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CAN AXIOMATIC DESIGN IMPROVE THE BUILDING PROCESS?

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1 ABSTRACT

This paper has its focus on the Swedish building industry and the necessity of improvements in order to stay competitive. The central part is the building process, which is defined here as the process from the idea to develop or acquire land to the management of the accomplished building. It can be divided into three parts: product design, product production and product use. The aim of this paper is to clarify where improvements could take place within the building industry in general and in real-estate development in particular. The aim is also to discuss if Axiomatic Design can be used in order to improve the building process especially in the definition of goals and decisions undertaken in the early stages of the process. The paper concentrates on these decisions since they have such a great impact on the following stages of the process and on how high customer value can be reached. The paper can also be seen as a description of a research project within the Swedish research program Competitive Building. The project has recently started (September 1, 1999). The aim of the research project is to seek a higher customer-value, in short and long term as well as a more effective building process than obtained through the methods applied today (within the industrial partner JM AB). The main goal is to generate a normative description of the development of a large project, within residential project development, based on scientific methods.

Keywords: Axiomatic Design, building process, product design, production, customer value

2 INTRODUCTION

In the 1980s there were important changes taking place in the economy of Sweden. These changes had a great influence on the Swedish building industry since government regulations for this industry were eased. Businesses had to change the focus from building what the state wanted to what the client asked for. The industry is to an increased extent now meeting the same challenges as manufacturing industry.

Another important challenge for this industry is the indications of a need for 25 000 dwellings per year in the near future, whereas in reality the number produced is 13 000 – 14 000 (1999) < Boverket (1999) >.

In Sweden there are companies that are responsible for the process from the acquisition of the land to the management of the buildings. These actors are defined as project developers (real-estate developers). It is from their view that this paper is written.

The lead time from the acquisition of the land to the moment when the residences are sold and the customers move in, is in some projects as long as 8 years. Due to this the financing costs become significant. The ability to create commercial and residential areas that are appealing to customers in spite of the variations in the market demand, the economic situation and changes according to political decisions over long periods is important. If the final product fits the market and is profitable in such a way that high customer value can be reached, both in a short as well as a long term, competitiveness will be stimulated.

Due to the pressure from the market forces, the building industry has to:

- understand and include its customers < Atkin (1997) >;
- be better at what it is doing;
- be better in doing it right from the beginning and in making the right decisions rapidly;
- strive for higher precision and deliver the right things at the right time and to the right price;
- minimize the lead-times and especially TTM (time to market) of construction projects;
- develop its forms of collaboration and organization.

To fulfil these statements, continuous work in improving quality and productivity is crucial. Increasing the ability to define and meet the functional requirements throughout the process is also important. To know the vision, goal and strategy of the management at all levels of the company throughout the business process is essential < Kjellberg (1999) >.

In this paper productivity is defined as "doing what has been decided with the lowest contribution of resources". The word

quality is here used in the meaning of "fitness for purpose" and is closely connected to the customers' requirements. Customer requirements can be divided into two groups of (customer) values:

- measurable values;
- non- measurable values < Nylander (1998) >.

Measurable values emanate from the object and are practical; functional qualities including everything that can be clearly-defined, measured and quantified. The non-measurable values, on the other hand, emanate from the observer and are closely connected to his/her perception of the object. Aesthetic and social values belong to this group.

Correct quality, a high customer-value and high productivity characterize successful projects. The customer is satisfied with the product as well as the other aspects, internally and externally, at the same time as the project has been completed as financial viability and with short lead-times. Good collaboration between all participants, subcontractors, consultants and employees throughout the project is another attribute of a successful project.

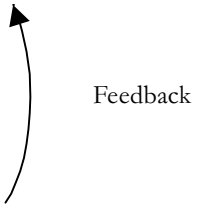
Making certain choices in the early stages of a building project has an important impact on the final product. The product must fit the market and be profitable in a way that high customer-value can be reached, both in the short and long term.

Is it possible to reach higher customer-value and a more effective building process by applying fundamental principles of design?

3 THE BUILDING PROCESS

The building process can be divided into three parts: product design, product production and product use or in these seven processes:

- Acquisition
- Early Design (planning)
- Detailed Design (design)
- Procurement
- Construction (production)
- Sales
- Facility Management



In this research project the focus is on the decision processes during Acquisition, Early Design and Detailed Design, which fall within the first part, namely product design. Construction on the other hand, is another word for production. Feedback includes every way of learning from something or somebody (from the past to the present) in order to reach improvements. It includes learning from previous stages to the later within or between construction projects, within or between company functions.

The decisions undertaken in the beginning of a project can be divided into two parts.

1. Decisions during the process of acquisition.
2. Decisions during the planning and design phase.

Figure 1 illustrates how the land value increases during the planning and design phase < JM (1998) >.

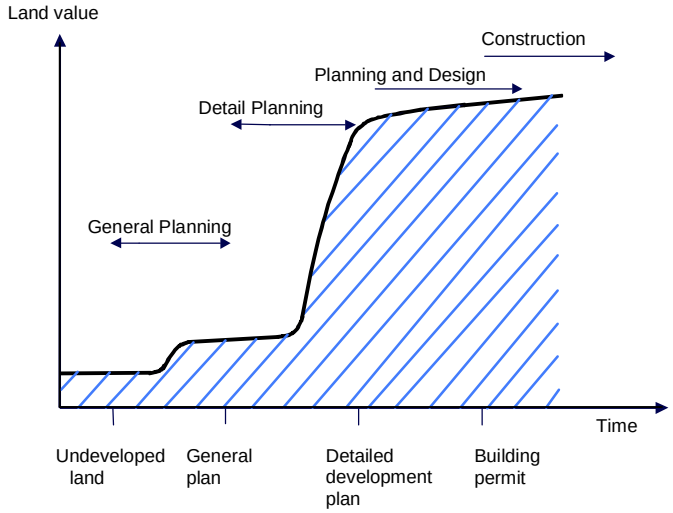


Figure 1. The planning phase of Project Development

The following picture illustrates the importance of the early decisions according to the costs committed < Lu (1991) >. This figure comes from the manufacturing industry but is applicable and valid to the building process design as well. The terminology for the manufacturing industry is marked just below the x-axis. The terminology for the building industry is placed below.

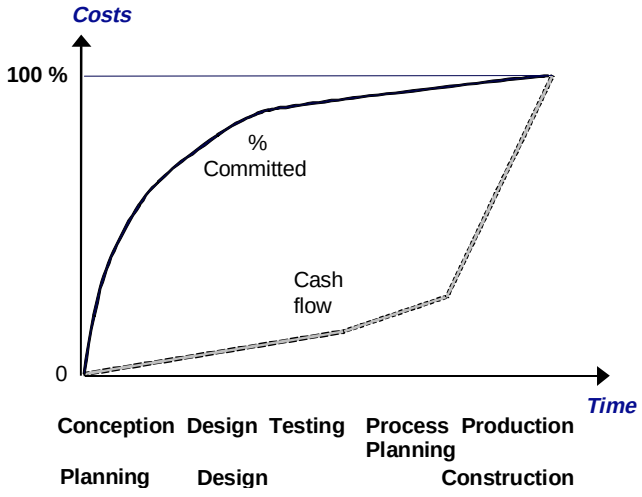


Figure 2. Cost variations during a project's phases

At the moment of construction, the total committed cost has in most projects reached 70% of its final figure. It is therefore easy to understand the importance of making the right decisions during the early periods of a project's building process.

The following remarks must be considered when adapting this figure to the design of the building process within project development.

- The curves should begin above the origin of coordinates on the y-axis, since the project developer, from whose view this is considered, has invested in land or a building before the planning phase.
- It seems correct that the lower curve is relatively flat up to the construction phase, where it rises considerably according to increased invoicing. This is something that has to be further investigated, for example, by interviews with practitioners.

The parameters ruling the early decision processes can be divided into the following.

1. External parameters: The market, the economic situation and politics (state regulations and subsidies included).
2. Internal parameters: The company's overall visions, goals, strategies and activities set up by the management group, established within the organization. (This is often expressed in company policies, different strategies and recommend-ations)

In an Axiomatic approach the external parameters can be seen as a part of the context and the constraints < Nordlund (1996) >.

4 THE SYSTEM - COMPANY

To achieve the desired goals of an enterprise, it can be considered as a system that has to be designed in order to satisfy a specific set of functional requirements and constraints < Suh et al. (1998) >. A brief illustration is shown below.

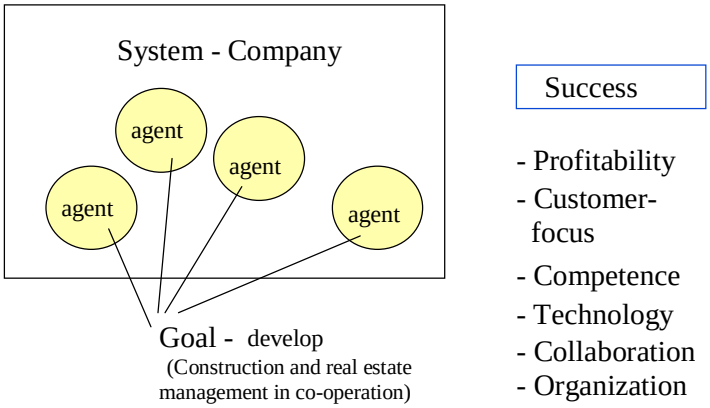


Figure 3. The company – a system

In the view of a real estate developer the agents are defined as every group of people more or less concerned with the company's core activity – project development. This can also be one single person. It can be a department, a project team within a department or a part of a project team that engages an external specialist for a certain task. One example of this is marketing activities. The agents can be seen as enablers (Design Parameters, DPs or Process Variables, PVs) of the goals and strategies according to "activities" in figure 4, in the use of the method Axiomatic Design.

Here the overall goal for the system is defined as success. In order for the company to succeed, the system must secure profitability. To have the right customer focus is important in order to be able to sell its products. (The customer is located in the customer domain according to figure 5) The appropriate competence must exist within the company's organization in order to make the right decisions and accomplish the work. There has to be technology in order to produce suitable products for the market as well as appropriate forms of collaboration and organization. To fulfil these goals an analysis based on Axiomatic Design is proposed.

An example: if profitability is considered as one of the systems most important functional requirements (FR), the following equation can be used in the analysis:

$$\text{Profitability} = \frac{\text{Income - Costs}}{\text{Capital}} \qquad (1)$$

The appropriate design parameter (DP) is then chosen as:

DP1: Successful project developer

At the next level in the decomposition the following FRs can be stated:

FR11: Increase the income
FR12: Reduce the costs
FR13: Minimize the capital

The corresponding DPs can be stated as follows:

DP11: Highest possible customer satisfaction
DP12: Effective project management
DP13: Productive equipment and short lead times

The design equation and matrix is as follows, where X signifies a strong relationship between the FRs and DPs:

$$\begin{Bmatrix} FR11 \\ FR12 \\ FR13 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP11 \\ DP12 \\ DP13 \end{Bmatrix} \qquad (2)$$

The design is uncoupled, according to Axiomatic Design < Suh (1990) >.

An alternative to DP12 could be stated as "using standard components" < Psilander (2000) >. (The matrix is uncoupled also in that case.)

5 THE RESEARCH PROJECT

The research project is organized as a case study and it is connected to the Swedish construction project *Årstadal*, including about 2 000 apartments, services and amenities. Data are collected by studies of literature, through interviews and observations.
The project is conducted in the following seven phases.

1. Prestudy. Set up the design of the research project. *An analysis of the company's visions, goals, strategies and activities have been accomplished (in a framework according to figure 4) as well as a study of the early stages of acquisition and planning for the project Årstadal.*
2. Investigate the needs of the future customers in the construction project *Årstadal*. Customer is here defined as the people who will buy and/or live in the produced dwellings. *The customer requirements will be captured mainly through qualitative interviews with the help from an external marketing firm. The researcher will have an influence on this work by her participation in all the phases of the survey.*
3. Translate those requirements into functional requirements for the construction project *Årstadal*.
4. Analyze and decompose according to scientific principles of design (Axiomatic Design).
5. Propose improvements.
6. Create a normative description of the decision processes of a large project (*Årstadal*). This could serve as a basis for a decision tool.
7. Generalize and develop theories.

The research project is interdisciplinary including two different fields of science: social science (descriptive) and engineering science (normative). A decision framework based on Axiomatic Design is combined with Qualitative Methods. The latter is used to facilitate the understanding of the customer requirements, especially according to aesthetic and social values.

In the illustration below the customer, functional, design and process domains are replaced with the following terms: visions, goals, strategies and activities < Kjellberg (1999) >.

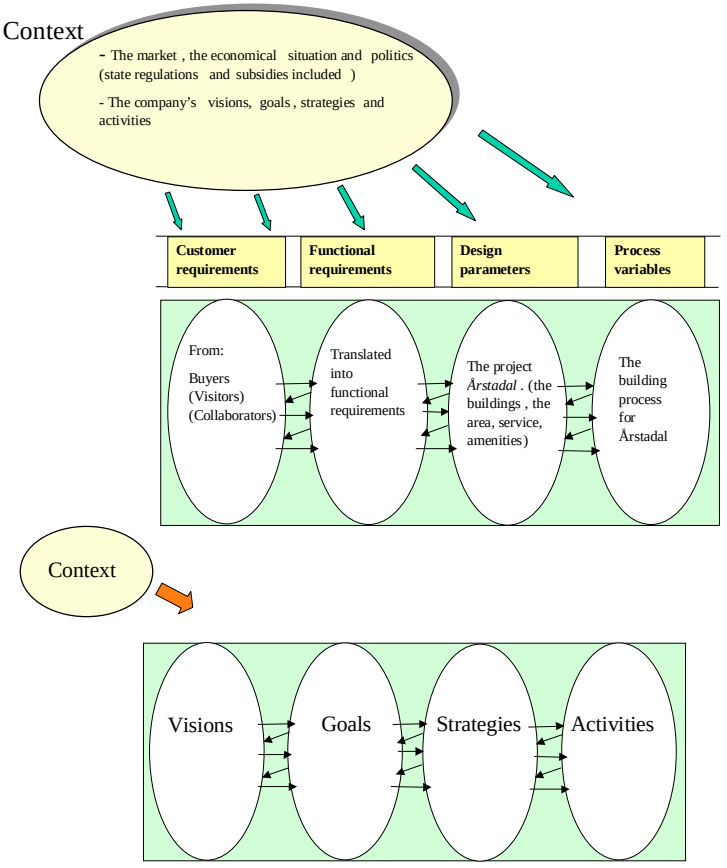


Figure 4. The Company's visions, goals, strategies and activities in a framework based on Axiomatic Design

Figure 5. The research project in a framework based on Axiomatic Design

6 DISCUSSIONS/CONCLUSIONS

Can Axiomatic Design improve the building process?

Previous research has shown that frameworks based on the method can be generalized and adaptable to many problems, even outside of the field of engineering. A good example is Nordlund's "*Information Framework for Engineering Design based on Axiomatic Design*" < Nordlund (1996) >. Since the building industry has many similarities with the manufacturing industry, where the method has been and is being applied and developed, an application and adaptation of the method seems promising

also within the construction industry (and the type of problem described in this paper). A reference of a doctorate thesis dealing with construction and Axiomatic Design is *An axiomatic approach to performance-based design* by Albano < Albano (1992) >

But one important difference between the building industry and manufacturing industry still remains. In spite of the ease of the state involvement in the construction industry in Sweden, its influence on the design of the building process cannot be neglected. The aim of housing policies is to provide the possibility for everybody to afford a good residence. Examples of traditional ways of fulfilling this aim are regulations and subsidies. Unfortunately, state involvement has in many cases resulted in housing areas, with a high level of standardization, that do not fully appeal to customers. This is valid for Sweden as well as for many other European countries.

In spite of the ease of state involvement, builders and the final user's (customer) influence on the design is still limited. The parts having an influence on the design are the following, in order, according to < Eliasson et al. (1998) > (The project developer belongs to the third part):

1. the state as regulator;
2. the state as financier (subsidizing);
3. the builder (building proprietor, building contractor); and
4. the final user.

This is valid, above all, for apartment blocks and owner-occupied houses (the latter built before January 1, 2000) with interest subsidies and state granted loans. The number of projects without any state intervention in the loan procedures is decreasing in some market segments. The impact of the state as a financier is hence reduced.

In a framework based on Axiomatic Design the state intervention in the building process can be considered as parts of the Functional Requirements and/or as Constraints.

The elements and features of Axiomatic Design that can help to improve the building process are as follows.

- The method implies a structured and systematized decision process by using axioms, corollaries and theorems in the decomposition of the problem.
- By starting with the customer requirements, transform them to functional requirements and, thereafter, looking for accurate solutions, creative work and openness to new technology is encouraged. The design team is less attached to old solutions. This characteristic of the method could help in the direction of modernising the design phases in the construction industry, by striving at correct quality, a high customer value and a high productivity.

Axiomatic Design does not help in finding accurate information needed to be able to solve stated problems. This falls outside of the method. How does one ensure that the design team has accurate information at every stage in the decision processes? In the industrial part (JM AB) there are a number of digitally based systems with the objective to provide employees with the accurate information. Investigating all of them falls outside of the research project discussed in this paper.

Other methods (than Axiomatic Design and Qualitative Methods) to be used to answer and validate the stated research problem have to be investigated.

7 ACKNOWLEDGMENTS

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