Proceedings of ICAD2002
Second International Conference on Axiomatic Design
Cambridge, MA – June, 2002
ICAD 017

A FRAMEWORK FOR DECISION MAKING IN CONSTRUCTION - BASED ON AXIOMATIC DESIGN

Royal Institute of Technology
Drottning Kristinas väg 35D
100 44 Stockholm
Sweden

Ulrika Sohlenius
ulrika.sohlenius@jm.se
MSc
Dept. Industrial Economics and Management
Royal Institute of Technology
Drottning Kristinas väg 35D

Carina Johansson
carinaj@recm.kth.se
MSc
Dept. Industrial Economics and Management
Royal Institute of Technology
Drottning Kristinas väg 35D

ABSTRACT
Governmental interference has decreased in the Swedish housing sector during the 1990s. Housing producers and customers, lenders, authorities and other actors are now facing a situation of increased influence of market forces. Making the right decisions early is crucial to meet customer requirements today and tomorrow.. Many parties are involved in the Swedish housing development process and the lead times are often long. Decisions are usually taken as a result of an iterative process where experience, intuition and the organizational structure play an important role. An approach based on fundamental principles of axiomatic design combined with the LOLA rule (LOw and LAte commitment) is proposed as basis for describing an improved decision process.

Keywords: customer requirements, design, housing development, variation.

1. INTRODUCTION

1.1 BACKGROUND

As in many European countries, governmental interference has decreased in the Swedish housing sector, during the 1990s. Housing producers (real estate developers included), customers (real estate owners and end-users), lenders, authorities and other actors are now facing a situation of increased influence of market forces. For construction firms and especially real-estate developers, this means that the early decisions are even more crucial in order to produce dwellings that fit the market and the business strategies of the company. Meeting target customer demands means, among other things, providing customized features in the products. Variation has to be provided where it adds value to the customer. At the same time as this must allow for efficient manufacturing and assembly.

Current practice of how housing producers satisfy target customers differs, as shown by these examples from Europe. Focus in these examples is on providing variation for the end user. In the Netherlands and Finland, open system building concepts have been implemented. Open systems allow for interchangeability of components from various manufacturers. These separate structures from the interior to provide a framework for simplifying technologies with the potential for facilitating maintenance, as well as change, adaptation and refurbishment in an economical way. The open system concept as applied in the Netherlands provides variation between markets and over time in some aspects. Gann et al (1999) points out that it gives customers a greater choice regarding internal layout, but generally only for those who can pay for it. The authors also point out that the Finnish approach to the open system concept does usually not include designing for future modification. The variety in choices for the customer is concentrated to the pre-construction phase. The Swedish approach to providing variation for customers is similar to the Finish. However, open systems are not commonly used in Sweden. So-called closed systems are used. These are company specific methods and components that are not enough standardized to be exchanged or combined with corresponding items from other manufacturers. The building system itself is used for competing on the market. Roy and Cochrane (1999) give an example of the lack of variance provided by volume house builders in the UK. Production ranges are in the first place defined by type of house, for example terraced house or detached house, by a small number of architectural styles and by the number of bedrooms. Internal layout and specifications are mostly fixed for a specific product range. The customer can choose kitchen and bathroom finishes, provided that the order is placed early enough in the building schedule. Companies with an internal architect are more willing than others to let standardization step aside in favor of more customized solutions [Hooper and Nicol, (2000)].

One of the challenges the house building industry is facing is to improve customer focus while improving its productivity.

1.2 AIM AND SCOPE OF THE PAPER

The aim of this paper is to describe an approach to use fundamental principles of Axiomatic Design as a framework to support decision-making that improves customer value in the housing development process. High customer value means high quality. The customer value should be maximized within the abilities of the company. This can be stated as reaching quality at high productivity. Quality is interpreted as "fitness for purpose" and is equal to meeting the customer requirements within the abilities of the company. Productivity is used in the meaning "doing what has been decided with the lowest contribution of resources". With the definitions above, quality is reached when defined functional requirements are met within tolerances with highest possible probability. Productivity on the other hand is maximized when defined targets are met with least possible use of resources.

The paper is focused on the typical Swedish housing development process. This process often includes long lead times. The developers' ability to deal with variation is therefor crucial in order to produce dwellings that fit the market today and in the future. Variation concerns variation between markets and over time. Here the context of a typical housing development project is described along with functional requirements and constraints deriving from the context. Examples of functional requirements and their variation between markets and over time are also described. Finally a basis for further work is proposed.

2. OVERLYING SYSTEMS AND THE CONSTRUCTION PROCESS

The context for a construction project can be seen as the result of a straining of the information in overlying systems.

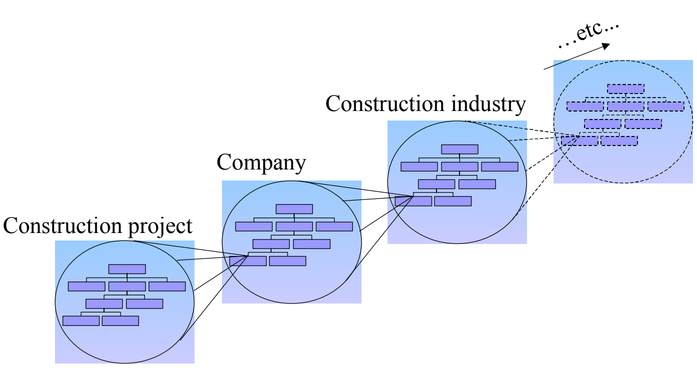

Figure 1. Fractal representation for systems. Each system is a part of a larger system. (Adapted after Hintersteiner J., Zimmerman R (2000)).

A construction project for a real estate developer can be described as the process from land acquisition to after sales. 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. To shorten this time has a potential to improve productivity by, for example, decreased capital cost. 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 [Sohlenius U., (2000)].

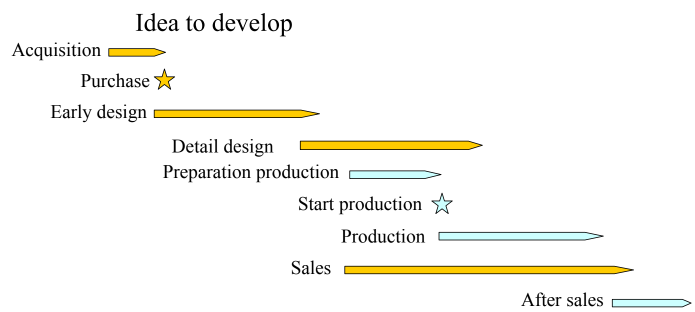

Figure 2. The construction process (adapted after Matss, (2002))

Making certain decisions 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. This means that high customer-value has to be reached, both in the short and long term. During the early stages of the construction process two main types of decisions are taken. These are:

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

During the acquisition process market analysis are undertaken and the result is often an estimate of the rate of absorption for different types of housing, over a specific period of time. The rate of absorption is defined as the number of units (by type, market segment and price) that are expected to be occupied (purchased or rented) within a specific period of time at prevailing prices [Carn and Rabanski, (1988)]. Based on the result of the market analysis a project idea is developed. The acquisition can be done as a buy, as an exchange or as a reception of the development rights for the land concerned.

Decisions taken during the planning and design stage are concerning the product and its production system. According to figure 2, the design of the product and its production system is dealt with concurrently during the phases early design and detail design.

3. THEORETICAL FRAMEWORK

Design of products and business processes is a decision process [Sohlenius G., (2000)]. Sohlenius also points out that there are several fundamental theories, axioms and principles available for the detail design work. These are based on for example natural science and mathematics. For the conceptual design there is a lack of fundamental principles. The author points out that Axiomatic Design, Robust Design and The Theory Inventive Problem Solving include fundamental principles, which are of importance at the conceptual design stage.

3.1 AXIOMATIC DESIGN

Axiomatic Design (AD) is a method that deals with decision making in design based upon axioms. It provides a framework to guide the designer through the design work. Design includes dealing with the relationship between what is going to be achieved and how it is going to be achieved. In AD the thought process is systematized by the use of four domains [Suh, (2001)]. (1) The *customer domain* expresses the needs of the customer. (2) The *functional domain* expresses the desired functions of the design object. (3) The *physical domain* expresses the physical characteristics of the design object. (4) The *process domain* expresses how to achieve or produce the design object. The relation between the domains is defined by the questions 'why?' and 'how?' The decision process is also systematized by the use of axioms, corollaries and theorems. A design is subject to certain constraints. Suh (2001) mentions two kinds of constraints. These are input constraints, which are specific to the overall design; and system constraints, which are specific to a given design and a result of design decisions made.

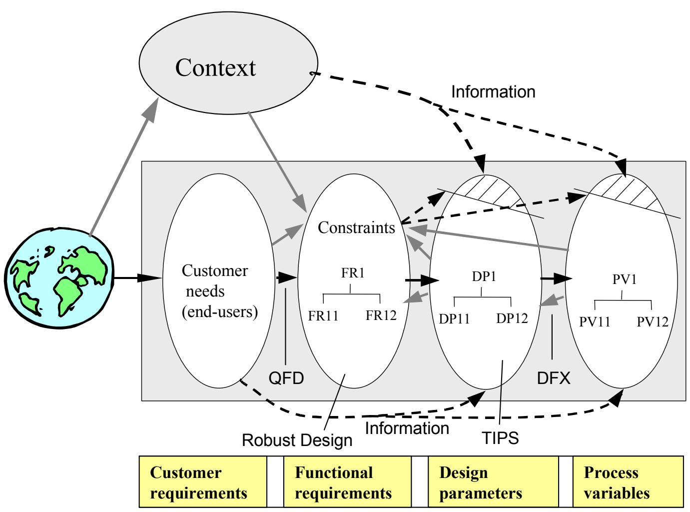

Figure 3, Decision Framework based on Axiomatic Design [Nordlund (1996)]

3.2 THEORY OF INVENTIVE PROBLEM SOLVING (TIPS)

TIPS is used to stimulate creativity. The procedure starts with an analysis of the problems to formulate technical contradictions. Technical contradictions mean that if a parameter of the system is improved, it affects another parameter negatively. The technical contradictions are then reformulated to physical contradictions. Physical Contradictions means that two mutually opposite requirements of one parameter have to be fulfilled at the same time. Finally the problem is solved with separation principles. The opposite, simultaneous requirements can be separated in time, in space, or by structural change. Under such separate conditions, the system may satisfy the opposite conditions separately.

3.3 ROBUST DESIGN

Performance variations in products are cased by noise. Three types of noise cause undesired variation. These are variation in condition of use, production variation and deterioration i.e. variation with time and use. Optimization of robustness minimizes deviations and keeps performance economically close to customer satisfaction [Clausing, (1994)]. Four activities are included in robust design; (1) Product parameter design, the systematic optimization of the robustness of the product design. (2) Tolerance design, to select the economical precision levels around the nominal target design value. (3) Process parameter design, the systematic optimization of the most important production processes so that they will produce more consistent products. (4) Online quality control, interventions on the factory floor to further improve production consistency. The first activity is the most powerful since it reduces all three kinds of noises without increasing cost.

3.4 QUALITY FUNCTION DEPLOYMENT (QFD)

QFD helps to deploy from the voice of the customer into the design of the product and the production system. To do the planning for the new product, QFD uses a matrix known as the House of Quality [Clausing (1994)].

3.5 THEORY OF FLEXIBILITY

The theory of flexibility and the LOLA-rule, developed by Paul Valckenaers, is an attempt to define what flexibility is mathematically. LOLA stands for LOw and LAte commitment. [Mårtensson (2000)].

A design is subject to continuous changes and all of these can not bee foreseen by the designer. The designed solution is therefor subject to a changing environment. According to Mårtensson and his interpretation of Valckenaers work, flexibility is a measure how many state changes a solution can survive.

The meaning of the LOLA-rule is that as little as possible should be decided as late as possible. This can be interpreted as making sure decisions early and unsure decisions late.

3.6 MODULARIZATION

Modularization is a principle of design that divides a system or structure into standardized elements - modules that can be interchanged. A modular system is a set of modules with which product variety can be created. The common elements and interfaces are the platform and the product variants constitute the product family.

Since quality varies between markets and over time, there are reasons to design the product in a way that satisfy various customers' demands at the same time as it can be produced efficiently. Depending on such things as a company's strategies and its customers' requirements the design of a product will be different. A modular approach to the design can support achieving variation to satisfy different customers' requirements efficiently. To achieve a good design, it is important to be able to capture customer and company requirements at the conceptual design stage and translate these into physical features of the product. The same principle applies when adopting a modular approach to the design.

4. CONCEPTUAL MODELS FOR DECISION MAKING

When designing a product or its production system, many decisions have to be taken. Some of these are crucial for the continuation and the outcome. The crucial decisions can be defined as those that must be taken in order to take the next step in the process. An example of a crucial decision in real estate development, is when deciding to purchase a piece of land or not. Another crucial decision is connected to what to build on the land in terms of types of houses, for example row houses or detached houses. The authors' initial interviews with practitioners indicate *inter alia* that the long time periods as discussed above, in combination with the great number of interested parties involved, make these decisions hard. The interviews also point out, that these decisions are results of iterative processes, where intuition and experience together with organizational structures play an important role.

As pointed out by Fagerström (2001), a good decision can be defined as a decision that brings the decision-maker closer to the objective. The ability to define the objective is related to the competence of the decision-maker. The competence can be defined as "an ability to act in a skilled way with proper actions at the right time" [Kjellberg (1999)]. This includes the ability to define objectives and make decisions to reach stated targets. According to Kjellberg (1999) we are limited – or helped – to be competent by tools, methods and organizational structures.
In order to make good decisions, competence and the right information are needed.

The information is represented in models, which can be seen as a projection of the real world [Fagerström (2001)]. When making decisions accurate information is promoted by models. When the decision is carried out, it has an effect in the real world. A criterion for a good decision is a decision that brings the object formulated by the decision-maker closer to the objective.

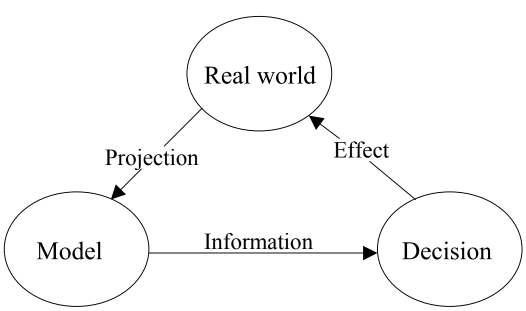

Figure 4, Model concerning basic parts and relationships in methods for development processes [Fagerström, (2001)].

According to Fagerström (2001), all activities are initiated by a decision and a meaningful decision must be followed by an activity.

The use of Axiomatic Design, has shown that the ability to define objectives and make decisions to reach stated targets are improved if fundamental principles for definition of goals and decision making (Axiomatic Design) are applied. See for example Nordlund (1996).

The decision process for real-estate development can, at a conceptual level, be described as below:

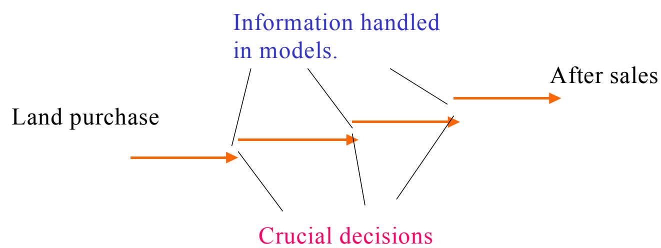

Figure 5, A conceptual model of the decision process for housing development

The crucial decisions according to the figure above correspond to Functional Requirements in an analysis according to Axiomatic Design.

When designing a product the decision process can be carried out in the following 3 levels of abstraction:

1. System design
2. Subsystem design
3. Component design

Each level corresponds to different levels in the design tree according to Axiomatic Design.

When adapted to real estate development, the system design level can be identified as the phase early design (se figure 2), which leads to a conceptual sketch of the building being developed. Subsystem design, on the other hand, concerns the development of the internal layout of the building. It includes the selection of structure and services etc. One of the results from this design phase is the final distribution of apartments. Component design concerns the design of the components such as type of walls, doors etc. All three levels contain crucial decisions, which can be characterized as sure decision and unsure decisions.

5. CONTEXT

The context of a real estate project can be seen as the result of a straining of the information in overlying systems. A real estate development project is a part of a market system. The factors affecting demand and supply can contribute to the understanding of this market system. Laws and regulations are also strongly influencing the design of housing as well as the conditions of the site itself. These factors are described here and a few examples of constraints and needs deriving from them are presented. In addition to the described factors there may also be other factors to take into consideration in a specific case.

5.1 HOUSING DEMAND

Demand for housing is affected by the state of the market. A household is the basic consuming unit in the housing market. The demanded amount of housing in a particular market at a specific point in time is determined by several factors [Carn and Rabianski, (1988); Lipsey et al (1990)]:

- The number of households in the market. This is the result of net household formation. New households are formed and households move in and out of a local market.
- Economic characteristics of households. Average income, income distribution and assets determine this.
- Demographic characteristics of households. Households can be described for example by their size, age, composition, stage in family cycle, occupation and status.
- Tastes and preferences of households. Not only economic and demographic characteristics determine housing demand. The tastes and preferences of households with similar economic and demographic features can be quite different.
- Prices and availability of substitute goods. Substitute goods are for examples other types of dwellings, other types of tenure forms for dwellings, and other types of goods in general such as cars.
- Prices and availability of complementary goods. Complementary goods are used together. Examples of complementary goods to housing are property tax, insurance, maintenance and repair, running costs such as heating, and interest rates.
- Expectations about the future levels of housing prices, interest rates, incomes etc.

Housing units are allocated to households based on their ability and willingness to pay. Ability to pay refers to present and expected income and assets. Willingness to pay refers to prices of housing (price for buying and renting), prices of complementary and substitute goods and expectations about future levels of prices and rents. The willingness to pay is also influenced by tastes and preferences.

5.2 HOUSING SUPPLY

The supply side of a real estate market can be examined by looking at new construction separately from the existing stock. The amount of goods a company is willing to produce is influenced by such factors as [Carn and Rabianski, (1988); Lipsey et al (1990)]:

- The price of the good itself. A basic hypothesis in economics is that for many goods, the higher the price, the larger the quantity that will be supplied, other things being equal.
- Price of the inputs. Inputs refer to all things a company uses to produce its outputs, for example labor, materials and machines.
- Goals of the company. The visions, goals, strategies, activities and measures influence all levels of a company. These are often expressed as business idea, policies, internal standards and procedures.
- State of technology. What is produced and how it is produced is at any time influenced by what is known. Over time knowledge changes and so does the quantity supplied and characteristics of the supplied goods
- The number of builders/ real estate developers in the market.
- Builders/ real estate developers expectations about future sales.

5.3 SITE CONDITIONS

The site for construction of new housing cannot be considered in isolation from its surrounding environment. Existing buildings, roads, green spots etc influence the design of the house. The physical conditions of the site itself such as topography and ground conditions also influence the design.

5.4 LAWS AND REGULATIONS

Housing developments are subject to several legal constraints. These include on the highest level general land use planning regulations and on the lowest level detail regulations on the design of individual components.

5.5 CONSTRAINTS AND FUNCTIONAL REQUIREMENTS

When designing a real estate development the above described factors are playing an important role for formulating needs and constraints. These are a few examples of needs and constraints deriving from these factors. The needs and constraints in turn affect the choice of functional requirements, design parameters and the process variables.

Examples of constraints that refer to the factors influencing housing demand are the level of unmet demand (number of units) and the willingness to pay for a certain housing product. These constraints are quantified or identified through market analysis. Buildings often have a long life cycle and the initial cost for buyinga home is considered as significant for many customers. This makes the whole life cost of the house important. Whole life cost can be defined as 'the present value of the total cost of that asset over its operating life including capital costs, occupation costs, operating costs and the costs or benefit of the eventual disposal of the asset at the end of its life' [Hoar and Norman (1990)]. Whole life costing is particularly useful for option selection, for example determining whether a higher initial cost is justified by a reduction in future costs. Different bodies involved in a real estate development project may have different views on how to equate initial and operating costs. A real estate developer may be concerned mainly with construction cost, while the real estate owner or end user will be concerned with the operating costs. The whole life cost can thus influence the customers' willingness to pay for a certain housing product [Johansson and Öberg (2001)]. It is therefore related to that constraint. Functional requirements that can be derived from factors influencing housing demand refer to households' tastes and preferences. A proper specification of what questions the market analysis has to answer is required to allow for accurate quantification and identification of the constraints and functional requirements related to the factors affecting housing demand.

Constraints and functional requirements that refer to housing supply can for example be the number of units the company is willing to produce. It can also be the capacity of the existing production system. Another example, which refers to company goals, is company internal environmental requirements that go beyond the legal environmental constraints.

Site conditions influence constraints and functional requirements in terms of for example height and shape of the new buildings. Laws and regulations that affect constraints and functional requirements concern for example fire safety and sound insulation.

6. FUNCTIONAL REQUIREMENTS AND VARIATION

Long term success and profitability requires satisfying divers customers' requirements. Products must be designed to meet individual customer demands that differ between markets and over time (in respect to the business strategies). These requirements include values that are both measurable and non-measurable [Nylander (1998)].

Gann et al (1999) comment on the need to inform customers about the implication of various design choices, since housing remains a product where little information is provided on component life, running and maintenance costs and environmental issues. A study by Leather et al (1998) indicate that knowledge among home owners about costs for maintenance and repair work generally is poor at the same time as costs is an important constraint for how and when maintenance and repair work is carried out.

6.1 MEASURABLE AND NON-MEASURABLE VALUES

As described in Sohlenius U (2000); "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."

According to Lundequist (2000), Konrad Marc-Wagou recommend a division of qualities (or values as discussed above) in the following three levels:

- The first group concerns qualities of the object, either they have been observed or not. These qualities are measurable and concern length, width, weight, price etc.
- The second group concerns the qualities of the object, which are perceived subjectively by the five senses: sight, hearing, taste, smell and perception of touch.
- The third group depends upon individuals different sets of values. These qualities can only be established through a discussion of values.

According to Axiomatic Design, the Functional Requirements must be expressed with tolerances. This in order to be able to choose the Design Parameter that in the most robust way fulfils the stated Functional Requirement. Many Functional Requirements have their origin in the so-called non-measurable values, as discussed above. They are hard to quantify and to give tolerances.

According to Nylander (1998) the non-measurable architectural properties that are essential to the overall quality of the home, concern different properties. Some examples are material and details, axiality, movements, light and room placements. To obtain a home with good architectural quality these properties should be taken into consideration during the design phases.

Another way to deal with quality connected to non-measurable values (aesthetics in architecture) is to assure that the profile for the real estate development is expressed early in the construction process. The profile should be expressed clearly, origin in the market analysis and be communicated to the whole project team.

According to Lundequist (2000) the aesthetics in architecture deals with what is understandable and clear and for this reason useful. The responsibility for dealing with this type of aesthetics lies on all the actors in the construction process. Lundequist recommends aesthetic co-ordination.

The authors propose that this co-ordination is conducted with a respect to the early market analysis. The market analysis is also a base for the development of the profile for the development as discussed above.

6.2 VARIATION BETWEEN MARKETS

Markets consist of buyers and these differ from each other in various ways. Some of the factors affecting demand also describe how buyers or households differ. This concerns for example ability to pay, demographic features and tastes. Markets can be broken down into segments i.e. large identifiable groups within a market. By evaluating the attractiveness of segments, the company can chose its target markets.

In order to reach high customer value (right quality) for the target market, the product has to satisfy the needs, the expectations and make the customer delighted. To structure the customer needs Gustavsson (1998) describes the Kano model, which includes five dimensions for describing quality. These are:

- Basic requirements. These are requirements connected to what the customer take for granted.
- Expected requirements. These include issues that the company uses to compete with others on the market.

- Attractive requirements. These are connected to what makes the customer delighted. If these are excluded the customer will be disappointed.
- Indifferent requirements. These do not have any customer value.
- Reverse requirements. These are qualities that make one customer satisfied while it makes another customer dissatisfied.

These can be used to support structuring the customer needs and focus on achieving right quality.

6.3 VARIATION OVER TIME

Constraints and functional requirements may change over time, for example as a result of changes in factor affecting demand and supply. All changes cannot be foreseen and therefore unpredictability is important to consider. The LOLA rule is one way of dealing with unpredictability. Some changes that occur during the life cycle of a house can however be foreseen. These refer for example to the need for repair and maintenance as well as obsolescence.

A house is a product with a long life cycle. Some parts of the house may last up to 100 years and sometimes even more, while other parts have significantly shorter life expectancy, in some cases only a few years. The life of the structure of a house is normally longer than the life cycle of components such as service installations. During the lifetime of a house, the requirements of the owners and occupiers are likely to change. The household occupying the house in the beginning may not be the same some years later, with subsequent householders perhaps of different size and composition. Even these may change as families evolve. For every change, new requirements and preferences will occur. Obsolescence, new requirements and preferences are reasons for allowing for quality variation in the same product over its lifetime. Environmental aspects also influence the variation over time. At the end of a component's life cycle it may for example be desirable that it can be easily separated from the rest of the product for recycling.

7. FURTHER WORK

Based on the points raised, a basis for further research is proposed. The intention is to describe a decision process for the early design phase in housing development with focus on design of the product. The proposed approach is based on Axiomatic Design and uses the productivity equation as a starting point. The LOLA rule is applied. Further, the use of other methods such as Robust Design and TIPS will also be investigated.

According to Suh et al (1998) an enterprise can be considered as a system that has to be designed in order to satisfy a specific set of functional requirements. The analysis below suggests the basis for further work. Profitability is considered as the Functional Requirement on the highest level.

The analysis is based upon the following equation:

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

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

DP1: Successful real estate 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 and optimal use of the production system
DP13: Productive equipment and short lead times
[Sohlenius U. (2000)]

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 (2001)].

According to the LOLA-rule, sure decisions should be taken early and unsure decisions should be taken later. From a customer perspective, the sure decisions concern issues that are common for all customers. They should therefor be taken as early as possible during the early design phase. Unsure decisions concern issues that vary between different individuals and should therefor be taken in discussion with the customer.
A principle for dealing with the so-called unsure decisions is using interchangeable modules and software.

Furthermore, the described decision process will be tested and evaluated through case studies.

8. CONCLUSIONS

The Swedish housing development process includes many parties and the lead times are often long. As a result decisions are usually a result of an iterative process where experiences, intuition and the organizational structure are playing an important role. Variation for customer is focused on the pre construction stage. Research by the authors has pointed to a need to investigate the possibilities of improving the decision process for the early design phase in order to achieve higher customer value. Identifying crucial decisions in the early design phase could give a good base for defining necessary types of models for good decision-making (e.g. which questions the models should answer). It could also highlight which are the activities that have to be put in place in order to reach the objectives. An approach based on fundamental principles of axiomatic design combined with the LOLA rule is proposed as basis for describing an improved decision process.

9. ACKNOWLEDGEMENTS

This work was supported by the Swedish real estate developer *JM AB* and by *Competitive Building,* the National Graduate School and Research Program for the Swedish Building Sector. The program is financially supported by the Swedish Foundation for Strategic Research. The work was also supported by the Development Fund of the Swedish Construction Industry.

10. REFERENCES

[1] Albano, L. 1992. "*An axiomatic approach to performance-based design",* Massachusetts Institute of Technology, Boston.

[2] Carn, N, Rabianski, J. 1988. "*Real Estate Market Analysis – Techniques & Applications"*, Prentice Hall, London, UK. ISBN 0-13-763368-8.

[3] Clausing, D. 1994. "*Total Quality Development",* New York, ASME Press, USA.

[4] Fagerström, J., Moestam Ahlström, L. 2001. "*Demands on Methods for Developing Work Focused on Concurrent Engineering"*, Proceedings of ICPR-16

[5] Gann, D. Biffin, M. Connaughton, J. Dacey, A. Hill, A. Moseley, R. And Yong, C. 1999. "*Flexibility and Choice in Housing".* The Policy Press, UK.

[6] Gustafsson, A. 1998. *"QFD Vägen till nöjdare kunder i teori och praktik" (in Swedish), (QFD The way to satisfied customers in theory and practice)*, Studentlitteratur, Lund, Sweden. ISBN 91-44-00820-1.

[7] Hintersteiner, J. D. and Zimmerman, R. C. 2000. "*Implementing Axiomatic Design in the systems engineering process: An Axiomatic Design maturity model".* Proceedings of ICAD 2000 First International conference on Axiomatic Design, Cambridge, MA – June 21-23 2000.

[8] Hoar, D. and Norman, G. 1990. "*Life Cycle Cost Management",* Qantity Surveying Techniques – New Directions. The Royal Institution of Chartered Surveyors 1990. BSP Professional Books.

[9] Hooper, A. and Nicol, C. 2000. "*Design practice and volume production in speculative housebuilding.* Construction management and economics (2000) 18, 295 – 310.

[10] Johansson, C. Öberg, M. 2001. *"Life cycle costs and affordability perspectives for multi-dwelling buildings in Sweden",* Proceedings of the 2nd Nordic Conference on Construction Economics and Organization 24 – 25 April 2001, Gothenburg, Sweden.

[11] Kjellberg, A. 1999. "*Teams - what´s next?"* Keynote paper, Annals of CIRP Volume 1/1999.

[12] Leather, P. Littlewood, M. and Munro, M. 1998. *"Make do and mend: explaining home-owners' approaches to repair and maintenance,"* The Policy Press, UK.

[13] Lipsey, R., Steiner, P., Purvis, D., Courant, P. 1990. *"Microeconomics",* Harper Collins Publishers, UK.

[14] Lundequist, J. 2000. *"Byggnaden som system och upplevd helhet"(in Swedish), (The building as a system and experienced as a whole)* Designjournalen nr 1, pp 20 – 25.

[15] Matts, M. 2002. Unpublished document, JM AB.

[16] Mårtensson P. 2000. *"Conceptual design of manufacturing subsystems", Licentiate thesis,* Department of Manufacturing Systems, The Royal Institute of Technology (KTH), Stockholm, Sweden.
ISRN KTH/TSM/R--01/--SE.

[17] Nordlund M., *"An Information Framework for Engineering Design based on Axiomatic Design", Doctoral Thesis*, Department of Manufacturing Systems, The Royal Institute of Technology (KTH), Stockholm, Sweden, 1996. ISRN KTH/TSM/R-96/11-SE.

[18] Nylander O (1998), "*Bostaden som arkitektur,*" *(in Swedish), (The architecture of the home*"*)* doctoral thesis, Department of Building Design, Chalmers University of Technology, Gothenburg, Sweden.

[19] Roy, R. and Cochrane, S.P. *"Development of a customer focused strategy in speculative house building,"* Construction Management and Economics (1999) 17, 777 – 787.

[20] Sohlenius, G. (2000), "*Productivity, Quality and decision theory based upon Axiomatic Design"*, Proceedings of ICAD 2000 First International conference on Axiomatic Design, Cambridge, MA – June 21-23 2000.

[21] Sohlenius, U. (2000), "*Can Axiomatic Design improve the building process?"*, Proceedings of ICAD 2000 First International conference on Axiomatic Design, Cambridge, MA – June 21-23 2000.

[22] Suh N.P., "*Axiomatic Design: Advances and Applications".* Oxford University Press, 1990. ISBN 0-19-504345-6.

[23] Suh, N.P, Cochran, D.S. and Lima, P.C. 1998. "*Manufacturing System Design",* Keynote Paper (DN), Annals CIRP Volume 2/1998.