ROUTLEDGE RESEARCH IN ARCHITECTURE

# ARCHITECTURAL SYSTEM STRUCTURES

*Integrating design complexity in industrialised construction*

KASPER SÁNCHEZ VIBÆK

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## Note

1 Realdania is a major private Danish 'strategic foundation created with the objective of initiating and supporting projects that improve the built environment.' http://www.realdania.dk/English.aspx accessed on September 3, 2011.

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# Introduction

## Handling complexity in architecture and construction

> Design today has reached the stage where sheer inventiveness can no longer sustain it. To make adequate forms, one must be able to explore the relations between circumstances more fully than is done at present, so that the decision as to just where to apply precious and limited inventive power can be made.
> (Chermayeff and Alexander 1965: 161)

### Industrialised architecture

The concept of *industrialised architecture* does not in itself point towards a specific architectural expression or the appearance of a specific (new) architectural style. Neither can one talk about a distinctly identifiable building typology; it is not about industrial architecture! While industrialised architecture as field of research still has the architectural result as object, it quickly also involves the *organisation* and *production processes*, *and* their industrialisation that leads to this result. Architecture is generally about creating the best possible physical surroundings for human life, and decisive for the architectural solution space and final result of all creation is not only the material but also the tools, the related techniques and the organisation of people around these.[1] Rather than dealing with a specific result, industrialised architecture is a particular way to construct or assemble buildings – and a way to *think* about architecture and construction – that, however, has significance for the result: the finished work or building.

To deal with industrialised architecture as field of research here should not be seen as a direct promotion of organisation, processes and results falling within this category as being something particularly conducive for the architectural result. Rather, it should be seen as a critical discussion of and taking a stance on a range of tangible tendencies that is observed concerning the way we presently build. This, on the one hand in relation to architects and other consultants that are contributing to the project basis of building projects as well as on the other hand in relation to stakeholders involved in the practical realisation of building projects. The latter group of stakeholders is increasingly becoming a mix of industrial manufacturers producing parts in off-site factory environments and the more traditional builders as contractors and their subcontractors that process and adapt building materials and

components directly on the building site. Countless times construction has been compared with the product industry and its mass-produced standard goods for large markets. Although much within the construction sector can be regarded as production there are reasons to believe that construction seen as *architecture* has – and probably always will comprise – elements that cannot be produced as finished goods in a true industrial sense. This is partly due to the fact that architecture is fundamentally bound to time, place and culture in a different way by constituting the framework of rather than the tools for human action and development. An important question here becomes: 'What is then industrialisation of *construction*?'

## Division of labour and the modularisation of construction[2]

Although in some primitive form it has always existed in human communities, the division of labour is one of the most significant characteristics of modern society. In 1776 the British economist Adam Smith described the division of labour as one of the most efficient ways to improve the productivity performance of companies hence increasing the wealth of nations.[3] His best known example is a pin-manufacturing company. After splitting up the process of making pins into different subtasks – thus specialising the workers – productivity rose by a factor of 240 (Smith 1776). Since the time of Smith, a pronounced division of labour has spread to all areas of society that partly due to this fact have become increasingly complex. Construction and architecture is not an exception.

Industrialisation within construction starts later than the general industrialisation of society. Up until the massive industrialisation of building processes and products in the 1960s, the division between the crafts and professions 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 – or systems of coherent expert knowledge – with clearly defined interfaces to adjacent modules.[4] Construction specifications, i.e. drawings, had a substantial set of conventions, allowing a few instructions (as e.g. lines and signs) to be clearly comprehended due to a large amount of implicit – or *embedded* – knowledge. The dimensions of the windows on the plan of a masonry building, for instance, are 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. The *complexity* of the design task is reduced by making use of this embedded knowledge of the implicit building tradition applied by the craftsman.

Today, 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 manually based 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. Although the fundamental architectural challenge is relatively unchanged and still generally is about creating the best possible physical surroundings for human life (in all aspects), the premise for solving this task as specific buildings has changed considerably – building has become much more complex both as object (material) and design task (process). Simultaneously, the possibility for the architect of drawing on coherent knowledge from the crafts has been reduced. It is not that expert knowledge in construction has decreased – quite the contrary – but this knowledge no longer relates to and is no longer automatically embedded into a coherent way of building. Local vernacular architectures are expressions of such traditionally coherent knowledge systems with the crafts as subsystems. However, although the crafts still exist to some extent, they no longer cover construction as a whole. More and new areas of specialisation have emerged as crystallisations or fusions of earlier trades as e.g. foundation work, flooring, ventilation, alarm and BMS systems, etc.[5] A next question then becomes: 'How can this increased complexity and knowledge fragmentation in construction be handled in order to facilitate a focus on the architectural core instead of getting lost in technical and economical details that, however, still needs consideration and control?'

## Architecture as (industrialised) production

The present monograph claims that the architect has a special integrative role among and in relation to the stakeholders involved in construction.[6] *Etymologically* speaking architect means *master builder* or *supreme carpenter* (Becker-Christensen 2001) and the architectural profession deals (to a great extent) with the conception and the creation of physical wholes. It is the task of the architect to bring different knowledge systems and their physical outcome or products together in order to create these wholes – or coherent systems – that become more than the sum of their constituent elements: they become architectural works. However, it seems that the architect's tools for creating this integration or synthesis has not evolved parallel to the described development and specialisation within the construction sector in general and the building component industry in particular. The architect is trained with and still widely works from a 'craft-based' approach that through use of a range of materials transforms an architectural concept into a true physical form. The modules or *systems* used for architectural thinking, it is argued here, still predominantly correspond to the traditional crafts rather than to the specialised and partly industrialised building industry that is supposed to produce them. That this is *also* the case for the processes of most of the traditional contracting companies does not necessarily reduce the problem

in relation to the handling of complexity. There is apparently a growing gap between how on the one hand architecture is conceived and, on the other hand, how it is or can be produced. Just the mere expression of architecture as *production* probably 'grates on the ear' of many architects.

If, however, we assume that industrialisation and a new, more complex, division of labour is a *condition* – not just an option – that architects and other stakeholders in construction have to respond to but simultaneously also stress that, architecturally speaking, industrialisation is a *means* not a goal in itself, then perhaps the discussion is less controversial and can become more fruitful. Thus the discussion of industrialisation of construction and industrialised architecture can be diverted from a dialectic perspective of pros and cons towards a focus on potentials and perspectives of a conscious and critically well-balanced application of industrial logic in construction and architecture.

Industry and industrialised production methods draw on strict methodologies and systems in order reduce or handle complexity. While these methodologies and systems earlier inherently meant standardisation of the *product*, modern information technology has gradually facilitated the standardisation of even complex *processes* that on the contrary can lead to huge variety when it comes to the resulting products. This phenomenon is often termed *mass customisation* with direct reference to and as an alternative to traditional mass production. A present parallel tendency is found within the construction sector with reference to and as an alternative to the first wave of industrialisation in construction in the 1960s (Beim, Vibæk and Jørgensen 2007: 25; Jørgensen 2007). While the first industrialisation wave in construction was heavily standardised in its architectural expression and almost became an architectural style in itself, the present industrialisation of construction and architecture points towards a systematisation of project-specific and context sensitive solutions.

## Product architecture

Within the product industry when designing e.g. cars, computers, washing machines or bags, the notion of product architecture is used to describe, analyse and optimise how production and product in the most adequate way can be divided into a number of constituent elements of processes and/or physical modules. Product architecture is not about architecture in the sense that architectural designers usually apply it but refers to organisational and product structural issues. The product architecture defines how different subsystems form part of a complete supply chain and production line, and how these subsystems are assembled in the final product without this structure necessarily being perceivable to the end user. Through the product architecture, a system level is established that sustains the whole while simultaneously splitting up this whole into meaningful elements that subsequently as more or less interdependent entities can be treated (designed and produced) separately – as processes and/or physical elements that perhaps even are

performed by different independent suppliers. The product architecture as a design and production tool reduces the complexity of the design task without necessarily reducing the complexity of the product itself. This is particularly the case, when subsystems or elements of the product architecture are based on standardised solutions or well-known principles and/or processes.

In contemporary architecture and construction there is no self-evident product structure as it earlier was provided by the crafts – although in a non-conscious manner. The gap between how architecture is conceived and how it can be produced is enhanced due to both technical as well as economical causes. A way to identify and work systematically with 'the product architecture of contemporary construction' could become a useful tool – not just in construction phases but equally during the earlier architectural design phases. Precision, strict methodology and control can also be used in a creative manner!

## Scope

The research behind this book has had the overall purpose of examining what role system design, systems thinking and systemic building concepts play in relation to modern industrialised construction with a focus on how this world of ideas is expressed in architecture.

## Main question

*How can systems thinking help bridge the apparent gap between architectural ideation and its subsequent realisation as process and result in contemporary industrialised construction while simultaneously handling the increased complexity of specialisation and technical development?*

## Goal

To propose an analytical structure (interpreted as a tool or a model) for clarifying the potential of industrialised construction as positively enabling rather than limiting the architectural solution space.

## Work packages

The research, the main question and the goal was operationalised into three main 'work packages':

1 a theoretical study;
2 an empirical study;
3 model generation.

Although overlapping in practice, the work packages are expressed in the sequencing of the following parts (I to III) of this book.

The elaborated model presented in Part III – 'Model' represents the *analytical structure for clarifying the potential of industrialised construction.* The model is used for generating theoretical scenarios as well as for analysing empirical evidence. These exercises contribute to the qualification of the model and its possible explanative power and application within both architectural research and practice.

## Non-scope

The model is not – at first – developed as a software tool. The core of this initial model development is the *content* and its *explanative power* rather than its technical functionality and performance. Focus on the two latter aspects would move a lot of effort (work) into *programming* which needs to be preceded by a proper *understanding* of what should actually be programmed. What need the model is supposed to cover and in what way comes first! This does, however, pose certain limits to the complexity and the contained data layers of this preliminary version of the developed model in order to make it manually applicable.

The model is not a production planning tool and (intentionally) omits aspects like time and economy. Again this is in the first place to keep coding parameters and the visual result of a coding relatively simple. Although later, possibly software based, versions could include such (and more aspects) it is so far an open question whether these *should* actually be integrated. A risk could be that too many and too specific parameters reduce the flexibility of the model and thus possibly its applicability to *early* architectural design phases where many aspects (should?) remain on an abstract level in order to keep the architectural solution space sufficiently open. A stance here is that the field of production planning and cost control is much better managed through the wide range of existing techniques, tools and software programs already available that integrate many technical aspects that cannot be included within the framework of this research.

The model does not deal directly with the question of architectural quality. However, in the hands of the right person (e.g. a qualified architect) it can support the architectural design work by, for example, *reducing complexity in focus* as an intermediate model. This can, it is assumed, enhance the probability of architectural quality in the final result. In other words: it is a tool to create a better overview and facilitate the process by *clarifying the potential of industrialised construction* scenarios within architectural design.

## Contribution to a wider knowledge context

In general the subject of industrialisation within construction seems more prevalent in Western industrialised countries, such as those in Northern Europe or similar climates where the weather factor combined with high labour costs encourages the development of more automated and off-site dominated production techniques. However, the current project points out that this *can never*

*be an either/or*. Architectural creation and construction will always be a combination of on the one hand on-site and perhaps more labour intensive craft based work and, on the other hand, off-site prefabrication of varying degrees of automation and of integration of the final product delivered.

The ambition is – although this project still mainly stays on the theoretical level – to bring the theoretical conceptualisation of this special field of knowledge closer to implementation in architectural and construction practice. The main problem as stated in the introduction is an apparent gap between how architecture is conceived and how it is or can actually be produced. The model developed is intended as an analytical tool for enhanced understanding and potentially as a proactive design tool for early design phases. Through early visualisation of industrialised production scenarios within architecture, it becomes more probable that architects or other professionals can influence or make active demands to an industry that often (and perhaps logically) seem dominated by technical and economic aspects of production rather than visionary architectural thought.

In a context where the creation of architectural artefacts changes rapidly partly driven by new technological possibilities (pull), partly forced by external factors[7] (push) the model is proposed as a tool to help describe and handle the structural complexity of any building through the procedural and material organisation behind their immediate appearance.

## Organisational location and genesis

The present monograph is the result of research conducted at CINARK – Centre for Industrialised Architecture. Organisationally located under the Institute of Architectural Technology at the Royal Danish Academy of Fine Arts, School of Architecture. Since start-up in 2004 CINARK has developed knowledge around the processes as well as the products – or physical results – of architecture and architectural creation exposed to modern industrialised means of production. Architectural quality is a holistic concept than cannot easily be reduced or atomised into clear, quantifiable sub-parameters that normally characterise an industrialised logic. This tension between on the one hand the constituent (industrialised) parts and processes and on the other hand the architectural whole has been a central research focus and has led to the present examination of systems and systems thinking in architecture.

## Structure of the book

The book is structured around four parts that express a logical progression in time and knowledge development from a theoretical exploration over a practical exploration to the proposal and application of an analytical model ending in a final discussion of the findings.

Part I is called 'System'. This part is the theoretical exploration of the book. Here different theoretical paths of systems thinking are examined with

reference to the research problem defined in the Introduction. Chapter 1 is a historical view of systematic thought in architectural theory. Chapter 2 deals with different applied classification systems and taxonomies in construction as opposed to architectural creation. Next follow two chapters on other kinds of systems theory outside the field architectural construction such as industrial production theory and general systems theory. Chapter 5 seeks to draw out and define central concepts as they are subsequently used in this book as well as to establish a particular taxonomy of integrated complexity.

Part II – 'Product' – is an exploration of the practical reality within architectural construction and its current level of industrialisation and systemic elements. Chapter 6 deals with the emergence of system products within the field of construction seen as combinations of matter, process, and thought and seeks through specific examples to show how a movement from construction of projects to production in projects can possibly enhance industrialisation of construction. Chapter 7 deals with the application of the taxonomy established in Chapter 5 to such system products in a kind of initial product catalogue. Finally, Chapter 8 introduces industrial ecology as a strategy for discrete controlled products.

Part III – called 'Model' – is the presentation of a model as the primary theoretical outcome of the research. The elaborated model represents an analytical structure or a supportive tool applicable to contemporary and/or future architectural construction. Chapter 9 presents the model its current state as a way of visualising system structures in architectural construction. Subsequently the model is applied as an analytical tool to a series of cases (case studies).

Part IV – 'Reflection' – is a discussion of the most important findings from the case analyses and the general applicability of the proposed model. The final chapter draws up the main conclusions in a short form related to the main problem and hypotheses and points out further development perspectives and future research needs.

## Notes

1 For a discussion of *architectural solution space* – the set of all possible solutions for a given set of conditions or parameters – seen in an architectural context see Vibæk (2007).
2 This paragraph is partly taken from Beim, Nielsen and Vibæk (2010: 77f.).
3 Wealth of *nations* is not necessarily coincident with general wealth of the individual citizens.
4 The British sociologist Anthony Giddens uses the notion of expert systems to explain how people in their everyday life draw on large amounts of embedded knowledge when e.g. taking the bus or using the telephone (Kaspersen 2005: 439; Giddens 1990).
5 BMS = Building Management System is a computer-based control system that controls and monitors the building's mechanical and electrical equipment. Available online at http://en.wikipedia.org/wiki/Building_management_system (accessed 8 August 2011).
6 For a similar assertion, see Bachman (2003: 6).
7 Economic, ecological, organisational factors, power relations, decline of the old crafts, etc.