ARCHITECTURAL CONSTRAINTS FOR DESIGN AUTOMATION OF MULTI-STOREY TIMBER HOUSES IN SWEDEN

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Abstract: This paper describes some of the characteristics of the constraints, caused by the architects' decisions, that affect the choice of technical solutions in timber engineering and especially in design of multi-storey houses. The constraints serve as requirements on design automation algorithms that are supposed to select the most cost-effective technical solution and design the selected solution within a given set of architectural constraints. The results presented in this paper are a very condensed version of the results from interviews with all of the architects involved in multi-storey timber residential house projects up to May 1998 in Sweden.

Keywords: Design automation; timber houses; design parameters; constraint; object-oriented

1. INTRODUCTION

What is the characteristic of the constraints, caused by the architects' decisions, that affect the choice of technical solutions in timber engineering and especially in design of multi-storey houses? The answer of this question is of major importance in development to design automation systems for multi-storey timber houses. This paper is an attempt to answer this question.

1.1 The fragmented building process

A building's lifecycle includes the general phases of planning, design, construction, facility management and demolition. In response to the complexity of today's construction industry, the industry has involved specialists in each of these areas. Specialisation has resulted in fragmentation within the industry. Although all participants in the building process use the same information, the industry is characterised by redundant manual processing of that information between phases, between disciplines within a phase, and between tasks within disciplines. The vertical and horizontal fragmentation of the building industry reduces quality and increases the life cycle costs of the final product.

This paper is focused on the design phase of the building process and specifically the phase between the architectural design and the structural design. Today there often is an information loss between the architect and the structural engineer due to manual data processing. This loss of information is a hindrance to a cost-effective design process. A design automation system for multi-storey timber houses makes it possible to reduce, and hopefully eliminate, the information loss between the architect and the structural engineer.

1.1 Purpose and contents of this paper

The study presented in this paper is the first step of a research project called "Design Automation for Multi-storey Timber Houses". The objective of the project is to:

- Identify the constraints, caused by the architects decisions, which affect the choice of technical solutions in timber engineering and especially in design of multi-storey houses.
- Find algorithms that automatically can select the most cost-effective technical solution given a set of constraints.
- Integrate the found algorithms to a programmable logistic and/or mathematical model.

This design automation project is a specialisation and a natural continuation of the wider work " Pre-engineered buildings - a system approach towards a more efficient building process" [1].

The purpose of this paper is to present results from the first part of the project concerning architectural constraints for design automation systems and thereby contribute to a better knowledge about what requirements a software developer have to meet in order to develop a competitive design automation system for timber houses.

In the opening section of this paper the problem of the fragmented building process is briefly discussed in general terms. Section 2 is a description of the design automation concept as it is used in this study. In section 3 the concept of architectural constraints is discussed. The description of the inquiry method is found in section 4 and the presentation of the inquiry results is found in section 5. Further work is presented in section 6 and the conclusions will be found in section 7.

2. DESIGN AUTOMATION

Design automation within the building industry in its broader sense includes automation of every stage of the design phase in the building process. The definition of what stages that are included in the design phase can vary. If the design phase is defined as "From architect's desk to start of manufacturing and/or construction", the design phase include several challenging tasks to automate such as the architect's exterior and interior design, the structural engineer's evaluation of structural alternatives and structural design of the selected alternative and the detailer's production of material lists, cutting lists, shop drawings and erection drawings. Tasks such as preliminary cost calculations, environmental impact, energy loss calculations and acoustic calculations can be added to that. All of these tasks are important to include in a design automation system in order to comprise the entire design process but it is an extensive task to achieve.

Oliver and Betts [2] point out the emerging information technologies in the architectural profession and decision support systems (DSS) for the design process is one of them. They predict that a DSS for the design process will *"go beyond merely providing timely information - they will be interactive with the design process. By using previous "cases" and a selective procedure the system will make alterations to drawings. As an example, given a bathroom plan and a specification, the system would plan the most optimum layout for both ergonomic considerations and those of the mechanical servicing."*

There are already much work done within the design automation field, both scientific and commercial. Various works can have different approaches but there are often a common purpose; reduce the redundant manual processing of data by increased use of computers and thereby reach a more cost-effective solution with improved quality. These benefits are also recognised by Sacks & Warszawski [3] which have a similar approach to design automation as in this project. They describe an architecture and operation of an automated system for generation of design and planning information for multi-storey rectangular buildings. The system receives the developer's requirements as input and generates the information necessary for the realisation of various design and construction stages. The system, called ABS (Automated Building System), includes object representation of the project, knowledge modules for information processing and linkage to various databases. Through employment of templates with knowledge driven parameters, the design of building layouts and work assemblies is simplified.

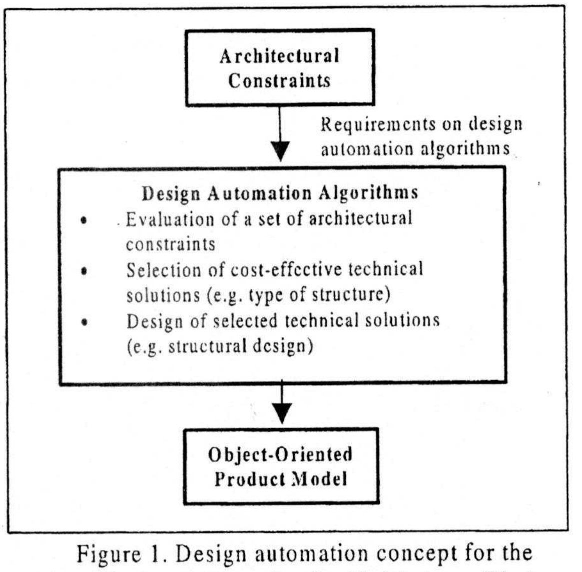

Figure 1. Design automation concept for the project "Design Automation for Multi-storey Timber Houses"

Design can, as mentioned, include many tasks depending on the definition of design. The focus in the project "Design Automation for Multi-storey Timber Houses" is mainly on stage of evaluating and designing the structure of multi-storey timber house. This project has thereby a more narrow limitation than the ABS approach. The "developer's requirements" in ABS can be compared with the architectural constraints presented in this study (see Figure 1). The constraints serve as requirements on design automation algorithms that are supposed to select the most cost-effective technical solution and design the selected solution within a given set of architectural constraints. The result will finally be transformed to an object-oriented product model.

The "intelligent" part (evaluation and selection) of the algorithms can be done with different approaches. Object-oriented analysis [4-5] and case-based [6-8] reasoning are two common approaches in expert systems. They are both possible to apply on the evaluation and selection part of the algorithms but there is a significant obstacle to apply case-based reasoning on design of multi-storey timber houses in Sweden. A comprehensive case library is a central part of case-based reasoning and such a case library is not possible to create today since the available cases for multi-storey timber houses are very limited due to earlier (up to 1994) regulations that did not allow multi-storey timber houses. Therefore the object-oriented analysis approach seems to be a more suitable approach in this project.

3. ARCHITECTURAL CONSTRAINTS

What is the characteristic of the constraints, caused by the architects' decisions, that affect the choice of technical solutions in timber engineering and especially in design of multi-storey houses? This question was given in the introduction section and the reason behind the question can be find in Figure 1. The exterior and interior design of multi-storey timber house done by the architect affect the entire following design process. Today the structural engineer manually processes the constraints given by the architect, i.e. he evaluates the constraints, selects a suitable structural alternative and perform the structural design. In order to automate this process it is important to predict what requirements the architects can have on different design parameters. This study is performed to provide the characteristic of the architectural constraints, i.e. to find out the architects' view on the range and importance of different design parameters in multi-storey timber houses.

A formal and useful definition of constraints and design parameters is given in [9]. Constraints represent the bound on an acceptable solution and are of two kinds: *"input constraints, which are constraints in design specifications, and system constraints, which are constraints imposed by the system in which the design solution must function."* The architectural constraints are according to the definition input constraints. The design algorithms must of course consider the system constraints as well but that is not discussed in this paper. Design parameters are defined as *"the key variables that characterize the physical entity created by the design process to fulfill the functional requirements"*.

The questions in the inquiry presented in section 5 are derived from about 40 design parameters that are identified as crucial for the structural design of multi-storey timber houses. The chosen design parameters are based on results presented in [1].

4. INQUIRY METHOD

The choice of wood as structural alternative in Sweden started in 1994 after the deregulation of the Swedish building market in 1993. From 1994 up to may 1998 there were nine residential multi-storey (3 storeys or more) timber houses completed in Sweden. All of the architects involved in these projects were contacted and all of them accepted to take part in this study.

A questionnaire was prepared including the design parameters discussed in section 3. The questions were generally designed to find out the range and the importance of each design parameter. The first part of a question was open-ended to find out the architect's view on the range of the design parameter. The second part of a question had four alternatives from A (unimportant = not or little variable) to D (very important = high degree of variability) to find out the importance of each design parameter.

Each of the architects were visited an interviewed. The answers from the interviews were then printed down from the recordings and sent back to each architect together with an explanation of the importance alternatives (A-D) for each question. The architects were requested to validate their answers according to the printed answers and the attached explanation. Finally all of the answers were compiled in order to draw further conclusions.

5. INQUIRY RESULTS

The results presented in this section are a very condensed version of the results from the interviews with the architects. It is only the second part of each question, i.e. the importance of each design parameter, which is presented in this paper. A paper comprising the questions and the answers to the first parts of the questions will be presented later on.

In the leftmost column in Table 1 below the average ranking point of each design parameter is given with the range 1-4. After that the design parameters are given, then each architect's ranking point and the four last columns contain an explanation of each importance alternative (A-D). The importance is quantified so that A=1, B=2, C=3 and D=4. That means that e.g. a ranking point 4 correspond to continuos variability in column D.

Table 1. The architects ranking of each design parameter

Point	Design Parameter	Architects								VARIABILITY			
										None	Some	Discrete	Continuos
		1	2	3	4	5	6	7	8	A (1)	B (2)	C (3)	D(4)
4.0	Roof slope	4	4	4	4	4	4	4	4	E.g. 1:2	E.g. 1:1 or 1:2	E.g. 1:1, 1:2, 1:5, 1:10, 1:16, ...	Exact slope can be given
4.0	Placement of balcony	4	4	4	4	4	4	4	4	Pre-defined	Only the long sides	All walls	All walls + corners
4.0	Apartment area	4	4	4	4	4	4	4	4	Pre-defined	E.g. each 5 m^2	E.g. each m^2	Exact area can be given
4.0	Flooring material	4	4	4	4	4	4	4	4	Pre-defined	Plastic and linoleum	B + wood	C + paving tile/clinker
3.9	Inner angel of an angled house	4	4	4	4	4	4	3	4	E.g. 90 deg.	E.g. 90 or 135 deg.	E.g. 90, 100, 110, 120, 130, ...deg.	Exact angel can be given
3.9	Types of entrances	4	4	4	4	4	4	3	4	Not possible to indicate	Entrances in line with the facade	B + external entrances	C + indented entrances
3.8	Placement of bay	3	4	4	4	3	4	4	4	Pre-defined	Only the long sides	All walls	All walls + corners
3.5	Bays	4	3	3	3	3	4	4	4	Not possible to indicate	E.g. a couple bay models	E.g. several models of bays	Free design
3.5	Facade material	3	4	4	4	3	3	4	3	Wood and metal sheet	A + plaster	B + sheet materials	C + brick and concrete
3.5	Balconies	3	3	4	4	3	4	3	4	Not possible to indicate	E.g. a couple balcony models	E.g. several models of balconies	Free design
3.5	Position of kitchen fixtures	3	4	4	3	3	3	4	4	One of the walls in the kitchen	Two of the walls in the kitchen	Three of the walls in the kitchen	All of the walls in the kitchen
3.5	Length of main body of the house	3	3	4	3	4	4	4	3	E.g. 16 m	E.g. 16 or 32 m	E.g. 16.0, 16.6, 17.2, 17.8, ...m	Exact length can be given
3.5	Width of main body of the house	3	3	4	3	4	4	4	3	E.g. 7 m	E.g. 7 or 10 m	E.g. 7.0, 7.6, 8.2, 8.8, 9.4, ...m	Exact width can be given
3.5	In plane displacements of the house	4	4	4	3	3	4	2	4	Not possible to indicate	Between staircases	Between and within staircases	Between and within staircases and within apartments
3.5	Types of room connections	4	3	4	3	3	4	3	4	Door	A + portal or similar (partly open)	B + wholly open	C + indoor windows and glass sections
3.4	Position of visible building services	4	3	3	3	3	4	3	4	Pre-defined	E.g. a couple pre-defined pipe positions	E.g. several pre-defined pipe positions	Exact position of building services can be given
3.4	Number of floors	2	3	4	3	4	3	4	4	3 floors	3-4 floors	3-6 floors	3-8 floors
3.4	Roof material	3	4	3	3	3	4	3	4	Metal sheet	A + bitumen felt	B + tiling, concrete tile and fibre concrete tile	C + grass and sedum
3.4	Number of openings	3	3	4	3	3	3	4	4	Pre-defined	0-2 openings/ external wall and room	0-4 openings/ external wall and room	Any number
3.4	Types of windows	4	3	4	3	3	4	3	3	A number of standard windows from one manufacturer	All standard windows from one manufacturer	All standard windows from several manufacturers	C + non standard windows designed by the architect
3.3	Possibilities to change room connections	4	2	3	4	1	4	4	4	Not possible to indicate	E.g. pair doors	E.g. folding walls	E.g. sliding panel
3.3	Types of doors	4	3	4	3	3	3	3	3	A number of standard doors from one manufacturer	All standard doors from one manufacturer	All standard doors from several manufacturers	C + non standard doors designed by the architect

Point	Design Parameter	Architects								VARIABILITY			
										None	Some	Discrete	Continuos
		1	2	3	4	5	6	7	8	A (1)	B (2)	C (3)	D(4)
3.1	Geometry of the house can be build up by:	3	3	3	3	4	3	3	3	A rectangle	Polygon with right angles	Polygon with free angles	C + circles, ellipses and circle segments
3.1	Width of the room	3	3	3	3	3	4	3	3	E.g. 3.60 m	E.g. 3.60 or 4.20 m	E.g. 3.60, 3.70, 3.80, 3.90, ...m	Exact width can be given
3.1	Roof types	3	2	4	4	4	3	3	2	saddle roof + pentroof	A + mansard roof and hipped roof	B + eccentric saddle and saw tooth roof	C + arched roof
3.0	Storey height	3	3	3	3	3	3	3	3	E.g. 2.80 m	E.g. 2.80 or 3.10 m	E.g. 2.80, 2.90, 3.00, 3.10, ...m	Exact height can be given
3.0	Size of opening	3	3	3	3	3	3	3	3	Pre-defined	limited number of opening sizes e.g. 600x600, 900x900, 800x1200, ...mm	Width and height can be varied in step of e.g. 100 mm	Exact size can be given
3.0	Through or not through apart-ments (width direction)	3	3	3	3	3	3	3	3	Not possible to indicate	Through apart-ments and not through for gable apartments	B + not through for inner apartments (single sided)	C + not through for apartment reaching from gable to gable
3.0	Floor to ceiling height	3	3	3	3	3	3	3	3	E.g. 2.40 m	E.g. 2.40 or 2.80 m	E.g. 2.40, 2.50, 2.60, 2.70, ...m	Exact height can be given
3.0	Position of opening in facade	3	3	4	3	3	3	2	3	Pre-defined	E.g. Each 600 mm (horizontally) and e.g. 0, 600, 800 mm (breast work hight)	Each 100 mm both horizontally and vertically	Exact position can be given
2.9	Geometry of the apartment can be build up by:	3	2	4	3	3	3	2	3	A rectangle	Polygon with right angles	Polygon with free angles	C + circles, ellipses and circle segments
2.8	Placement of sanitary installations	3	1	3	3	2	3	4	3	Pre-defined	E.g. a couple pre-dined placements	E.g. several pre-dined placements	Any placement
2.5	Internal noise reduction level	3	2	3	3	3	2	2	2	Pre-defined	E.g. insulated or not insulated interior wall	E.g. several types of standard walls with given noise reduction value	Exact noise reduction value can be given
2.4	Height displacements of the house	3	2	4	2	2	2	2	2	Not possible to indicate	Between staircases	Between and within staircases	Between and within staircases and within apartments
2.0	Level differences within apartment	1	2	3	2	2	2	2	2	Not possible to indicate	E.g. a fixed 0.15 m difference	E.g. 0.05, 0.10 and 0.15 m difference	Exact level diffe-rence can be given
1.6	Occurrence of draining gutter in bath room	1	1	1	2	1	1	2	4	Not possible to indicate	Draining gutter with fixed position	Draining gutter with several possible positions	Any placement
1.5	Possibilities to move interior walls	3	1	2	1	2	1	1	1	Not possible	E.g. a couple pre-defined positions	E.g. several pre-defined positions	Any position
1.1	Possibilities to move apartment separating bearing walls	1	2	1	1	1	1	1	1	Not possible	E.g. a couple pre-defined positions	E.g. several pre-defined positions	Any position

The results in Table 1 are given in falling ranking-order with the design parameters with highest ranking-point first. Generally the result shall be interpreted so that if a design parameter have a high ranking-point the degree of variability must be high and if the design parameter have a low ranking-point the degree of variability only have to be modest or not variable at all to satisfy the architects' requirements. That means that a design parameter with high ranking-point require more of the design automation algorithms than a design parameter that can be made to a constant that does not have to be automated at all.

An implication for the ranking-points in Table 1 is to let each of the design parameters be assigned to the level of variability (A-D) that the ranking-point shows. For example a design parameter with a ranking point between 2.6 and 3.5 can be assigned a C (3) degree of variability. That would involve that e.g. the design parameter "Placement of sanitary installations" with ranking-point 2.8 should be discrete variable (C = "e.g. several pre-defined placements"). In this way all of the design parameters can be assigned a certain level of variability. These levels will serve as requirements on the design automation algorithms for multi-storey timber houses.

6. FURTHER WORK

The further work in the project "Design Automation for Multi-storey Timber Houses" will focus on finding algorithms that automatically can select the most cost-effective technical solution given a set of architectural constraints and on integrating the found algorithms to a programmable logistic and/or mathematical model.

The work is supposed to continue until the beginning of 2001 and the expected results from the research is programmable logistic and/or mathematical model that can handle a set of architectural set of constraints and select the most cost effective technical timber solutions to the given constraints. The intention is that the model should be suitable for implementation in an arbitrary commercial software system for design, manufacturing and construction of multi-storey timber houses. The results will be public and published in papers and a doctoral thesis.

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REFERENCES

[1] P. Svanerudh. *Pre-engineered buildings - a system approach towards a more efficient building process* (in Swedish). Lulea: Lulea University of Technology. Licenciate Thesis 1998:04. ISSN: 1402-1757.

[2] S. Oliver & M. Betts. "An information technology forecast for the architectural profession". *Automation in Construction*, Vol. 4 pp. 263-279. 1996.

[3] R. Sacks & A. Warzawski. "A project model for an automated building system: design and planning phases". *Automation in Construction*, Vol. 7 pp. 21-34. 1997.

[4] M. Alshawi & J. Underwood. "Applying object-oriented analysis to the integration of design and construction". *Automation in Construction*, Vol. 5 pp. 105-121. 1996.

[5] C. K. Kim & S. E. Lee. "MLG Database Model for Object-Oriented Modelling of Buildings in Relational Database Framework". *First International Conference on New Information Technologies for Decision Making in Civil Engineering, Montréal, Canada, October 11-13, 1998.* Vol. 1 pp. 355-366.

[6] S. Iliescu et al. "A Case-Based Reasoning Framework for Preliminary Building Envelope Design". *First International Conference on New Information Technologies for Decision Making in Civil Engineering, Montréal, Canada, October 11-13, 1998.* Vol. 1 pp. 401-412.

[7] H. Rivard et al. "Case-Based Reasoning for Conceptual Building Design". *First International Conference on New Information Technologies for Decision Making in Civil Engineering, Montréal, Canada, October 11-13, 1998.* Vol. 1 pp. 355-366.

[8] N-J. Yau & J-B. Yang. "Applying case-basaed reasoning technique to retaining wall sections". *Automation in Construction*, Vol. 7 pp. 271-283. 1998.

[9] N. P. Suh. *The Principles of Design*, Oxford University Press. 1990.