate the so-called pre-construction agreements. Whereas most public clients will be forced into the traditional/lump sum option, it is possible for non-public clients to disregard the normal tender process if they wish to negotiate directly with the supplier/contractor. This is increasingly done for the 'cladding package', but almost never for any other part of the construction process. The contractors make their offers based on outline drawings, performance specifications and sketch design details. After commissioning, the entire design process is taken over by the contractor with the architect and client in a reviewing role. The potential problem with this approach is that "the tendered item could change quite significantly during detailed design and this is beyond the control of the design team".[4] The architectural intent and quality expected by the client or the architect are not always matched by the product supplied.

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[2] Vaz, Dwayne (2007)
[3] Ibid
[4] Ibid

Permasteelisa is a world leader in unitised cladding systems. The following analysis draws primarily on an interview with Mikkel Kragh, *Arup,* and the experience obtained from Jesper Nielsen's involvement in the development of facade systems in composite materials for Permasteelisa.

Business concept and strategy

Strategy and goals

Prefabricated unitised facade panels are not exclusively produced by Permasteelisa. Several other manufacturers offer similar products. Permasteelisa's main strength lies in a business model that has allowed them to manage and deliver very large and complicated projects with a minimum of risk. The high degree of integration and prefabrication, the ability to handle customised solutions at prices comparable to those of 'standard systems' and the unparalleled service provided to customers are all connected to the world of large-scale jobs. The lower limit for commissions is normally stated as 4 million Euros, as profits are low on contracts smaller than this. The more complicated the design, the higher the minimum contract value limit.
Permasteelisa tries to overcome this problem by letting sub-suppliers deliver solutions for technical subassemblies such as solar shielding devices etc. But these suppliers are not as flexible as Permasteelisa and are consequently only in a position to offer standard solutions. The strategy is to tie stronger bonds to some preferred suppliers, allowing them time to create products for the customised cladding industry.

In recent years, Permasteelisa have moved into the housing market, primarily in the Netherlands. This market poses another major challenge, as the aesthetic and performance requirements for housing is very different from those of commercial buildings. Variation needs for openings, balconies, geometric complexity and not least, a significantly higher thermal insulation performance impose dramatically different demands on engineering and production.
Another main focus for the company will be interiors. Prefabricated partitioning systems can be procured in virtually the same way as facades and they are principally manufactured from

the same materials. Technically, they are less risky, and due to changes in trends and organisations, they generally have a shorter lifespan. This makes them even more attractive to the supplier.

Organisation

The Permasteelisa Group operates in four continents through more than 60 companies located in 27 countries and 20 directly and indirectly owned plants. Permasteelisa's principal centres are located in Italy, in Vittorio, Veneto (in the province of Treviso), in Germany (Gundelfingen), in the Netherlands (Middelburg), in the USA (Windsor, CT), in Singapore, in China, Hong Kong (Donguan) and in Thailand (Bangkok). These head offices include research laboratories and product test centres. All operations related to the management and execution of contracts take place at these head offices, from assisting architects on the scheme design level through to production and testing – from the assembly of components in the factories through to on-site installation.

Product and production

Technology

So far, the product is entirely based on extruded aluminium profiles, glass, gaskets and sealants as the main components. Permasteelisa manufactures single and double-skin facades ranging from relatively simple, small-unit, low-rise office facades to advanced systems with integrated and active climate-regulating solutions. The company has taken the innovations in ventilated facade designs developed by the architects and cladding consultants in advanced projects and refined the concepts. The reduction of solar gains from the facades have had the primary focus in the developments so far, as this is a key challenge in the performance of glazed office buildings. Different factors are now revealing the limits of designing with aluminium:

• An increased attention to heat loss, partly driven by an interest in making systems for housing, but also due to an increased demand for insulation of office buildings. The aluminium profiles of today have thermal breaks built in, but there is a limit to the insulation values obtainable with these systems.

• The energy prices and attention to CO2 emissions have made the use of aluminium in very large quantities less attractive, and the dependence on one raw material places the industry at risk. Therefore, the industry is putting a lot of effort into researching the possibilities of using alternative materials such as composites. The performance advantages of thermoset composites such as GRP (glassfibre reinforced polymers) are attractive, but a number of challenges regarding fire resistance, tolerances and lead times have to be overcome before commercialisation.

Configuration and web

The strategy of negotiating for very large projects and engineering everything from scratch, used by e.g. Permasteelisa, does not imply the immediate use of configuration tools and certainly not web-based configuration. In an advanced cladding system contract, the value proposition is not mainly related to the product, but to the service involved in developing the right product together with the rest of the design team. However, in a general future scenario, where modular cladding systems are perhaps not exclusively related to signature buildings for corporate headquarters, this could change completely. If modular orunitised systems were suddenly – through certain standardisation – seen as a means of realising high performance housing facades with integratedsustainable technology at a reasonable price, the need for the configuration of smaller production batches would quickly arise. In this case, the highly industrialised production of unitised or modular facades would be extremely well-suited for a mass-customised integrated product delivery, just as window manufacture is today.

The royal library, Copenhagen. Schmidt Hammer Lassen Architects 1999
Photos: SHL Architects

Quality

The sheer size of the organisation allows Permasteelisa to work with quality quite differently from other manufacturers of customised systems in the construction industry. In-house laboratories and testing facilities permit the company to control all materials and products, and the negotiation power towards the raw material suppliers allows them to influence the quality of the used materials. With the acquisition of Gartner, Permasteelisa even had their own aluminium extrusion plant for a while.[5] For a company producing unique products (for each individual project a new design is developed) they can control the quality through a very organised process, where the main series is not commenced before a fully functional set of prototypes using the final extrusions have been scrutinised. Another important aspect is the control of interfaces. By controlling the entire envelope of the building and defining a clear interface to the rest of the house, this kind of cladding contractor can use highly developed internal interfaces between the elements and work with a very integrated design. This again permits a high degree of transfer of experience and innovation from one project to the next and also helps to avoid the repetition of unpractical solutions. The main source of defects in customised curtain-walling does not seem to originate from the aluminium systems, but rather from the glass industry. Spontaneous breakage of glass is a problem, which the float glass manufacturers invest a lot of research into solving.

Sustainability

The focus on reduced consumption of energy for cooling was, in fact, an important driver in the development of double-skin glass facades in the 1990's and thus indirectly one of the reasons for Permasteelisa's growth, as this kind of technically complex cladding systems are much better developed as pre-fabrications.
The extensive use of aluminium is of course not ideal in the CO2 balance, but facade systems are easy to split up for recycling, and the control of the material flow in the demolition phase is easy. The present experiments with composites incorporate a very thorough screening of all materials in order not to create a new dependency on a material that, like aluminium, will turn out to be environmentally problematic. In these considerations the research of processes to separate fibres and matrices in composites is of major importance.

User aspects

From Permasteelisa's point of view, the user is the architect. Cladding manufacture in general only addresses the end user – i.e. the daily user of the building – in single-family housing, and unless the possibilities of mass-customisations become endless, the company will probably never move into this segment. As the company only targets large projects, the user relation is very uncomplicated, as the project manager will be in direct contact with client, cladding consultant and architect.

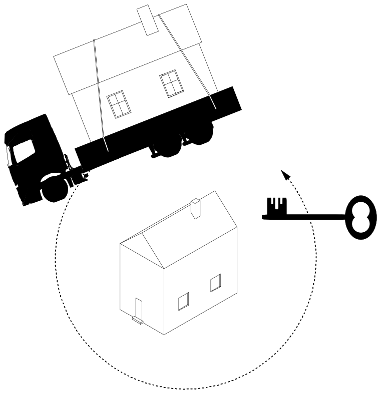
5 However, recently the plant has been sold off.

An example of a turnkey delivery from Willa Nordic. Photo: Willa Nordic

CASES

– all-encompassing building systems

In the following sections, four examples of turnkey delivery are presented. They are characterised by either light or heavy construction, fixed or flexible solutions and small or big customers. The first concept is primarily for single-family housing while the others are systems for multi-storey housing. All four examples are based on empirical data collected specifically for the present research.



Turnkey delivery

WILLA NORDIC

– Light construction, flexible solutions, small customers

The all-encompassing building system or solution delivered from Willa Nordic is based on light prefab construction (wood and plasterboards) offering flexible solutions to small, usually private costumers. The following analysis is based partly on an interview with Sales Representative Kjeld Kielstrup from the Danish division and partly on an earlier interview with Mattias Hjälmeby, Sales Director at the main office in Sweden.[1] Furthermore, the project group has visited the factory twice (2004 and 2008).

Production in the factory, Willa Nordic. Photo: CINARK

Company profile

Willa Nordic (WN) was established as a housing manufacturer by the end of the 1980's and today employs approx. 75 people of whom about 40 work in the production unit. The company offers unique individual housing solutions designed by architects who are either associated with Willa Nordic or selected directly by the client. The final product is primarily detached single-family homes but some midsize semi-detached housing projects have also been done for developers. WN produces approx. 140 units per year.

The primary target group is quality conscious private clients, who also weight other parameters than price, square metres and technical quality. Hence, the company does not compete with the cheapest housing manufacturers on the market which have the most standardised products. A modest vision is that everybody looking for a house designed by an architect should choose Willa Nordic. Presently, there is no special need for publicity, which is indirectly carried out by former clients and architects using the concept.[2]

1 Vibæk Jensen & Beim (2006), p. 149.
2 This interview was made in connection with the CINARK research project *Kvalitetsmål I den arkitektoniske designproces* (Strategies and goals in the process of architectural design) Vibæk Jensen & Beim (2006).

Business concept and strategy

Strategy and goals

In order to keep product development at a continuous pace, it is an explicit strategy to use external architects, although some of them are permanently associated. This means that the production system and business concept are continuously challenged in a way that would never be possible if the architects were directly subject to the company. It is, however, an advantage if the architect is aware of the production system and its possibilities and constraints. In order to facilitate this, a catalogue with commonly used details from prior projects is available.[3]

Through factory prefabrication, construction time on-site is reduced, while simultaneously the percentage of man-hours used in the design phase has increased. Knowing specific detailing much earlier in the process and avoiding improvisation on-site, facilitates a more uniform quality and makes it easier and more probable to warrant the final result.[4]

Willa Nordic does not design or produce building components as e.g. doors or windows themselves – the focus is on creating good spaces and buildings, and according to Mattias Hjälmeby, this can be done perfectly within the existing range of products.[5]

Organisation

All Willa Nordic's off-site manufacturing is done in one single factory in Stockaryd, Sweden, and the products are then shipped to their final destination. Some parts are outsourced, e.g. the trusses, which are made on a neighbouring factory, or kitchens, which in Denmark are produced by HTH – there is no need for reinventing something which already exists. [6]

Sales offices are distributed all over southern Sweden and a further two are located in Oslo and Copenhagen, respectively. Other international sales are managed from the main office. About half of the building contract is included in the factory production and delivery, while mounting and finishing is carried out by local craftsmen but always coordinated by Willa Nordic, which also provides all materials needed on site. Willa Nordic mainly has fixed local partners, but the client can also choose to be partly in charge himself. The focus on private non-professional clients requires considerable attention from the sales offices.

The extended need for design planning has made it necessary to open an extra office in the nearest bigger town, Jönköping, in order to recruit staff.

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[3] Ibid p 154.

[4] Specific warranty services are rare in the construction business. Some Japanese prefabricated building concepts, however, offer 20 years' warranty on the building structure - e.g. Sekisui Home or Toyota Home.

[5] Ibid, p. 156.

[6] Interview with Kielstrup.

Transport/export/import

The primary market is defined by transport times and distances by lorry and apart from southern Sweden, this comprises a part of eastern Denmark (Copenhagen) and south-eastern Norway (Oslo). Only a few projects have been realised in Finland and even though Central Europe, e.g. the Netherlands and Germany, has also sparked some projects, the fixed production location of the relatively large sandwich panels is still a considerable limitation when it comes to export to a global market. The main obstacle, however, is to localise local craftsmen who are willing to work with the system and know the standards. Still the request exists and in some cases the flexibility of the product overcomes the transportation and organisation problems.[7]

Photos: Willa Nordic AB.

[7] Recently, French developers have showed an interest (Interview with Kielstrup).

Product and production

Technology

Characteristic for the Willa Nordic houses are the high degree of individual adaptation combined with the extended use of prefabrication. Exterior wall panels including cladding and load-bearing interior wall panels finished on one side[8] as well as floor slabs are delivered from the factory. Roof solutions are delivered as a kit including prefabricated trusses. The truss production is outsourced. All non-bearing partition walls are made on site, as are kitchen mounting, bathroom installations and other finishing. The considerable freedom of choice and the many individual solutions limit the appropriateness of increasing the level of prefabrication – the goal is not industrialisation as such.

The factory currently produces 140 houses a year, which is actually slightly fewer than some years ago – 15 houses per year are sold in Denmark. However, the average house today is bigger than before and has furthermore become more expensive due to solutions of higher quality. This is an explicit strategy of the company in order to distance the company's products to the most standardised housing products on the market, and despite the unit reduction, this has resulted in a bigger turnover. A few standard types can be found in the portfolio. The ONV house designed by the Danish office ONV is one and this type of projects gives both volume and PR, although only a few houses are sold.[9] According to Mattias Hjälmeby, one fourth of the Swedish clients are initially very interested in the ONV solution, but due to the standardised concept and the reduced capacity to adjust to specific site conditions as e.g. topology and sun orientation, only a few clients end up with this solution.

The typical solution – a house of approx. 150 m2 – costs about SEK 1,500,000 (€ 150,000) from the factory (the delivered prefabricated product) and a further SEK 1,500,000 in on-site work. To this should be added the price of the land.

From a production perspective, the Willa Nordic system cannot be characterised as highly industrialised. Most of the production is carried out under roof (prefab), but as traditional craftsmanship with only a few automated procedures, e.g. cutting and lifting cranes. The rest is done with nail guns and drilling machines. Even when it is done this way, e.g. window mounting is four times as quick compared to on-site mounting. However, at process level, Willa Nordic is quite industrialised. The process (flow) is exactly the same regardless of how the house is designed, even though design planning time and construction may vary. Moreover, Willa Nordic spans the entire value chain from the first contact with the client to the final turnkey delivery with a strict focus on

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8 Thus leaving access for installations etc. before closing on site (Interview with Kielstrup).
9 Presently only about 20 units in total in Sweden.

customer value rather than industrialised means of production.[10] Flow and customer value are equally important 'industrial' parameters.[11]

Configuration and web

"[…] you [start] to make good business when you can manufacture a special solution from standardised parts, which are put together in different ways leaving a sufficient amount of variables to make what architects and clients want".[12] Ideally, you only have standard details while at the same time leaving everything open to change. This, of course, is contradicting, but when blurring the borderline between product and process, it does become a meaningful goal to pursue. Willa Nordic does not have the production volume to justify heavy investment in IT integration all the way from order to production. However, the catalogue of details shows the will to standardise without seriously limiting the solution space. [13+14] These details could easily be imagined as parametric models that could be downloaded by the architect, inserted into each project and 'stretched to fit', but so far these details are drawn by hand (on a computer!) Kitchens are outsourced, and here configuration is partly introduced, e.g. by the Danish HTH, which – like many others – offers a 'kitchen drawer' on their homepage, where the private client can use the assortment and compose or configure his/her own kitchen before buying.[15]

Quality

One of the main qualities of Willa Nordic is the widely flexible solution space offered by the building system and the process applied. While the standardised process resembles that of other companies delivering all-encompassing systems, Willa Nordic claims to offer free customer choice within this process – and does to some degree succeed while only being slightly more expensive than more standardised concepts. This makes the system applicable even to architectural offices wanting to make special solutions within a limited budget. Standard solutions like BoKlok or standard systems like Myresjöhus and others are often not capable of adjusting to special topological conditions such as slopes or different combinations of view and sun orientation. Here, the Willa Nordic system has a clear advantage. According to Mattias Hjälmeby, only the architect is capable of creating architectural quality in all its complexity. It takes special training to be able to combine the many different and heterogeneous parameters, and the technical staff do not have the necessary qualifications in this sense. This could, for instance, be a question of integrating the daylight or finding a timeless solution and adapt it to suit the client – not according to a current trend – so that it will work for many years[16]

Like other all-encompassing systems, Willa Nordic offers precise scheduling and fixed prices, which

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[10] Vibæk Jensen & Beim (2006) p.153 and 160.

[11] According to Lauri Koskela industrial production is a combination of transformation, flow and customer value. Koskela, Lauri (2000) *An Exploration towards a Production Theory and its Application to Construction*, VTT Technical Research Centre of Finland, Helsinki.

[12] Mattias Hjälmeby IN: Vibæk Jensen & Beim (2006).

[13] Whether standards limit or enhance possibilities is, apart from being a question of level, also a question of temper! Here, details are standardised, but possible (house) solutions are sought maximised.

([14-16] see next page)

also remain important parameters of quality – especially for private clients with limited finances.

Sustainability

An explicitly formulated aim is to build energy efficient houses. The fixed details described earlier are all designed according to an intention to reduce the energy consumption and comply, as a minimum with current local legislation demands on the building site. Although the customer can choose less efficient solutions, Willa Nordic will always inform about how efficiency could be increased. With regard to sustainability in a broader sense, it has recently become an important branding parameter. This is partly noticed during production, where waste is thoroughly classified: Plastic and metals are compressed and sold for reuse, while sawdust is converted into compressed sawdust blocks used for heating. At component level, heating systems are water carried and the window standard is energy efficient. Furthermore, Willa Nordic offers heat recovery ventilation systems and geothermal heat systems as optional choices.

User aspects

The direct contact between the Willa Nordic sales staff and the client (end user) is very important and gets much attention in the company. As mentioned, the aim is to provide a system and a process that maximise the choice of the end user who by using certain standard details can get an individual design almost for the price of a standard house.
In the preliminary phases, the sales staff try to get an idea of requirements and style preferences, which can then be used for the first sketches. The consequent use of architects facilitates the translation of user demands into a realistic design within a feasible economy and increases customer satisfaction. In Denmark most often Danish architects are used in order to adapt to national and local building traditions, building codes and user/ custom expectations.

From the mid-1990's up until recently, property prices in most of the western world have increased at a pace previously unknown. This has particularly been the case close to the centres of the big cities. Hence, from 1996 to 2006 the price of flats in Denmark rose by 353 %. In the same period the average income rose just below 50 %.[17]
This fact has gradually pushed out even middle income groups from the big cities, forcing them into large distance commuting in order to keep their jobs – often service jobs as teachers, nurses or policemen which are essential for the functioning of a modern city.

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14 For an explanation of the concept, see Piller (http://www.mass-customization.de/glossary.htm) on stable solution space or Sánchez Vibæk (2007) Flexible Solution Space.
15 HTH Kitchen configurator: http://www.gds-hth.dk/Default.aspx?ID=250.
16 Vibæk Jensen & Beim (2006) p.150.
17 Source: Statistics Denmark (www.dst.dk) - from 1993 to 2006 the cost of flats increased by 455 % - unconfirmed numbers for Copenhagen speak of 600 % increase over ten years (www.billigeboliger.dk).

BILLIGE BOLIGER[1]

– Light construction, standard models, big customers

As an electoral promise in November 2005, the present local government of the City of Copenhagen presented a plan for the construction of 5,000 economically affordable dwellings in the city within 5 years. One of the initiatives sparked by the implementation of the plan was the establishment of an a utonomous private non-profit foundation, Fonden Billige Boliger (FBB), which is in charge of the planning, construction and sale of affordable dwellings.[2] In November 2006, an architectural competition resulted in projects from six architectural offices being selected for further elaboration. Among them the project from ONV Arkitekter/Tegnestuen Mejeriet, was chosen for the realisation of the first building project, which was finished in the spring of 2008. The project is based on light construction of standard models for big costumers i.e. FBB.

The following analysis draws partly on an interview with Søren Rasmussen, owner of: ONV Arkitekter, partly on information from the website www.billigeboliger.dk. Furthermore, experience from related CINARK research on prefabrication is used supplementally.

Business concept and strategy

Strategy and goals

In the case of the Copenhagen affordable housing initiative, the office was instructed to use a specific Estonian manufacturer, Kodumaja, for the production of the volumetric units. Units are then shipped by boat to Denmark for mounting and finishing on site. This ‘globalisation’ made possible through prefabrication should considerably reduce construction costs by minimising the need for Danish high-wage on-site work and maximising Estonian low-wage factory production with a prefab level around 80 % and a production price of DKK 7,500 per square metre (approx. € 1,000). The strategy is thus an economical rather than a technical optimisation, and the applied production technology resembles what you would find among Danish and Swedish building manufacturers.

Company profile

ONV Arkitekter (ONV) is a small Danish architectural office established in 2000. The office has a special focus on light prefabricated volumetric modules used for institutional purposes as well as for dwellings where e.g. the ‘ONV-bolig’ (ONV dwelling) as a standardised single-family housing concept is produced by both Danish and Swedish manufacturers for the national markets.[3]

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1 Danish term for ‘*affordable housing*’.
2 However, the 5,000 dwelling goal is to be reached by a combination of several initiatives.
3 http://www.onv.dk

Organisation

In order to keep costs low, the standardisation level on the production line is high and in collaboration with ONV, the original competition proposal has been through several modifications in order to fit the production system of the factory. ONV only designs up to scheme design level including some typical details. This means a man-hour reduction of 40-50 % compared to a normal lump sum tender. All drawings are then redrawn and elaborated for the production by the manufacturer in order to prevent any misunderstanding during production. However, this ‘translation’ may itself lead to misunderstandings between the architect and the manufacturer, who will consequently have to double-check the production drawings in order to ensure architectural consistency.

The first part of project covers 12 affordable dwellings of a total of 36; the remaining 24 are sold at normal market conditions. Part of the economy generated by the sale of these ‘market dwellings‘ is used to extend the mortgage period on the affordable dwellings thus contributing to reducing the price.

As mentioned above, the foundation (FBB) is in charge of the planning, construction and sale of affordable dwellings – primarily in Copenhagen City. However, as it ended up as a private autonomous foundation detached from the city council, it is not necessarily geographically limited in its activities and could expand all over the country.

Transport/export/import

The whole organisational setup is based on savings obtained by outsourcing to low-wage countries, which at the moment can still be found relatively close in Eastern Europe. However, this model is very vulnerable to presently increasing prices in new EU countries, e.g. Estonia. With longer transportation distances it is probable that profits will disappear and the use of volumetric modules in this case accentuates this problem further. This could lead to a return to local (Danish) production forcing manufacturers to a higher degree of automation, as pointed out by Søren Rasmussen. By implementing more advanced technologies, international export perspectives could become an issue. This was one of the main strategies in the Swedish NCC Komplett concept presented in a later section.

Product and production

Technology

In the first project, which was finished in the spring of 2008, each dwelling is composed by either two or three volumetric modules. It takes less than two days

at the factory to produce each module. Modules are assembled with Black & Decker tools[4] on conveyor tables and trolleys on rails that can flip over. The modules are built as insulated wooden frame slabs closed and reinforced by chipboard combined with insulated wooden frame panels into volumes. Partition walls are added. All finishing including installations (electricity, plumbing and heating) is completed at the factory except the external cladding, which is added on site in order to avoid straight joints between the modules. The modules are transported to the building site and mounted on an onsite prepared concrete base creating a closed but ventilated crawl space between the soil and the wooden construction. 15 dwellings are stacked together in 2 or 3 days followed by 4 to 7 weeks of finishing, including external cladding and connection of all installations. Trapdoor access facilitates the connection of installations at the site and between the modules.[5]
The foundation (FBB) has used consultants in order to optimise production. This has resulted in a division between modules with and

Karens Minde, Low-cost housing. Photos: ONV Arkitekter

[4] nailguns, drilling machines etc.
[5] (http://ing.dk/artikel/81436).

without installations. The more complex modules containing installations have no variations, while the more simple modules are used to make variations in the plan solution – both within and between plans. The 12 affordable dwellings each cover 85 m2 distributed on two floors with an interior staircase connection. The remaining 24 dwellings, which are sold on normal market conditions vary in sizes between 121 m2 and 131 m2.

Configuration and web

The general level of production automation is low, and manual procedures predominant due to the low-wage strategy explained above. The standardised character of the product (the affordable dwellings), does not, in its initial form, make much space for configurational adaptation of each project. Minor variations in the plan solutions have been implemented at an early stage, but everything is fixed before production start-up – any subsequent change would mean new drawings, loss of efficiency and budget overrun. However, if the production volume reaches the goal of the 5,000 dwellings in 5 years there will probably be both a request and an architectural need for a higher degree of adaptation. Presently, the facade cladding added on site is the only straightforward changeable element – detached from the factory production. In other projects, Søren Rasmussen, ONV, has experienced how even minor variations in industrialised housing production are difficult to control. It seems simple to draw everything as you like, e-mail it to China and then receive the finished result by ship, but the repetition of a standardised core is essential and accelerates the process tremendously – thus also defining what is economically viable.

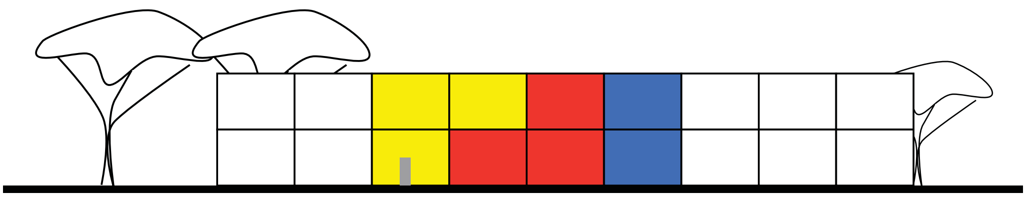
Quality

The manufacturer has been in charge of selecting and purchasing all materials according to their own standards except the electrical installation, where national differences in legislation have made it necessary to involve the foundation (FBB). The layout of the plan is designed by the architect (ONV), but within the possibilities of the production system. To ONV, an important point has been to work with these possibilities (and constraints) from the start, thus making the layout an integrated part of the architecture instead of afterwards having to force an architectural vision into a frame that does not fit. In the context of
affordable housing and industrialised production, according to Søren Rasmussen, it is important not to pursue a specific formal expression and then try to produce it in a cheap way. The focus must depart from the very principles of the applied building system in order to achieve a good result.
In the initial building project, the final cladding has been added on independently of the factory

production, and somehow it hides the industrialised look that often characterises modular building and – in particular – the volumetric version discussed here. According to Søren Rasmussen, the strongest constraint within the Kudomaja system is the floor height. Variations and double height are apparently not within the possible solution space of the system within the given economy, which has furthermore resulted in a reduced standard height.[6]

Sustainability

No extraordinary initiatives towards environmentally friendly solutions have been implemented. Still, all dwellings comply with the Danish energy class 2 classification concerning insulation and energy consumption, and the ventilation system reduces loss through heat recovery. Thus, the dwellings perform significantly better than required by current standard demands. Wood is in general considered a sustainable construction material and waste is considerably reduced through the industrialised production process. Furthermore, daylight is sought maximised e.g. through skylights combined with exterior shutters protecting against overheating. The layout of building volumes is compact, thus reducing exterior surface. At the social level, the original ambition of the municipality of Copenhagen was to demand 10 % affordable dwellings in any future housing project in Copenhagen – both in order to reach the desired volume and to ensure a demographic variation in new neighbourhoods. This has, however, proved difficult to carry out within current legislation and has so far been limited to the mix of affordable dwellings and 'market dwellings' in the specific projects carried out by the foundation (FBB).



[6] However, in one of the other selected competition projects by the architectural firm, Tegnestuen Vandkunsten, the volumetric modules were tilted 90 degrees in order to make a double height-space.

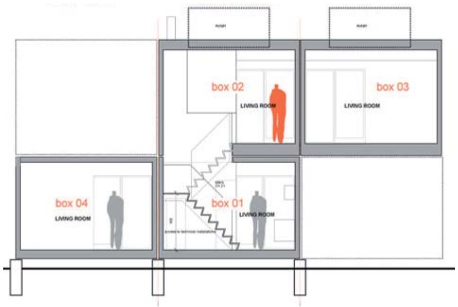


Diagram of dwelling units and a section of a single dwelling. ONV Arkitekter.

User aspects

Despite the standardised concept, a few additional choices are left open for the first time-buyer of the affordable dwellings. It is thus possible to place an extra partition wall, upgrade fixtures or to choose different tiles in the bathroom and in the kitchen. Each choice is a deviation from the standard solution and results in an extra charge. Changes can only be made before production starts. To have choice itself as a standard requires – even for minor adjustments – a lot of management. This again makes it very expensive to administrate. The risk of a free choice is also that laymen do not necessarily have the qualifications to choose. Alternatively, a choice between 'design lines' fixed by an architect would be considerably easier to control and might perhaps even give greater user satisfaction.[7] A problem concerning standard in housing, as opposed to traditional product industry, is that only a few people explicitly appreciate the idea of buying a fixed but tested house concept – we never get ahead of the prototype or the beta version.

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7 The strategy of design lines is strongly accentuated among Japanese housing manufacturers (Vibæk Jensen 2006)

NCC KOMPLETT

– Heavy construction, flexible solutions, big customers

In the light of an ever more pronounced lack of manpower in the Swedish building sector and a wish to break with traditional patterns in the building industry, the Swedish contractor *NCC* initiated a process in 2002, which was supposed to lead to the development of a more industrialised 'production' of housing solutions.
The vision was a highly automated 90 % prefabricated building system combined with dry on-site mounting offering flexible solutions for multi-storey dwellings.
After four years of development, a completely new and partly patented building system, *NCC Komplett*, was presented in May 2006 at the time of the opening of an NCC-owned subsidiary, *NCC Komponent* AB and a new production facility in Hallstahammar northwest of Stockholm The system is based on heavy construction providing flexible solutions for big customers. After less than 2 years of production – and a total investment of SEK 1 billion (approx. € 100 million) – the factory closed down. The last construction module left the facility in April 2008, and in October 2008, the last building block built with the system was finished on-site. The closing down was decided due to failing revenue even though the order book was full.[1] However, the system still represents an interesting approach to the industrialisation of building, which deserves attention among the other systems discussed within this research.

The following analysis is based on inputs from various sources, which are held up against each other and discussed by the authors. None of the external contributors or websites used can be held responsible for the statements in this section, which should be considered exclusively as the interpretation of the authors. Informant identities have consequently been concealed, whereas some websites are stated for reference. Although validity and reliability can thus be questioned, we do, however, think that this section helps to clarify some general issues in the present paper – albeit as more of a journalistic approach than substantiated research.

Company profile

NCC AB is one of the largest contractors and developers in Scandinavia and a result of a series of mergers with company roots back to 1875. NCC works with all types of construction, roads and property development with local subsidiaries in Sweden, Denmark, Norway, Finland and Germany and considerable activity in the Baltic countries. In 2007, the company had about 21,000 employees and an annual turnover around SEK 58 billion (approx. € 5.8 billion).

[1] http://www.building-supply.dk/article/view.html?id=18794

Business concept and strategy

Strategy and goals

As any other contractor, NCC struggles with controlling on-site construction to prevent difficulties from leading to an instable economy as well as quality problems. The aim of the development project was to reduce on-site construction time by 75 % by moving towards a higher degree of (off-site) prefabrication. Through rationalised factory production with less need for manpower, the total construction time was to be reduced by 50 % in total. Furthermore, the controlled factory environment should facilitate better quality control during the entire process. By having an in-house production facility and through direct purchase, the idea was to cut through the conventional value chain and to create a system that could be used directly by architects for project design and which could subsequently be produced and assembled for the client by NCC.[2] From the beginning, in-house architects were engaged in the system development and later used for costumer contact (with the architectural offices), in order to facilitate the use of the system, as well as for feedback for system modification and adaptation. Accomplished projects and their details were compiled as experience and reference for future projects, and the elaboration of an internal price list for additional options (balconies, different roof solutions etc.) was initiated.

Organisation

From the beginning, the system was directed both at NCC's own project developments and at external clients, where the latter part in November 2007 constituted about 50 % of the volume of orders. In a more long-term perspective, the intention was to radically challenge and possibly change the general organisational setup between the different actors in the building sector. By moving from construction into factory production based on direct purchase, the value chain was changed considerably, thus leaving some of the traditional stakeholders out and putting others together in a different and more direct manner. The production facility was a subsidiary of the NCC group – ideally eliminating the need for the traditional contractor and various subcontractors in the value chain.
Production and mounting was carried out by semi-skilled workers, and job rotation was used systematically – even between factory production and site assembly. Assembly teams consisted of 4 workers and a site leader, even for large projects.

Transport/export/import

The logistics system was based on road transportation by lorry and the prefabricated elements leaving the factory were dimensioned specifically for a rational packing of standard lorries. When reaching the total production capacity, a lorry should be leaving the factory every 15 minutes, and in order to achieve a reasonable

[2] In the first phase NCC would even be the client themselves, in their capacity as property developers.

transportation economy, the project radius for the factory was limited to a distance of about 300 km. In the first place, project development was thus exclusively directed at a national market, focusing on production instead of the varying legislation demands and differences between countries. However, the possibility of export to Scandinavia was under consideration.

Product and production

Technology

The Hallstahammar factory was built for a production capacity of 1,000 flats per year, but it never reached total capacity due to the short period of functioning where processes and products still had to be adjusted and refined. Production was arranged according to just-in-time production principles (JIT), with five sub-lines (walls, floors, ceilings, technical shafts/ modules and kitchens) all ending directly on the loaded lorry – produced and packed for the right assembly sequence on site.

The building system is based on a combination of load-bearing facades and load-bearing partition walls.[3] All wall panels are made of reinforced concrete with integrated vertical steel profiles. This enables working with very close tolerances and provides the basis for a total integration of installations including a dry 'plug-and-play'-assembly of the panels, kitchen and bathroom modules and all installation conduits through hatches. Exterior wall panels are finished with doors, windows, wallpaper, radiators and exterior insulation prepared for plastering on site.

Interior partition wall panels are structurally equal to exterior walls although non-insulated and are used together with the exterior walls to reach sufficient transversal stiffness. Kitchen modules including integrated installation shafts are mounted on-site as I or L-shapes.[4]

Floor and ceiling slabs are made as steel frames with profiles produced in the factory from steel coils and finished with plasterboard, plywood and parquet. Slabs are divided into floors and ceilings in order to provide sufficient sound insulation. A basement or a ground slab is prepared on the building site by traditional methods

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3 See typology in the section on structural building systems.
4 The L-shaped kitchen is divided in two on two adjoining wall parts.

and all other elements are assembled as dry 'click'-assembly on site inside a gigantic dismountable assembly hall, which excludes the factor of bad weather conditions during assembly. Elements were lifted off the lorry and put in position by use of an integrated overhead crane. The assembly hall and assembly system could handle projects from 3 to 8 storey's height and a building length up to 60 metres without the hall needing to be moved. After assembly, the exterior was finished with plastering, thus hiding joints and reducing the industrialised look.[5] Balconies could be added optionally. Although designed for flexibility, the standards of the system produce certain constraints. Some are listed here:

NCC Komplett production line, Illustration: NCC AB

Solution > Result

• Load-bearing facades >
No curtain-wall facade is possible
• Slabs are not dimensioned for exterior wall load >
No recessed penthouse
• Max 8-metres wall panels >
If longer they are split in two and a transversal partition wall needs to be placed in the division.
• All walls are load-bearing >
Limited number of holes for windows and doors
• Window sills always have the same recession and no corner windows possible
• About 10 fixed bathroom solutions

Configuration and web

[5] Alternative cladding types were to be introduced later.

NCC Komplett construction site. 'One moment please, Assembly in progress'. Photo: NCC Komplett

Production is based on direct input from a design system developed for architects. The design system consists of a plug-in made for the ArchiCAD environment, which provides parametrical modules that are put together in a 'drag-stretch-and-drop' process. Here, the architect works as a kind of 'configuration manager' within the limits of the system designed for a high degree of flexibility.[6] If something can be designed within the system, it can be produced at the factory. Ideally, all elements or modules are uniquely and directly produced from the CAD model in the design system, but the system can only handle fully described parts and was to be gradually extended. However, even fully described, statics and final project design still has to be revised and adjusted by NCC – in practice, envisaged direct link between architect and production line is in made impossible, e.g. by local authority processing and site-specific codes about depth, heights etc.
The context – organisational as well as physical – is never exactly the same, and consequently it is very difficult to integrate completely in an automated or standardised way.
An identical problem is pointed out in the analysis of the MTH system in a later section.

The quality in the design and the building system lies in the mentioned relatively high formal flexibility combined with high technical quality and extremely low tolerances. At finish and detail level, freedom and choice are, however, restricted to a few standards based on a philosophy of rather having one or a few high-quality solutions at a good price (big quantity purchase and easier process handling) than leaving the choice more open. An example is the standard 260 cm floor height. Another is the use of a few types of bathroom layouts with qualities above standard as regards tiled walls, spotlights, floor heating, glass shower walls, towel dryer, mirror wall and high quality cabinets for storage. Concerning colours, and in some cases even materials of the interior, the customer could choose between already composed design packages for bathrooms, kitchens and wallpapers.

NCC Komplett, Assembly on site. Photo: NCC AB

Quality

The intention was to make a formally, aesthetically

[6] Of coruse, the degree of flexibility can of course be discussed – see e.g. examples on constraints above. However, the vision was that the system should have few formal limitations and thus become a professional tool for the architect. On the other hand, at detail level, the system was very standardised (windows, floors, kitchens etc.)

and architecturally flexible and somehow neutral system where neither system nor prefabrication were expressed in the final result. An open question, however, is whether the concept was still too rigid or dominating? Would architects actually feel that they designed a Komplett house when using the system?

Sustainability

No special initiatives or focus on sustainability were integrated in the first version of the Komplett system. An internal checklist was used to avoid particularly adverse impact on the environment. Furthermore, certain principles and standards already generally used by NCC also applied to NCC Komplett, and the mere use of a more industrialised and controlled process would normally make the system perform better than average seen in an overall perspective.

User aspects

NCC used both introductory market surveys and later post occupancy evaluation in order to adapt the concept and the system to the demands of the users. In the 1960's and 1970's, the western world made, '*standard homes for standard people*'. This responded to the demand at the time – a massive general need for housing. Today, it is more difficult to define the customer or user who demand dwellings designed for specific individual needs, e.g. based on much more diverse family and cohabitation patterns. In this case, such demands are sought integrated at conceptual and systemic level – not at the individual level. Thus, NCC Komplett has a high design flexibility directed at the architect, but at the same time it presents a rather low conversion flexibility (and flexibility of use) directed at the inhabitant after moving in, at the 'second-hand buyer' or at a future conversion or rehabilitation project.[7]

Causes of the failure

Many different explanations could be given for the missing success of the *NCC Komplett* system. The truth is probably a combination of many aspects. Part of the explanation was that perhaps the system came too early on a market not yet prepared for this level of industrialisation. Furthermore, the system was perhaps too flexible compared to e.g. BoKlok, with too many adaptations allowed in the completed projects to take efficient advantage of present production technologies. On the other hand, one might ask if the potential flexibility was actually fully used. The standardised look of the completed projects may have limited a general and widespread interest in the use of the system – regardless of plans for further variation possibilities – and thus obstructed the spread of the considerably different organisational principles applied – even though

[7] Vibæk, Kasper Sánchez (2007) Flexible Solution Space

sufficient demand was present.

The explicit intention of formal, aesthetical and architectural neutrality of the building system itself in order to embrace a larger market is perhaps a dead end.[8] A possible alternative strategy of a more specific system, being visible in the final design, would have provided a stronger architectural expression. Diversity would then be a question of having a choice between different systems with different expressions and possibilities. History, however, shows many examples of very elaborate and specific building systems that all end up as emblematic pieces of architecture, but never get anything near to industrialised mass production. A too specific building system usually comes short of adapting to varying situations and contexts and is often associated with the inventor, e.g. the architect, which makes others refrain from using it. However, the extremely limited period of time allowed to prove efficiency seems striking. After an investment of SEK 1 billion (€100 million) and a four-year period of system and organisation development, production was closed down after less than two years of activity. Despite the fact that the system was produced industrially as a product, it seems that the economical setup for the production still remained rather traditional in the sense that it was all too project based, thus not integrating in an appropriate and realistic manner the depreciation of the huge investment needed for development and adjustment – even after production start in the first projects.

A similar incident happened just six months later with another Swedish building system, *Open House*, which is not analysed in this project due to research access problems.[9]

A Lean Construction alternative where the focus is moved towards the building site and processes rather than being directed at industrialised fabrication and products could be investigated. A critical aspect would be the ability to show the value of iterations and to integrate these iterations that in particular characterise the architectural design process. Iteration is contradictory to the Lean concept! There seems to be an inherent conflict here between a 'traditional' design process and an industrialised production process.

Product structure and delimitation

8 Neutrality of a building system is not the same as neutrality of the final result – the Komplett construction system is hidden behind plastering.

9 See http://ing.dk/artikel/85659. In spring 2007 the project team was denied access to the Open House factory, and no interviews were given. The explanation was too much activity and a lack of time.

MT HØJGAARD

– Heavy construction, standard models, big customers

On the basis of many years of experience in housing construction MT Højgaard (MTH) developed 'the residential housing concept in 2006; it consisted of the future' consisting of four different models: *Urban Living* (the 'Nærbo' model), *Active Living* (the 'Aktivbo' model), *Ideal Livin*g (the 'Idealbo' model) and *Basic Living* (the 'Basisbo' model).
The housing concept comprises a range of residential property models targeted at defined user groups, varying from low-income groups such as young and elderly people as well as high-income groups of wealthy seniors and families. Based on extensive analyses of the Danes' ways of living and their requirements to their residences, MTH developed and designed four concept models that fulfil the needs of four major target groups, however, only three of them have been further developed for construction and marketing.
The various categories are all based on the same organisation of the supply chain and the same structural principles. The building system delivered from MTH is based on heavy prefab construction (concrete), offering fixed concept solutions (turnkey contracts) to professional customers. The following analysis is based on an interview with the Section Manager, John Sommer MBA [1] and project material used both for documentation and for presentations for potential customers.

Company profile

MT Højgaard is one of the Danish market's leading building and construction companies. The present company was founded in 2001 on the basis of the contracting firms Monberg & Thorsen and Højgaard & Schultz. These two former companies have a long history in Danish construction business both founded in the late 1910's and both basing their primary construction activities on reinforced concrete. The company has now grown and has various business activities beyond regular contracting. Today, MT Højgaard also acts as project developer as well as having activities in design and consulting services.
MT Højgaard's business activities are primarily located in Denmark, but they also have subsidiary business activities in Greenland and Portugal and run large projects in Sweden, United Kingdom, Sri Lanka and Panama. They have a long tradition for building design activities in the contracting industry, but they primarily carry out design for projects where MT Højgaard handles both building design and implementation. They provide consultancy engineering for civil works, buildings, industrial plants and environmental consultancy services, where their key competences are technical and constructional know-how. Equally, they offer consultancy services, management and supervision for building and civil works nationally and internationally. In 2007, the company had about 6,044 employees and an annual turnover around DKK 11.7 billion (approx. €1.6 billion).

[1] The interview was carried out February 1.st, 2008, by Anne Beim and Jesper Nielsen.

Business concept and strategy

Strategy and goals

The motive behind the housing concept has been to improve the total economic setup in MTH housing activities, as well as fulfilling the demands of the customers and end users. Additional goals are listed below:

• Strive towards standardised solutions and a high frequency of repetition
• Horizontal integration (e.g. the use of EJ Bathroom pods assures the same high quality and product performance)
• Short processing time
• Knowledge about end user needs are incorporated
• Timeless architecture
• Elimination of defects and insufficiencies – (the average cost of repairing one defect in construction is DKK 15,000 (€2,000))[2]

The aim of the housing concept is to provide very efficient logistics and reduced time spending. By using optimised prefabricated basic elements and standardised production methods for the housing blocks, MTH is able to build much faster, cheaper and very efficiently – which they claim is attractive to the customer and the end user. When the order is placed, MTH is able to offer a preliminary project brief with a price estimate within in a couple of weeks.

The building concept provides advantages for end users, the clients (investors or developers) and MTH, due to the economy generated by the scale of the concept (volume) and the structural flexibility that can meet individual needs. To the clients, it means that MTH can build multiple square metres of high (standardised) quality. And to the end users the concept enables them to get customised housing that fulfils their needs at a high quality but still at a reasonable price level. The main idea of the housing concept is that all the various types are constructed with similar prefabricated basic elements, e.g. wall and roof elements that just have to be put into place when they arrive at the building site. The bathroom arrives fully equipped as a unit and only needs water supply and sewer supply to be fully functional.

Strategy

During the development of the housing concept, MTH initiated extensive user surveys that took about six months to execute. The surveys were led by sociologist Jens Hansen. As part of the user surveys, the *Gallup Compass* methodology was used.[4] It defines four different segment groups among people who are potentially looking for housing or a place to live.

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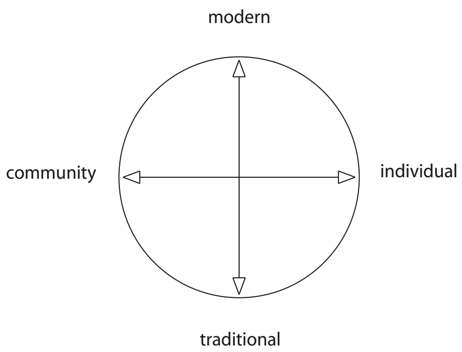
[2] February 2008 price level.

[4] Gallup Compass is a survey tool for defining segment groups in society. Based solely on questions concerning personal opinions it gives detailed information about the customers' assessement, values and lifestyle. The methodology provides precise profiles of the customers, Mediums, brands that are not only limited to demographic target groups. This analytic tool divides the Danish population into 9 homogeneous groups. For further info, see: http://www.gallup.dk/vores-markedsfokus/medier/printmedier/gallupkompas.aspx.



Trough these analyses, MT Højgaard sorted out three different user segments that were interesting for the development and direction of their housing concept. They are characterised as follows:

User segment A > Concept No. 1
– Low income groups:
This group represents: "Those who want *value for money*" and they number approx. 850,000 individuals in Denmark. On the basis of the specific segment characteristics, MT Højgaard has developed *Basic Living* (the '*Basisbo*' model) in collaboration with the architectural firm, Poulsen & Partners, Architects. The *Basic Living* housing concept is altogether robust, in terms of flexibility, its open plan and the use of daylight.

User segment B > Concept No. 2
– Elderly people:
This segment represents the ones who are: "*Traditionally oriented*". The concept *Ideal Living* (the 'Idealbo' model) was developed together with the architectural firm Mannick & Storm A/S, Architects. This user segment represents approx. 530,000 individuals and consists of 80-85 % elderly people, characterized by low income, but often having a considerable amounts of assets. 15 % are young people with a preference for traditional values. The housing concept incorporates covered balconies and the image of masonry constructions.

User segment C > Concept No. 3
– The creative class:
For this segment, the housing concept *Urban Living* (the '*Nærbo*' model) was designed in collaboration with the architectural firm *Juul/Frost Architects*. Two different types were designed, a low-rise dwelling scheme and a multi-storey housing block. The segment numbers approx. 600,000 people who can be characterized as oriented towards modern living and attracted to the idea of community. They are primarily under

45 years of age and often vote for the Danish social liberal party, are members of various non-profit organisations and are interested in environmental issues. The dwellings are designed in such a way that it is possible to meet the neighbours when returning home from work.

All housing concepts were launched in 2006. Concept No. 1 – *Basic Living* – and No. 3 – *Urban Living* happened to survive, whereas concept No. 2 – *Ideal Living* – died. The concept as first developed did not show the economic advantages expected. “Anything could be built at that price level”.[5] However, *Ideal Living* was reworked into the *Active Living* model. This was a new residential type for active elderly people. Supposedly, 3,000 flats that are unsuitable (too small) for elderly people are built per year in Denmark.[6] *Active Living* strives for more space per flat unit.

Procurement

The overall housing concept is conceived as a turnkey contract at a price level of approx. DKK 14,000 (€1,866) per m2 incl. VAT. It has been of vital importance to MT Højgaard not to develop the projects in-house, but instead to hire a number of known business partners – e.g. architectural consultants who work on different housing concepts, each reflecting their different professional profiles. MT Højgaard rather wants to build up long-term and trusted partnerships with consultants, suppliers and sub-contractors rather than heading for the cheapest bid from project to project. If they did so, they would have to deal with different partners in the various projects, which would require extra resources and adjustments in order to agree on the elements of the housing concept. However, over time the development towards long-term partnerships will eventually end up with strictly defined conceptualised projects. In addition to providing a surplus in 2007, the housing concept has caused a rub-off of new technology to the benefit of the rest of the business organisation.

Organisation

In order to restructure and trim the organisation of the construction processes in terms of optimising off-site and on-site production, MT Højgaard applies horizontal integration, e.g. they always use fixed suppliers such as EJ shower units (*EJ Badekabiner*, see chapter 4) and *EXPAN* concrete elements, which makes it easier to reach the price estimate and work out a detailed time schedule. TrimBuild® is also used as an underlying management tool for the various housing concepts. It is an efficient tool developed by MT Højgaard for systematic construction process management, based on the idea of Lean Construction.

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[5] From the interview with John Sommer, Section Manager, MBA, MT Højgaard, February 2008.
[6] According to the Danish newspaper, Jyllandsposten.

The aim of TrimBuild® is to create the most efficient design and building process in any given conditions.[7] It strives towards less waste, greater efficiency and increased value – to the benefit of all parties. The solution is a set of procedures and ground rules that radically and efficiently change the way of operating for all involved parties at all stages of the building process. Various deliveries, e.g. flooring, are put into place when the crane is working.

Although the logistics of construction can be difficult to manage and control, MTH has developed methods to ensure an optimised production process and so achieve higher value. For 10 years, MTH has worked on reorganising and optimising the building process, from initial design to final delivery of the finished building. It is aiming at balancing optimisation and administration. At one point, all the electrical sockets were placed in every room in one sequence; however, that meant more administration than price reductions. MTH does not believe in 'Total Concepts' such as the *NCC Komplett* – the concept seems to be dependent on too heavy capital bindings. Also, due to local planning regulations etc. there is a need for great flexibility in the construction solutions.

Transport/export/import

The logistics system of the housing concept is based on road transportation by lorry, and delivery by suppliers who are located close to the different construction sites. MTH benefits from the fact that e.g. the EXPAN concrete element supplier has factories and assembly units at five different locations spread all over Denmark. In that sense, transportation time and insurance are not overwhelming and depend on the type of prefabricated elements (concrete wall elements or volumetric wooden elements).

In terms of importing components or material, the balconies were made by a local blacksmith for the first *Basic Living* project, but there are plans about outsourcing the production and buying prefabricated components (China).

MTH has no ambition presently to internationalise their concept or to export the housing projects, due to the fact that the international markets are

[7] http://www.mthojgaard.com/pages/concepts_trimbuild

based on different legislations and cultural values. Standards, norms and building codes required for building products and constructions also differ greatly from the Danish construction business and legislation. Neither does MTH consider selling the housing concept since it cannot be legally protected in terms of royalties or patenting. The number of variable parameters alone will make it difficult to protect.
However, they might be able to sell part of their housing concept as know-how.

Product and production

Technology

Within the various housing concepts, one can build anything from youth residences to retirement homes and luxury apartments, all based on the same project management model, construction concept and structural principles.
Urban Living and a new concept meant for active elderly people, *Active Living* are both developed on the basis of *Basic Living*. *Urban Living* is a low-rise housing complex, where the concrete element facade of *Basic Living* is substituted by wooden elements. Due to the high insulation properties of the wooden elements, extra indoor square metres are provided within the same gross square metres as in *Basic Living*.

Basic Living

This is the most rational of all the housing concepts. All materials and building components are chosen to meet the requirements of the target group. The design of this model also ensures optimum use of space. *Basic Living* was the first housing project built in Aalborg in northern Denmark. 69 rental flats were built in 2006 based on a hybrid structural principle mixing concrete elements and box units. In essence, one facade is used for load-bearing stability, whereas the other has total flexibility in both design and construction.

Basic Living. Photo: MT Højgaard A/S

Each flat is arranged around a prefabricated bathroom and kitchen unit, which forms a natural room divider. Further rooms are added in the larger flats. The toilet units carry the service systems for the kitchen and the basic heating system, which can

only be extended by adding new closed circuits from here. Electricity is led under the flooring in order to be connected and pulled through pipes in the wall.
Most often, exterior walls areerected with windows already fixed. The concrete elements are cast in a 'masonry mould' that resembles sack scrubbed masonry. The material is white painted concrete.

The concept focuses on short processing times and already known construction methods:

- The short amount of time spent in the project development and erection of the construction gives significant cost reductions (even at times when interest rate levels are low).
- Risks are reduced by applying known construction methods and shorter processing times (more security concerning the sales price).

At the moment it is possible to build *Basic Living* at DKK 11,600 (approx. €1,487) per m2 excl. VAT.[8]

There are limits to standardisation. It is evident that it is not possible to design the totally standardized construction kit, due to the fact that circumstances differ from project to project, e.g. the width of the building has to be able to vary, and with great precision. Also variations of the concrete elements are very expensive. It is still economically sufficient to have 2-3 different types that are used for variation, but different designs for each element are not viable economically. There is no price reduction in making different openings in the concrete elements since the price is determined by the measures of their outer size and not the amount of concrete that is used for making the element.
Concrete elements are still the cheapest construction method, as it is still not possible to build multi-storey housing with wooden structural elements in Denmark due to fire requirements. Even if the fire problem was resolved it would still be difficult to comply with the building codes concerning sound insulation when using wooden constructions. This will require two separated wall elements in order to provide the physical separation between two flats and therefore it also requires

[8] Price level at 1st February, 2008.

two lifts by a crane. Also, the painting job is more extensive when having to cover a wooden wall.
For facade elements where the sound insulation problem is not the same, wooden elements may have some financial advantages, since you can achieve a larger net floorage in the flat with the same heating insulation level. The technical construction concept is not different from industrialised building of the 1960's and the fundamental ideas are the same, but it holds a higher degree of variation and there more effort has been put into differentiating the various housing schemes by small changes. Furthermore, today there are much stricter demands to e.g. heating insulation sound insulation and ventilation, and the housing market is also much different from the market of the 1960's.

Photos: Urban Living and Active Living.
MT Højgaard and JuulFrost Arkitekter

- Totally different demands due to very specific local planning regulations.
- The target groups have become multiple and very different from one another.

Urban Living

Urban Living is constructed with load-bearing walls of lightweight concrete or wooden elements, although lightweight concrete elements are generally cheaper. The customer segment is very environmentally conscious and therefore prefers wood. MTH has considered the expenses when erecting the housing concept in volumetric elements (MTH is the owner of the factory *Scandibyg* that delivers pavilions); however, it proved to be cheaper to build them with regular facade elements. The main expenses when using volumetric elements are:

- Transportation: (the volumetric elements transport air). There is room for two flats constructed with sheet elements on *one lorry*, whereas *three lorries are needed* to transport only *one flat* when volumetric elements are used.
- Foundation: It is much cheaper to make a platform on the ground than to make foundation pillars, a ventilated inspection cellar and a wooden plinth (as Billige Boliger, which, however, has a different point of departure construction-wise).[9]

It is a fact that flooring has to be laid out at the very end of construction also in the volumetric elements, since the customers will not accept profiles connecting the joints of the floors. In certain cases, it can also be necessary to mount the gypsum plasterboard after arriving at the construction site. MTH concludes that the cheapest construction principle used for low-density housing is load-bearing walls of concrete with wooden facade elements.

Project design management

The housing concept can offer 2-8 storeys, and from 28 m2 to 140 m2 flats, with no balcony, balcony to one side or both sides of the building. Different technical concepts are also being used, e.g. a Dutch structural system. *Basic Living* is always the initial starting point from which improvements and variations are made in the design (the construction elements) until the design goal is reached. This is different from traditional methods where ambitious designs are altered and cut down in order to reach the price level of the bid. During this process, the investor/developer and/or the estate agent are also involved; they often ‘push’ the concept into a direction where they believe it can be sold.
Despite the different housing concepts, the detailing is pretty much the same and in that sense the detailing and the construction principles make up the ‘platform’.[10]

9 Jensen, Kasper Vibæk og Anne Beim (2006) *Kvalitetsmål i den Arkitektoniske Designproces,* (Quality Targets in the Architectural Design Process) pp. 94 -109.
10 Beim, Vibæk & Jørgensen (2007): *Arkitektonisk kvalitet & industrielle byggesystemer,* (Architectural Quality and Industrial Building Systems) p. 26.

When developing the architectural concepts (e.g. *Urban Living* by Juul|Frost Architects) a sort of graduating model is used were the fee is adjusted (reduced) in relation to when the details are being reused. Over time, the architectural fee will be approx. 30 % of the fee paid for the first project. In this way, the architects are compelled to use the same solution and details from project to project.

Configuration and web

Configuration software is not being used at the moment, but the construction report is connected to the sales process by a sort of checklist. This is made in such a way that the project is almost completed for construction by the time the contract has to be signed. In some cases, the architect is part of this process, but occasionally, the building scheme is planned solely by MT Højgaard until the contract is being signed. However, when handling the project with the local planning authorities, the architects are always part of the process.
Neither is the present construction concept using any sort of automisation for the manufacturing of the concrete elements. The motto is: “What is easiest to make at the construction site will have to be made at the construction site.”

Quality

According to John Sommer, the architecture of the MT Højgaard housing concept ought to reflect the preferences of the end users. Aspects of quality are therefore primarily to be found in the formal flexibility and in the end user focus. “We are not building monuments; we are building ‘from the inside out’. We do not need artistic architects to tell us how a window has to be placed in the construction. For too long, the market has focused on the high-end segments of society. When using the concept, we are mainly building for the group of people in the middle segment.”
As was the case with the *NCC Komplett,* the number of flat types, the material selection and the adaptability of the projects over time seem quite limited. However, in contrast to *NCC Komplett,* the housing concept of MT Højgaard is rather governed by market surveys and models rather than the manufacturing process that could theoretically be managed as more open to numerous architectural qualities. Similar questions as in the NCC chapter can be raised here: Is the concept too dominating in terms of both construction and process management? And do the architects feel that they are designing an MT Højgaard Housing concept? Do they feel limited, and if so do these limitations provide quality or a lack of the same?

Sustainability

Aspects of sustainability are not implemented in the present concept, however, MTH proclaims that the carbon footprint of concrete is not critical. MTH has not yet worked out calculations in terms of sustainability or CO2 emissions of the housing concept.

User aspects

In selling their housing concepts, MTH is struggling with the small Danish housing market.[11] They have no true possibility of doing business with leading international suppliers or production industries. At the same time, it can be difficult to build up construction or marketing systems that are more suitable for larger markets. MTH knows the *generic end-user* very well, but sells through the investor/developer or the estate agent. The company is not able to handle the end user customer, but focuses on business-to-business relations – however, they would be able to do business with a cooperative housing association. Variation in materials and interior design cannot be handled on an individual basis, but MTH will try to make what they call a 'Nordic Type' with light-coloured materials and another with dark-coloured materials. Then the end users can choose between these two. In terms of very well defined interior elements such as the colour of the kitchen cabinets, it is possible to let the end users have a choice, but it will always be the investor/developer who will manage this part.

Basic Living

The end users want flats with a lot of daylight quality, with plenty of room, but at a reasonable price. They are not very interested in the exterior architectural expression or the material qualities of the facade.

Urban Living

The end users want two entrances and also prefer to have a utility room. In the multi-storey housing schemes, the end users' request for social interaction is interpreted by Juul|Frost Architects as differentiated exterior hallways and staircases that include zones for resting and sitting placed as a distinct infrastructure at a distance from the housing block.[12]

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[11] The present international financial crisis has stopped almost all activities on the Danish housing market especially in the big cities such as Copenhagen, Aarhus and Odense.
[12] See the chapter: *"En udfordring af det arkitektoniske værk"* (A Challenge to the Architectural Work) IN: Lund, Lene Dammand, Line Eriksen Jens V. Nielsen (red.),(2005) Industrialiseret Arkitektur: Økonomi – proces – produkt/værk, pp. 76-84.

Active Living

Based on interviews with people 70+, the consultants *Ulveman* (sociologists) have helped define the user needs by using a ‘signal’, ‘frame’, ‘kernel’ model. The signal stands for the intangible, the emotional expression and impression that is given by the frame and the kernel. The *frame* is formed by the local environment and the building or the buildings in which the *kernels* are situated. The kernel is the actual flat where the inhabitants live.[13]

- Signal: the bathroom is big enough to change into a service unit for disabled or handicapped people. But the equipment is not installed since there is no wish to show this future alteration.
- Frame: not all building sites are suitable for housing for elderly people, especially when considering access to public transportation, the city and shopping etc.

The thorough user surveys have helped change some well-known clichés, i.e. that elderly people prefer to live among mixed age groups, they rather want to live together with people in similar circumstances, but do not mind living near other segment groups.

POE – Post occupancy evaluation

In general, after some time, the end users are interviewed about their experience and evaluation of the housing/dwellings in order to improve the housing concepts for the future projects. MTH expects that their housing concepts will change over time due to the feedback from the market and the end users.

[13] http://www.mthojgaard.dk/pages/aktivbo_kernen; http://www.mthojgaard.dk/pages/aktivbo_rammen; http://www.mthojgaard.dk/pages/aktivbo_signalet

PERSPECTIVES OF DIFFERENT STRATEGIES FOR DELIVERY

Except from the structural building systems, all the subassembly examples presented above are spatially well defined in the sense that there is a fairly clear physical border line between the space defined and provided by the different subassemblies and their physical context.[1] The structural building system, however, represents rather a functional delimitation, where the subassembly is spatially distributed (integrated) 'all over' the building while providing one single function: Load-bearing support. Some subassemblies, e.g. the bathroom pod, combine spatial and functional delimitation (segregation), whereas in the case of the installation shaft, a planned strategy has been to distinguish between the vertical common installation routes in the shaft (segregated), and the horizontal individual installation routes (with the same functions). The latter, which are distributed (integrated) around the building are left out of the product and subsequently produced traditionally on site. Windows could be an example of a subassembly, where each unit has a clear delimitation against the surroundings (segregation), while the complete window product delivery is spatially distributed around the building (integration). However, moving towards complete facade solutions,[2] the product becomes both spatially and functionally segregated from the rest of the building complex at one and the same time. An analogy expressing the two different strategies could be the modernist zoned city (segregation) versus the classical urban habitation, where functions are spatially mixed (integration).

As for the all-encompassing systems, they do of course have the inherent character of sub system integration when it comes to delivery (turnkey). The factory production (prefabrication) is usually equally integrated, as outsourcing is apparently only sporadically applied – most processes are effectuated in-house in one single factory. In the case of *MT Højgaard,* however, the bathroom pods and structural concrete elements are outsourced as segregated parts installed on site. Although very standardised, the prefabrication level of the rest of the building is, partly due to the heavy construction, relatively low. Outsourced bathroom pods were,

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[1] E.g. the balcony and the facade, the bathroom and the rest of the dwelling, the shaft and the living space and the facade and the base building.

[2] As in the case of Permesteelisa.

according to Niels Sandahl (*EJ Badekabiner*), originally also planned for the *NCC Komplet*t concept but they ended up producing the bathrooms in-house, thus opting for maximised profit and decreasing risk in favourable periods.[3]

Business concept and strategy

Procurement

The potential success of the different strategies into the industrialisation of the construction industry is closely linked to the market relation and the processes involved in the development of projects. The strategy of traditional delivery in the development of a site is based on the contact to an architect, either through direct commission, or in the case of large public assignments, through a competition. The architect will typically focus on the outline and spatial disposition by adopting a project oriented ‘top-down’ approach in the design. In the design process, the architect will work towards an ideal shape and a spatial arrangement, unique to the site and the brief. This process is typically staged, with the output of each stage being drawings and visualisations of increasing scale and detail. As the scale grows, the ongoing process of seeking technical approaches in order to solve the spatial challenges among all known and imagined solutions is a constant game of trial and error and as such an iterative process.

The tender documents and construction specifications within this strategy are not customised for any specific supplier or manufacturer. The specifications will prescribe processes that are a mixture of more or less manual crafts, and the specifications will typically be sorted according to these. Some of the prescribed processes will perhaps be suited for industrial production, others will stretch the capability of the industry beyond its limits and some processes will fall totally outside the viability of the production system. If the actual industrial potential of any project is to be exploited within this strategy, it will require the architect is at least partly familiar with the state of the art in order to prescribe processes adequate for industrialisation. The main advantages of this strategy – industrialised or not – is of course, that the client as well as the architect end up with what they dreamt of, if the client can afford it and there is enough time.
The disadvantages are that:

- If the budget is tight, they end up with less than they could have had with another, more rational strategy.
- The process is time-consuming and involves much iteration, in both design and execution stages.
- The industry is kept from specialisation and thus on a very low technical level.

In many ways, an opposite strategy is the turnkey

3 Interview with Niels Sandahl

delivery, where a contractor (often working as a manufacturer) offers a project suited for his production apparatus. The contractor will offer a project based on his experience and ability to deliver reasonable customer value at a competitive price. Seen from the customers' viewpoint, this is a very different way of investing. The contractor will often be chosen on the basis of a reference project, which then in quality and spatial arrangements will be the benchmark (or prototype) for the new contract. The customer in a way buys a (predefined) product – not a project.

This kind of contract could have its clear advantages. Customers seeking a very predictable outcome (the product), who are not interested in novelty aspects and those on a short time schedule will find the turnkey product very suitable to their needs. In some turnkey contracts, the contractor will employ an architect to ensure the architectural integrity of the project, but he will be restricted to design decisions within the overall framework of the system and production method, which will not influence the cost.

In case of the turnkey project, the focus is on the production system of the main contractor in the development of the project. If the traditional delivery/supply strategy (traditionally followed by architects) is all about finding processes that will compromise the architectural vision as little as possible, then the turnkey delivery strategy (promoted by the contractor) is all about finding a vision within the production system that will compromise its capabilities as little as possible. The turnkey contractor could have any degree of production facilities from all in-sourced to all out-sourced (e.g. as subassemblies). More outsourcing (MTH) will increase flexibility, but also decrease the profit and increase the risk. More in-sourcing (BoKlok) will lower the risk at the supply chain level and boost profit in favourable periods, but will (generally speaking) radically reduce flexibility. There are, however, examples of in-sourced companies using very flexible production platforms thus being able to adapt to different demands (Willa Nordic).

Common to both sourcing strategies is that the profit and survival of the turnkey contractor will depend on the

“Kip House” 3xN for M2, a company selling predefined single-family houses designed by architects. Photo: M2

optimisation of the production system, which again will be driven by standardisation and repetition. This internal demand for standardisation ties in very well with the concept of configuration (within tight limits), as the defining of the parts and variables in the system (building the product architecture) is one of the cornerstones in the development of product
configurators. Whether this actually leads to the concept of ‘mass customisation’ is another question, though. As almost all existing turnkey manufacturers base their business on economies of scale and optimisation by repetitive processes, the design flexibility of an engineer-to-order project is unreachable for this kind of industry. Willa Nordic achieves a high flexibility in geometry, but is very limited in the choice of detailing and materials.

Building configurators for these manufacturers will mostly address the individual home investor, as the flexibility in design demanded from large-scale housing developers will always necessitate amendment in the production specification due to e.g. local planning restrictions or site conditions.[4]

As the architectural flexibility, as well as the transparency of the pricing structures of the turnkey contractor are very limited, a healthy market structure based on these contractors will only exist, if there is an array of suppliers covering a very varied range of qualities and designs. Rather than making the individual systems capable of building anything, an architectural ideal within the turnkey delivery strategy could be to have a wider choice of systems, so that an investor could choose the right system optimised for his needs and preferences.

The equivalent of the 'architect's approach' in an industrialised reality will be the strategy of integrated product delivery – architecture as collections of integrated product deliveries – or subassemblies. When it comes to procurement, this strategy could, in theory, follow the traditional way of tendering individual packages, but in practice this does not work. As the supplier of an integrated product delivery is highly dependent on his production system and his knowledge within certain specialised processes, he cannot tender correctly on the material traditionally prepared by the architect, as this will:

- Be based on production processes not necessarily used by the specialist supplier and installation sequences referring to a craft-based approach.
- Prescribe solutions not covered by the supplier's guarantees.
- Be based on a non-modular approach forcing the supplier into on-site production processes.

There are two possible solutions to this very common dilemma: Either the supplier will price a solution solving the technical task, but not in the way the architect imagined, or he will calculate the prescribed solution resulting in a non-competitive price. The first solution, which will result in time-consuming design work together with the supplier after commission, influencing important design decisions already made earlier in the process. The second solution will force the team into saving processes,

[4] Interview with John Sommer, MTH

Interior, Kvistgård. Tegnestuen Vandkunsten, 2008. Photos: Adam Mørk

which are also time-consuming, non-productive and tend to generate mistakes in the finished work.[5]

One way of resolving this dilemma is to split the design work into a pre-contract and a post-contract phase. The pre-contract work is mainly concerned with outline design, scheme design and the part of detailed design necessary to determine the nature and position of all contractual interfaces and the performance of all components, but only the desired appearance of the visual ones. The actual construction and the chosen processes within one

[5] Interview with Søren Daugbjerg, CEO at Vilhelm Lauritsen, May 2008

specific package are determined by the suppliers, supervised by the architect. In the example of Permesteelisa, the application of pre-construction agreements where the contractor makes his offer based on outline drawings, performance specifications and sketch design details is a step in the right direction. Another interesting and more complete version of this (design assistance) is developed by Gehry Associates. [6]

This approach allows the suppliers to optimise their production and their degree of pre-fabrication, improve quality and encourage innovation. Present procurement methods do not allow this method, though, as:

- The suppliers of industrialised and configurable building assemblies only exist within certain areas of the construction industry, i.e. facades and bathroom pods.
- The consultant/architect is not interested in supporting this development and does not incorporate it in the outline design phase. They see it exclusively as a cost-saving option in the late stages of the design, when it is too late.
- The tender process is still firmly anchored in the 'crafts-tradition' and is based on the principle of getting a process prescribed in detail done as cheaply as possible. No tools exist for the more open principle of getting the best solution for the available means.

A process similar to the one described is in operation in the UK, where a 'contract manager' is responsible for the total economy of the project, making it possible, through successive estimations based on industry contacts to weigh several contractual splits against each other.

Segregation vs integration

Within the strategy of integrated product delivery (subassemblies), it currently seems more probable to develop business concepts and products based on segregated systems – rather than on integrated ones. In other words: There is a bias towards assemblies that – as most of the analysed examples – have a clear spatial delimitation in relation to their surroundings. The functional convergence seems less important

[6] Vaz, Dwayne 2007

Bedre Billigere Boliger, (Better Affordable Housing) Ølby, JuulFrost, Photo: CINARK

although it can be a strength (as is the case with the bathroom pod).[7] One explanation of this apparent preference for segregated assemblies could be the question of the interface.[8] Integrated subassemblies – e.g. a complete heating or flooring system – make it almost impossible to provide for all possible (unexpected) situations – especially when buildings are never detailed down to 100 % as is the case for e.g. cars, ships or aeroplanes. Unforeseen encounters between assembly and surroundings on site require adaptation and craftsman skills, which is exactly what is intended to be avoided while reducing on-site work to simple assembly. Segregated subassemblies with clear physical border lines make it much easier to define the interface with the surroundings and reduce the risk of interference problems between assemblies.

7 In the case of the balcony, the function provided is an enhancement of the general living space and is here consequently not considered as having a separate function. As mentioned, the shaft provides only the common routes of the different installation systems.
8 The interface problem is an ongoing discussion that deserves further elaboration. This has, however, not been possible within the framework of the present paper.

Company profile

Both EJ Badekabiner (EJB) and Altan.dk (ADK) have established completely autonomous companies specialised in the specific product, although rooted in related businesses. As for the NCC shaft, the idea of a subsidiary company has been introduced, but the product, which is still just a prototype, is not yet mature enough to be separated organisationally as well as economically from its source of origin. For regards the turnkey examples, Willa Nordic started specifically as housing manufacturer, whereas MTH and NCC are traditional contractors. Only the foundation for affordable housing (FBB) is rooted outside the construction business although indirectly related through connections to the large Danish social housing organisations. An open question could be whether it is an advantage to be rooted partly or completely outside the construction business. Both ADK and the NCC shaft have had considerable input through consortiums that bring in people and companies from other industries with other traditions. One of the main obstacles in making assemblies seems to be the divergence between the traditional division of labour in construction and the product structure of the assembly that impedes efficient production.[9] In Japan, two of the most important prefab housing manufacturers (both all -encompassing systems) are rooted in the chemical business (Sekisui Chemicals) and in car manufacturing (Toyota Home), respectively, and one of the most successful industrialised housing concepts in Sweden, BoKlok, was originally conceived by the furniture manufacturer IKEA before joining with the contractor Skanska. The analyses above, show attempts to create new companies as an active way of breaking up traditions and doing something in a different way. On the other hand, there is an obvious danger of leaving behind important non-explicit knowledge, which is embedded in the traditional crafts.

Strategy and goals

It seems essential for business concepts for building assemblies to limit rather than expand the product focus. As products and competitors are (still) relatively few in number, it is apparently not the size of the market that is the problem[10] – all the subassemblies

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[9] Compared to all-encompassing concepts, the obstacle when making assemblies is probably even more pronounced. Here, it is not only a question of splitting up the work operations of a whole house differently but of even splitting each building into assemblies produced separately by different companies.
[10] When it comes to all-encompassing systems, one of the main problems is exactly the limited size of the market. See later section.

analysed seem to operate on ‘blue ocean’ markets.[11] It is more important to have a clear product profile where the advantages concerning quality, price and time can be presented in an easily understandable way. Furthermore, the relatively high functional complexity of buildings – and in particular dwellings – quickly makes it difficult to control large assemblies and their interfaces within an efficient industrialised, yet flexible production system. The very same aspectis perhaps also the Achilles’ heel for the all-encompassing systems, which often forces them into too standardised solutions seen from an architectural point of view, partly due to a lack of production volume (market). The ‘price’ of better control of the production process is that these systems do not offer a sufficiently appealing solution space and consequently run the risk of becoming associated with a monotonous expression, thus reaching only a narrow market primarily concerned with price. This, in turn, can lead to even less production volume and further needs for standardisation in order to maintain revenues. However, the use of a standardised system necessarily results in standardised results, but mass customisation seems – apart from superficial add-ons as colour schemes or optional fixture brands – still seems far from realisation within the construction industry.

A question is whether the predominant ‘blue ocean’ market situation of the subassemblies and the integrated product delivery strategy actually provides more incentive for development and innovation than the ‘red ocean’ found among the all-encompassing systems and within the turnkey delivery strategy? Altan.dk actively uses the term as a way to classify their business strategy as innovative and expanding, but looking at EJ Badekabiner, it seems more like the close-to-monopoly market situation has resulted in increased production, but only very sporadic product development during the more than forty years of production. Although, the bathroom pod is a mature (well known) product, it is still produced as different projects with very little knowledge transfer between each project. Project based development is mostly inefficient if knowledge and experience are not systematically collected and implemented in future projects. Part of the explanation is an outdated tender system that, as explained in a previous section, excludes the manufacturer from participation in the preliminary phases of a project where essential choices determine later possibilities.[12] Fixed business partners on both sides of the value chain would be beneficial to the development of integrated product deliveries – an explicit strategy of Altan.dk. As phrased by Niels Sandahl, EJ Badekabiner, it would give the necessary stability in production flows and make space for development to produce for fixed partners who actually knew in which direction

[11] For further explanation, see analysis on balconies (altan.dk).
[12] See previous section on ‘Procurement’.

they wanted to go. When Audi chose to produce aluminium cars it was expensive – but still good business in the long run, even if other companies later copied the idea.

Organisation

Within traditional product delivery, the production is a subtle and often unpredictable mixture of manual and automated labour and also a mixture of on-site and off-site processes. Some processes, such as the production and erection of pre-cast concrete elements, are planned to the last detail and would qualify as industrial production. Others are ad-hoc and at the time of commission, they are often known only as tasks, priced by built area on the basis of experience. The systems work to some extent due to the tradition in the construction industry of working in a project-related manner. Everyone knows by experience what it takes to finish their part of the job and they normally show a good deal of flexibility in connecting to and helping the other crafts meets the general project schedule. In comparison to the manufacturing industry, the degree of specification is very low. This is to some extent counterbalanced by (and therefore dependent on), the experience of the subcontractors and the training of the craftsmen.

To go from construction to production and assembly calls for a considerably different combination of manpower and professions – a new division of labour. Semi-skilled workers in multi-skilled work teams combined with a more pronounced use of IT controlled machinery and management is thought to provide efficient and flexible production – matching the quality of the former crafts but with new divisions according to the different products (assemblies). Manufacturing products in a factory seems to remove some of the organisational obstacles found on site. This is probably due to the mere fact of not being at a construction site and thus it is to bypass traditional lines of divisions and ways of doing things. The product focus also has the advantage of leaving the division of responsibility more transparent and facilitating better possibilities of documentation and warranty.

The production or part of it can be outsourced, as in the case of Altan.dk, without the loss of product identity (the brand), which is quite different from the project orientation known in traditional construction, where there is no predefined product – only a specific project – and the constellation of client, contractor and subcontractors is always new. Organisation in production is (relatively) independent of the single order – of e.g. a specific project – and this provides the stability needed to establish confidence and co-operation between different stakeholders.

In the Altan.dk and NCC cases, consortiums with different stakeholders are used actively as kick-off in order to bring in new ideas and break with tradition. However, after the first development phase, the ownership of the new product is located within one single company – in both cases rooted in the construction business. Although different user groups are involved from time to time for different kinds of feedback, the further product development seems to be primarily located within the company – without the cross-disciplinary and inter-sectorial qualities found in the consortiums. The case of EJ Badekabiner with more than 40 years of production within one company resulting in very little product development could point at a need for constant challenge, which on the 'blue ocean' does not come automatically in the form of competition. Within the realm of architecture it is an 'old truth' that the client himself does not necessarily know what he wants. Innovation and development have many other sources.

Transport/export/import

The shift from project to product and from construction to production makes documentation and warranty aspects easier issues to deal with, as already mentioned. This facilitates actual type approval, has already been obtained by EJ Badekabiner on e.g. the Norwegian market. Although standards within the building sector are an extremely national issue,[13] the limited size and complexity of a subassembly combined with the fact that it is NOT a building come out as an export advantage compared to all-encompassing building systems where export is so far practically unknown. Even the BoKlok concept (owned by IKEA and Skanska), which operates on all Scandinavian markets as well as the British market, has national adaptations and actually works as a franchise concept, where a local contractor and developer (though often the national Skanska division) takes all the risk. The fact that subassemblies are smaller, less complex units than complete building systems and that itmay be easier to get (national) type approvals due to clearer functional delimitations and performance descriptions makes international export of building assemblies rather probable. This, in turn could result in a much more stable

[13] This fact is also discussed in the analyses of bathroom pods.

production and sales being less vulnerable in case of national economic slumps.The strategy of outsourcing production to low-wage areas, as in the case of Billige Boliger is based on a calculation of the relation between transportation distance and wage differences. As low-wage areas evolve, the critical distance will increase and could facilitate an alternative strategy of local (national) automation of the production apparatus in high-wage industrialised countries. This could then turn the market around and promote international export of smart technologies, as mentioned in the section on Billige Boliger.

Product and production

Technology

The cases analysed in previous sections do not represent any particularly innovative use of technology when it comes to production. The future visions of the NCC shaft production and the IT integration plan of Altan.dk do point towards a higher degree of automation, but so far this has only been sporadically implemented (Altan.dk). What distinguishes these products from traditional solutions is the split-up into subassemblies, the separate prefabrication and segregated assembly of these units and the resulting product character. These integrated product deliveries fundamentally challenge the way of considering the organisation of construction. In the analysed turnkey deliveries, the focus still remains on the complete house. Although partly factory produced and thus to some degree freed from traditional craft divisions, these houses are perhaps of a scale and a complexity, which, when combined wtih the project oriented market structure of smaller and/or one-time customers, complicates systematic product development and a more pronounced use of automation technology.

A general comment on industrialisation, which also concerns the building industry, is that the demand for a thoroughly planned process in industrial production makes the constraints – which are always there – more transparent in a specific project.The freedom in traditional construction is often a mere illusion.

Configuration and web

It is hard to find examples within the construction industry that fully exploit the envisioned potentials of designing and/or configuring a product digitally thus having a virtual prototype that ideally subsequently can be 'printed' directly in a production facility. Although technology is present it still seems to be too expensive to enhance the IT systems needed to control these processes.[14]
Part of the explanation is found in the large number of different and small stakeholders involved in building and a lack of stable business relations. This gives a general lack of incentive for large investments in the development of the necessary systems. A joint initiative is furthermore complicated by the fact that all professions involved have their own systems and standards, which requires a lot of translation – presently normally done 'manually'. In the shipyard industry, four of the world's largest manufacturers, including the Danish Mærsk-owned Lindø Shipyard joined together with a software company and invested more than DKK 1 billion in the development of such an integrated IT system. Although the construction sector is much larger, the fragmentation impedes such initiatives. If industrialisation is to gain importance in construction, digitalisation and the possibility of virtual prototyping somehow seem essential.[15] In a sector where traditional mass production at turnkey level will probably never become an issue (again), the control of individual adaptations in a standardised/automated production line is too complex to handle with manpower alone.[16] Furthermore, the communication and information flow between different stakeholders during the whole process could gain a lot using standardised digital platforms.These platforms do not necessarily mean control of size and shape of the products. As seen in the Permasteelisa analysis, many of the downsides of design and build processs relate to misunderstandings conserning scope and quality levels. The feeling of lacking control over the finished product could be radically reduced by online configuration tools, designed to match the expectations of clients/architects and manufacturers by settling the cost-driving specifications early.
In terms of integrated product delivery the bathroom pod is the product that most obviously lends itself to configuration by web tools. Although the specifier would be the architect and not the end user, it is easy to see the architect's potential future role in industrialised construction as 'configuration manager', being responsible for the performance criteria and interaction of the chosen systems, but not their actual production.
Finally, so-called web 2.0 systems can involve different user groups directly in the product and business development.[17]

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[14] Examples from other industries that have reached further into integrated IT solutions can be found within clothing, shoes, small accessories and furniture – see e.g. www.spreadshirt.com, www.ponoko.com.
[15] In traditional construction, prototype and final result is one.
[16] New industrialisation is about standardising the process rather than the product.
[17] Web 2.0 is a term describing the future trend in the use of World Wide Web technology and web design that aims to enhance creativity, information sharing, and, most notably, collaboration among users http://en.wikipedia.org/wiki/Web_2.0.

Quality

The interviews show a certain restraint when it comes to the question of quality. According to Niels Sandahl, EJ Badekabiner, 'good quality' is useless as a sales and branding parameter since nobody would claim to sell bad quality. However, it is a well known fact that the complex coordination of work and the risk of things falling-between-chairs on site do result in many misunderstandings and deficiencies in traditional construction. The factory production makes it indisputably easier to control and coordinate the processes and exclude the factor of weather conditions – which in Denmark at least, can induce an important dimension of uncertainty. Subassemblies – at least as we find them in building today – do, however, still require a certain amount of assembly and finish work on site – we are far from the 'click'-vision of the NCC shaft. In this sense, the integrated product delivery strategy is perhaps more vulnerable than the turnkey delivery.[18] However, even when factory production is maximised, buildings are – for financial reasons – never detailed 100 %. This is claimed to be too expensive but, as far as we are aware, it has never been proved cheaper from a life cycle point of view NOT to do it. While conceptually built for 'eternity', buildings are financially built for returning investments already at handover. By moving the focus from project to product with a relatively high production volume – made more probable by splitting the building into subassemblies – there might be a chance of placing further investments in the product development phases before assignment. This would hopefully give better quality, but also higher costs per unit.[19] However, as long as the tender system favours the lowest bidder on the basis of a preliminary description, things seem hard to change. Very specific preliminary descriptions isolated from a specific production apparatus tend towards disfavouring stakeholders on both sides of the table: We sell too cheap and even then we buy too expensive![20] The product focus of the integrated product delivery does, however, also have obvious weaknesses. If the focus on product development of subassemblies gets too introverted and detached from the building as a whole, there is

[18] Even the all-encompassing building systems, though, require different degrees of finish work on site. See later sections.

[19] As pointed out by Hans Mikkelsen, industrialisation does rather means more expensive but knowledge intensive products (Mikkelsen, Beim, Hvam and Tølle (2005); *SELIA – Systemleverancer i Byggeriet)* (SELIA – System Deliveries in Construction) However, as for the total economy of a building, this may turn out to be good business anyway.

[20] In 1940, John Ruskin, art critic, sage writer and social critic of the 19th century, phrased this problem in the following way: 'It's unwise to pay too much, but it's worse to pay too little. When you pay too much, you lose a little money – that is all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the thing it was bought to do. *(Continued on the next page)*

a danger of loss of cohesion in the final buildings. Even a strict definition of qualitative properties of a subassembly in itself cannot ensure cohesion with the surroundings. This will require that the product has a certain openness and adaptability towards the context in a broad sense, thus comprising the actual interface as well as technical aspects, aesthetics, functional schemes, economy, ecology, time, place and other values,[21] which all influence what we term the architectural quality.[22]

Among the analysed cases, architects are strikingly absent in the product development except from the first phase of the NCC shaft, which included an architectural office in the consortium and some user feedback concerning the proposed configurator.

An important challenge for the architect – employed internally or externally by the company – will be to define clear performance requirements in a wide definition as well as relevant relational (contextual) capacities in order to provide the necessary cohesion of subassemblies in the building.

Another potential problem in the use of subassemblies is that as building parts get larger and more complex (components => assemblies => all-encompassing concepts), choice may also get scantier. From an architectural point of view, the completely 'blue ocean' does not necessarily become a rewarding situation for quality.

According to Gert Jespersen, NCC, quality is partly a question of excluding human interference during production and assembly. This concept of quality leaves little or no space for the coincidental which is strictly seen as accidental. It seems rather dubious that this aspect can be reduced to simple algorithms – but how can this human touch be included in different ways?

Sustainability

None of the cases presents any particular strategies related to the question of sustainability. Still, it is a general opinion that factory production equals less waste and less time consumption which leads to a more appropriate use of resources. To make this true (or to prove it), it is necessary, however, that the product life cycle aspects are also taken into consideration so that your bathroom pod or facade system can be serviced, repaired and eventually replaced without losing these two gains. Altan.dk emphasises the few simple materials used in their solutions, which simplify disassembly and reuse.

In general, a better documentation on materials and joints makes service and recycling easier.

The turnkey delivery strategy – as seen in Billige Boliger – can make use of different international and national energy classifications, something that does not yet exist at subassembly level. This makes it easier for the all-encompassing systems to use sustainability as a branding parameter.

Systematic consideration of total energy and total economy solutions is still in embryo, but this is

The common law of business balance prohibits paying a little and getting a lot – it cannot be done. If you deal with the lowest bidder, it is well to add something for the risk you take, and if you do that, you will have enough to pay for something better.' http://en.wikipedia.org/wiki/Common_Law_of_Business_Balance.

21 Beim, Anne and Jensen, Kasper Vibæk (2007); *Forming Core Elements for Strategic Design Management.* Paper IN: Architectural Engineering and Design Management. CIB.

22 The term, Architectural Quality, has been discussed in the State of the Art earlier in this publication.

considered e.g. by Willa Nordic, who offers several optional choices regarding heating solutions. All-encompassing systems facilitate overall thinking. However, the development of the specific technological aspects of sustainability seems more probable at subassembly level.
An important general advantage of prefabrication in terms of sustainability is the work environment. Apart from problems with changing weather conditions, on-site construction has a a lot of other problems in terms of noise, fumes, work posture and drying periods that are much easier to control in a factory environment. Factory production in itself, though, does not guarantee a better work environment.

User aspects

Splitting the complete building into different building assemblies that are manufactured and put on a market as products may seem straight forward. However, it is not always that evident what the product actually is and how the connection between product, production, technology and user should be understood. In the cases discussed above, at least three quite different conceptions are expressed. What is actually the product? What do people buy? Who are the users/clients?
To Altan.dk, the marketing focus is directed at the end user – the actual inhabitant of the flat with a possible new balcony. This user does not buy a steel frame with railing and wooden deck, but rather ‘a dream or an experience’ of extending the home and bringing in the outside as a part of the living space. How it is done is of less importance apart from a usually limited economy with little space for budget overrun. However, the client is usually a housing cooperative or an owners’ association, where internal or external experts (consultants) get involved in the specific realisation of this dream and its adjustment to a common denominator comprising all the individual dreams, the physical context, legislation demands and the economy. Altan.dk deals directly with the client (not the end user) without any intermediary contractor as is usually the case.
To EJ Badekabiner, the delivered product is a finished bathroom pod with

all services ready to be used by the end user (the flat owner). However, this end user is never involved in the choice(s) of the product. The client is usually a developer in cooperation with an intermediary contractor – or sometimes it is the contractor himself who chooses the EJ solution in order to reach a certain match between quality and price as desired by the developer. The product at this level is more of a construction principle (box type[23]) with a certain finish selected by the client. As the end user does not know (or care) who made the product, and the quality of the finishing is selected directly by the client (developer or contractor), there is no other real branding values than time and price.

The NCC shaft as a product is even further from the end user, who will only indirectly make use of it when using the installations of his/her dwelling. Here, however, the user is the architect – who does not use the actual product (the shaft) but makes use of the configuration technology, which is a core substance of the concept. The client is either the developer or a contractor.[24] As an incentive for use, the architect is offered the possibility of designing the bathroom in connection with the shaft. Branding is thus primarily directed at the professional user.

This is also the case with Permasteelisa, where the client and the architect are seen as the users. Due to the close client-manufacturer relationship in the process, they have, within the financial framework, an almost unlimited degree of choice. Within the present setup, however, this only works with projects on a very large scale and is dependent on the design coordinating role of the architect.

In the case of EJ Badekabiner end user choice had been used in a couple of projects, but was no real success. The argument posed against it was that leaving things open for choice will increase costs and consequently leave you with fewer resources for the actual solution, the result being lower quality (e.g. cheaper materials). The same argument was used in the all-encompassing building system, NCC komplett, where a supposedly better kitchen and a better-than-standard floor height was chosen as standard solutions instead of leaving more choices to the end user. Still, a question open for discussion might be whether the quality of actually having the choice gives more value than the (high quality) standard solution – which, after all, will be relatively easy to sacrifice during the cost-cutting measures so commonly seen in construction?

Part of the answer is probably that it depends on what is left open and what is standardised – some aspects are important to an end user, some for the client and others again for e.g. the architect – and it is often the financial and organisational setup rather than architectural expedience that determines whether choices are left open for different stakeholders.

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23 The main principles or types are described above in the section on EJ Badekabiner.

24 It has still not been decided whether the shaft will be used exclusively in NCC-projects, or whether other contractors will be able to by it on the market.

One thing is to have a choice – another is to give feedback in order to provide for a (future) product that offers the closest possible match to what the customer needs. Recently, so-called web 2.0 initiatives have facilitated new connections between manufacturer, end user and product, where end users or expert users are more actively involved in product development. This philosophy takes inspiration from Linus's law that 'given enough eyeballs, all bugs are shallow' where free democratic access to knowledge and continuous feedback is supposed to create the most sophisticated results.[25]
A more traditional user feedback is seen in the Permesteelisa case where the company has taken the innovations developed by the architects and consultants in specific advanced projects and refined the concepts for general use. This form requires either personnel overlap between projects or a systematic knowledge transfer between projects and products.

Project or product (Bridging traditional and industrial product structure)
Even if buildings are always one-offs, it would be absurd to claim that they have nothing in common. Industrialised construction seeks to systematise what buildings have in common – both concerning specific solutions and concerning the way in which to do certain things. The most conceivable difference in architecture is style. This is, however, also the most superficial one, although to some extent rooted in available technologies and accessible materials. Subassemblies in building, as mentioned, have little to do with style and slightly more to do with function and organisation, which both offer more resistance to time than style. While all-encompassing concepts – manifested as whole buildings – turn out to present a certain style, the industrialised building composed by subassemblies can perhaps bridge the gap between the traditional project orientation and the industry's production orientation, thus resulting in unique projects based on composition and configuration of systemised products. Given enough choices, the task of 'configuration management' could turn out to be one of endless opportunities.

[25] By Eric S. Raymond. See: http://en.wikipedia.org/wiki/Linus's_Law

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FSC – Forest Stewardship Council: www.fsc.org

Gallup Compass:
www.gallup.dk/vores-markedsfokus/medier/printmedier/gallupkompas.aspx

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Ingeniøren: www.ing.dk

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M2 Housing firm: www.m2.dk/

MT Højgaard, Basisbo: www.mth.dk/boligkoncepter
www.mthojgaard.dk/da/articles/77FAC63B753575D8C1257122004D7DC1

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