A MODULARIZATION APPROACH TO HOUSING

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The manufacturing of customized products from standardized parts is common in many industries to obtain product diversification for fulfilling different customer demands. To become competitive in an international market, the housing industry now faces the challenge of creating design concepts that are adaptable to local conditions. A background study for research aiming at increasing understanding of how to create concepts for modular building systems that can be adapted according to product variance requirements and that allow for maintenance, replacement and upgrading to be done economically over the building life cycle in different countries is presented here. The study has found that housing conditions vary greatly over Europe and customization in housing is not very widespread. Many people live in inadequate housing, because they cannot afford to pay for refurbishment or a new home. An approach to modularization is proposed to identify how product variance requirements and components life cycle characteristics can be used to design dwellings, which can be run and maintained economically over their lifetime.

Keywords: customization, housing, housing condition, life cycle costs, manufacturing, modularization, product platform.

INTRODUCTION

Customizing products to fulfil various customer requirements by using standardized parts is a common approach in many industries. To be able to compete successfully in an international environment, the housing industry faces the challenge of adapting its products to different local conditions. Adapting a house to local conditions includes *inter alia* knowledge of how the requirements for housing design are influenced in terms of building owners' and occupiers preferences, components' life cycles, maintenance and replacements costs and intervals. This aspect is linked to the issue of housing affordability.

A background study for research aiming at identifying how to create concepts for modular building systems that can be adapted according to product variance requirements and that allow for maintenance, replacement and upgrading to be done economically over the building life cycle in different countries is presented here. A research approach is also presented including the conceptual framework for the study.

BACKGROUND

General

The life of the structure of a house is normally longer than the life cycle of components such as services installations. During this lifetime, the requirements of the owners are likely to change. The household occupying the house at the beginning may not be the same some years later, with subsequent householders perhaps of different

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sizes and composition. Even these may change as families evolve. For every change, new requirements and preferences will occur. Obsolescence, new requirements and preferences point to the need for a flexible housing product.

A house can, for simplicity, be seen as the sum of all its components and sub-systems. Ease of maintenance and replacement of components are examples of how the physical connection between the different components and sub-systems, as well as their interfaces, have influence on the performance of the building over its life cycle. Not only does the physical connection have influence on the performance of the building over its life cycle, but also how the individual parts work together. This concerns, for example, energy consumption, which is influenced by such factors as the overall energy efficiency of the whole building system, users' behaviour, climate and energy prices (Bertfelt *et al.*, 1992).

Different conditions for housing in Europe

The overall housing market in the EU can be described as fragmented with differences in consumer tastes, government support, differences in culture, climate, language and technical standards. Local markets may, however, be more consolidated. Ball (1999) identifies four characteristics, which broadly differentiate the institutional structure of the EU's housing markets. These are: significance and regulation of rental housing and scale of social rented housing; importance and type of housing subsidies and tax breaks; institutional structure of finance and regulation of new developments and the relationship of housing to the wider economy.

Differences in structure of the markets can be further illustrated by taking a closer look at the concept of occupational demand. According to Eccles *et al.* (1999) there are two basic ways of satisfying occupational demand: occupation through ownership and occupation through tenancy, lease or other contractual arrangement with the owner. The relative importance of owner occupation in a particular market is dependent upon such factors as custom, culture and practice, legal framework, tax incentives or disincentives, finance and funding, occupier preference and policy and investors' attitudes.

Occupational demand is affected by a number of factors such as location, design and fitness for purpose, accessibility, cost-in-use, flexibility, legal constraints and fiscal implications, finance availability, structure and cost, environmental concerns and taste (Eccles *et al.*, 1999).

The importance of each of these factors will depend on occupiers' requirements, the type of property and prevailing market conditions. These factors are different among as well as within the EU countries.

CUSTOMIZATION

Adapting the house for changing needs and requirements

A comparative study of flexibility and choice in housing by Gann *et al.* (1999) covering the UK, Finland and the Netherlands highlights some of the issues regarding current practice. None of the three countries seems to have developed and utilized technical systems that can provide real choice for a broad range of customers.

Volume house builders in the UK offer few choices for the customer according to Roy and Cochrane (1999). 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 put early in the building schedule. Companies with an internal architect are more willing than others to let standardization step aside in favour of more customized solutions (Hooper and Nicol, 2000).

In the Netherlands and Finland, open system building concepts have been implemented. These separate structures from the interior to provide a framework for simplifying technologies with the potential for facilitating maintenance, as well as economical change, adaptation and refurbishment. The open system concept as applied in the Netherlands gives customers a greater choice regarding internal layout, but generally only for those who can pay for it. The Finnish approach to the open system concept does usually not include designing for future modification and the flexibility is concentrated in the pre-construction phase. However, in both countries there is positive attitude within government, among technical experts and academics to develop a more customer focused housing industry (Gann *et al.*, 1999).

Gustavsson (1999) finds in her survey of Swedish manufacturers of prefabricated wooden houses that standard house designs are very conformist. Typical types are 1 storey and 1.5 storey detached houses with a usable floor space of 120-150 m2. In a house with 1.5 storeys the attic space can easily be fitted out when the household needs more room. Design practice is based on a simple box shape that can be enlarged in length, height and in different angles by adding modules. However, according to one manufacturer, very few standard houses are currently sold in the metropolitan areas, where demand is high. Most houses are adapted for the individual buyer, with assistance from a firm of architects[1].

Durability and renovation

A study on homeowners' behaviour and attitudes towards housing repair in the UK by Leather *et al.* (1998) suggested that homeowners are normally aware of the main problems with their properties. There is a general misconception about likely costs for undertaking repairworks and owners often miss more complex technical problems and wait too long before dealing with them. The owner's interest in the home and its condition was found to interact with the type of problem, owner's technical knowledge, available sources of advice and information on how to deal with the problem, the owner's financial situation and his or her willingness to undergo the disruption created by maintenance and repair work.

Regardless of people's preferences the most significant factors influencing household expenditure on repair, improvement and maintenance works were costs, finding and managing a competent builder, living with the disruption associated with building works, household life cycle and length of residence in a home.

Miettinen and Saarni (2000) refer to a survey conducted by the Technical Research Centre of Finland (VTT) on renovations of buildings. At the turn of the 1990s, total renovation costs for single family detached house were distributed as follows: improvement in the quality level 62%, cold/draught energy saving 7%, poor condition 7%, damage 9%, modification of space/change of application 13% and other causes 2%.

[1] From the author's informal discussions with a housing manufacturer.

Fulfilling customer demands

In order to be able to fulfil diverse customer requirements, Roy and Cochrane (1999) point to mass-customization and the use of product platforms from which a number of product variants can be derived. Gann *et al.* (1999) point to the need to distinguish between elements and parts which are of interest to the customer for choosing and changing themselves and those parts which require specialist knowledge before changing and how these relate to sub-system life cycles and reusability of components. A component-based approach for assembly of houses could be useful, especially if interdependencies between components can be reduced and elements separated according to different life cycles, making adaptability, maintenance, refurbishment and recycling easier.

All choices imply certain initial, running, maintenance and replacement costs. Gann *et al.* (1999) comment on the need to inform customers about choices, since housing remains a product where little information is provided on component life, running and maintenance costs and environmental issues.

Sarja (1997) describes the overall scheme of an integrated life cycle design process for sustainable building[2]. The main phases are: analysis of requirements; translation of requirements into technical performance specifications for technical systems (structural and building service installations); creation of alternative technical solutions; life cycle analysis and preliminary optimization of these alternative technical solutions and selection of optimal solution from them; and, finally, the detailed design of the selected technical systems. Sarja points out that a modular systematic approach helps to rationalize design, as the technical systems typically comprise different parts, each with different requirements regarding such issues as durability and service life.

Looking outside Europe – Japan

Prefabricated-housing companies in Japan produce detached houses using factory-produced parts, in a way that can be compared with the automobile industry. Some of the companies produce over 10 000 units per year (Sawada, 1997). Dwellings are generally demolished after 30-40 years, which is inefficient in terms of effective use of environmental resources and socio-economic investment (Suzuki and Ohara, 2000). To improve housing performance, research and development within the House Japan project, supported by the Japanese Ministry of International Trade and Industry, has been focused on reducing construction cost and life cycle cost, realizing high flexibility, high quality, comfort, and durability and improving energy efficiency – for further details see www.housejapan.or.jp

The developed concept for a detached house includes

- do-it yourself fitness, which is realized by a DIY oriented component system and a floor system which is easy to install;
- standardization of housing design;
- the house is easy to remodel by the use of a platform frame construction and wooden post and beam construction;

[2] A definition of sustainable building is given in Sarja (1997): “Sustainable building is a building technology and practice, which meets the multiple requirements of the people and society during the life cycle of the building.”

- The component system is rehabilitation-oriented by using removable interior and exterior components, flexible sanitary equipment and kit of components, which can be remodelled to change the use of the room;
- a design system that allows for customer participation;
- environmentally friendly technology with waste treatment system and materials for eliminating vibration and noise;
- recyclable construction materials; and
- energy efficient building system and a demand side management energy system

Methods for assessing housing performance, based on indicators, have also been developed.

A building and its equipment are often mixed in conventional housing structures, while the idea behind, for example, the flexible sanitary system developed within the Japan House project is *inter alia* to ease of construction, maintenance and replacement. This is realized through systematization and total modular implementation of sanitary and infill parts, a house zoning that allows for pre-installation of main piping under floors and a pressurized drain system that decreases limitations in pipe diameters and drainage grade. An analysis of the life cycles of buildings and components is required to allow for organizing the system efficiently (Mas, 2000).

RESEARCH APPROACH

Scope

Based on the points raised, a modularization approach is proposed for identifying how product variance, components' life cycles, maintenance and replacement costs and intervals can be used to design dwellings that can be operated and refurbished economically over their life cycles. The research will investigate how to create a concept for a modular building system, which can generate housing designs that suit conditions in different countries. Focus will be on how to obtain design concepts that can be adapted according to product variance requirements and which allows for maintenance, replacement and upgrading to be done economically.

The research will be limited to single-family owner occupied detached houses. This form of tenure lends itself to linking components' life cycle costs to the occupier and is easier than in the case of renting since, in the latter, contractual agreements would also have to be taken into account. A detached house allows for easier identification of the links between components' life cycle costs and user expenditures than would be possible, for example, in a multifamily building where the costs have to be divided between several users. For the same reasons, the form of tenure and type of house will also allow for easier comparisons between countries.

OVERVIEW OF CONCEPTUAL FRAMEWORK

Product platforms, product families and modularity

A product platform is the foundation of a common core technology, from which a number of products can be created (Blackenfelt and Stake, 1998). The platform is a set of sub systems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced (Meyer and Lehnerd 1997).

Modularity is referred to as the division of products into smaller building blocks or modules. A modular system is a set of modules with which product variety can be created. Hence, common elements and interfaces are the platform and all elements and interfaces that together make up the modular system. The product variants constitute the product family (Blackenfelt and Stake, 1998).

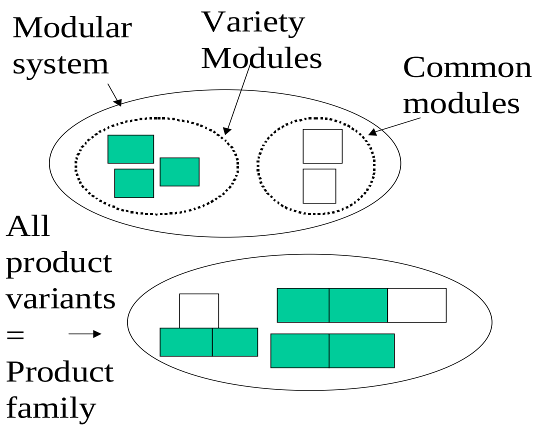

Figure 1: Modular system and product family (Source: Stake, 1999)

Erixon (1998) mentions some of the benefits of modular products, based on case studies in eight different companies.

- A modular design is a robust basis for product renewal and concurrent development of the production system.
- Short feedback links for failure reports can be secured if the modules are tested before delivery to the main line.
- Increased modularity of a product gives positive effects in the total flow of information and materials from development and purchasing to storage and delivery.
- Combining a modular design with product planning will simplify the product development process and planning of corresponding production system changes.
- Increased modularity leads to reduction of throughput times. An early fixing of interfaces between modules allows for product development activities to take place at the same time, separately for each module.

Considering all the advantages with modular products, how is it that not all products are modular? Baldwin and Clark (1997) point out that it is more difficult to design a modular system than a comparable interconnected system. The designer’s knowledge and experience play an important role for creating feasible modular concepts, as it otherwise may be easy to create concepts that are not workable from a technical or spatial perspective (Erixon, 1998).

Dividing products into modules

Several authors have developed methods and tools for modularization. These can generally be divided into four categories; methods spanning from market activities to detail design, methods for starting with a product specification and ending with a defined product architecture, guidelines for re-use and commonalty, and guidelines for creation of product platforms.

Erixon (1998) developed the Modular Functional Deployment (MFD) method, which is included in the category of methods spanning from market activities to detail design. The method includes five steps, as shown in figure 2.

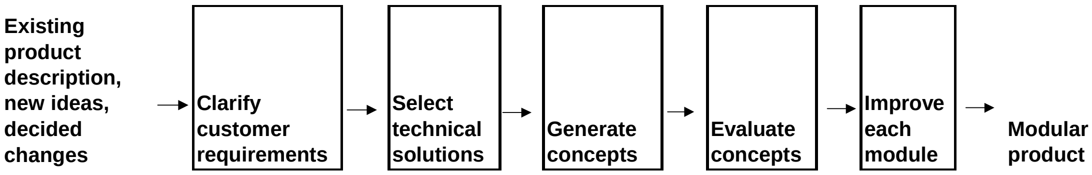

Figure 2: The steps of the MFD method (Source: Adapted from Erixon, 1998)

The core part of the MFD method is step three, where the module concepts are generated by evaluating technical solutions against so-called module drivers. The latter are the primary reasons for modularity. Twelve generic module drivers have been identified from case studies by Erixon (1998).

Development and design

- Carry-over: part of a product or sub-system that can be re-used in a future product generation.
- Technological evolution: A part or a sub-system that is likely to go through a technological shift during the lifetime of the product family. This can be caused by, for example, radically changing customer demands.
- Planned design changes: The part or sub-system is scheduled to go through a change according to an internally decided plan.

Variance

- Technical specification: The part or sub-system varies in terms of function or performance between the products in the family.
- Styling: The part or sub-system varies in terms of colour and shape between the products in the product family.

Production

- Common unit: The part or sub-system can be used across the whole product family.
- Process and/or organization re-use: The part or sub-system suits a certain process or has a suitable work content for a group.

Quality

- Separate testing: The part or sub-system should be tested separately.

Purchasing

- Supplier available: The part or sub-system may be outsourced.

After sales

- Service and maintenance: The part or sub-system needs to be easily serviced and maintained during the life of the product.

- Upgrading: The unit may be replaced for another part with different function or performance.
- Recycling: Environmentally hostile or easily recyclable materials can be kept separately to make recycling and disposal easier when disassembling the part or sub-system.

Stake (1999) investigates the differences between theoretical and empirical reasons for dividing products into modules. Stake finds that module drivers ascribed to the MFD method are satisfactory for identifying the reasons for modularity. However, there are no module drivers based on the technical reasons for grouping technical solutions into modules based on their technical relations or the functionality of the product. In the MFD method this consideration is implicit.

Whole life costing

Whole life costing is a proven means for measuring how design options affect the initial and operating costs of buildings. It 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 cost or benefit of the eventual disposal of the asset at the end of its life' (Hoar and Norman, 1990).

The main components of whole life cost are present or future capital sums, recurring costs i.e. running and maintenance costs etc and a sinking fund to repay the capital at the end of the life of the asset (Ferry *et al.*, 1999). To calculate whole life costs, all costs relevant to a project are added to estimate the total cost. Future costs are discounted to present day values.

Whole life costing can be used as a decision support tool during the design phase. In order to make a whole life cost analysis the adequacy of the predicted amount and timing of future resources are core issues. 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 or identifying whether or not a proposed change is cost-effective against the 'do-nothing' alternative.

CONCLUSIONS

Several points can be made to summarize the position in Europe. First, customization in housing is not widespread. Second, homeowners in different countries can face quite different local conditions. Third, housing is a product for which little information is given to customers regarding running costs and maintenance.

For housing producers aiming at an international market, by creating design concepts that can be adaptable to local conditions, many factors have to be taken into account. Adapting a housing design to local conditions in different countries includes allowing for building traditions and regulations, owners' preferences and the whole life costing of the building and its components.

Research by the author has pointed to the need for further investigation of the life cycle costs of dwellings. A modularized approach to design and construction is proposed. The research will be focused on identifying how to create concepts for modular building systems that can be adapted according to product variance requirements and that allow for maintenance, replacement and upgrading to be done economically over the building life cycle in different countries.

The MFD method developed by Erixon (1998) covers the division of a product into modules and spans from market activities to detail design. For the purpose of further study by the author, modularization will be confined to the MFD module drivers product variance and the after-sales i.e. user phase. The module drivers of *service and maintenance* and *upgrading* will be adapted to suit the requirement for including the life cycle characteristics of housing components and sub-systems. The method could serve as a basis for an examination of how design concepts can be created that are adaptable to local conditions, including the important aspect of life cycle costs.

REFERENCES

Baldwin, C. and Clark, K. (1997) Managing in an age of Modularity In Markets of One – Creating Customer-Unique Value through Mass Customization, edited by Gilmore, J. and Pine II, J. *Harvard Business Review*. USA

Ball, M. (1999) *Annual review of European Housing Markets 1999*. UK: RICS Books.

Bertfelt, O., Dorbell, T. and Rahm, H. (1992) *Sammanbyggnadsteknik och dess krav på ändamålsenliga datastrukturer, förstudie.* Kungliga Tekniska Högskolan, Sweden

Blackenflet, M. and Stake, R. (1998) *Modularity in the context of product structuring – a survey.* Second NordDesign seminar, 26-28 Aug. Royal Institute of Technology, Stockholm.

Eccles, T., Sayce, S. and Smith, J. (1999) *Property and construction economics.* UK: International Thomson Business Press.

Erixon, G. (1998) *Modular Function Deployment.* Doctoral Thesis, Royal Institute of Technology, Sweden

Ferry, D., Brandon, P. and Ferry, J. (1999) *Cost Planning of Buildings*. UK: Blackwell Science.

Gann, D., Biffin, M., Connaughton, J., Dacey, A., Hill, A., Moseley, R. and Young, C. (1999) *Flexibility and Choice in Housing.* UK: The Policy Press.

Gustavsson, C. (2000) *Arkitekterna och småhusmarkanden – en ögonblicksbild 1999.* Masters thesis, Chalmers Tekniska Högskola.

Hoar. D. and Norman, G. (1990) *Life Cycle Cost Management. Quantity Surveying Techniques – New Directions*. The Royal Institution of Chartered Surveyors 1990. BSP Professional Books.

Hooper, A. and Nicol, C. (2000) Design practice and volume production in speculative housebuilding. *Construction management and Economics*. **18**: 295-310.

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

Mas, Y. (2000) Sanitary Infill system for SI housing. *Working paper for the Japan House project* (6p).

Meyer, M. and Lehnerd, A. (1997) *The power of product platforms.* USA: The Free Press.

Miettinen, E. and Saarni, R. (2000) *Use of steel in house building.* Finland: The Finnish Constructional Steelwork Association Ltd.

Ministry of International Trade and Industry, *House Japan Project.* *http://*www.housejapan.or.jp (2001-03-15).

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

Sarja, A. (1997) *Research and development towards sustainable open industrialization in Building.* Function, environment and Technology, the Scandinavia – Japan Seminar on Future Design and Construction in Housing, October 6-8, 1997, Stockholm. Royal Institute of Technology, Sweden.

Sawada, S. (1997) *Changing Construction Markets of Japanese Companies.* Function, environment and Technology, the Scandinavia – Japan Seminar on Future Design and Construction in Housing, October 6-8, 1997, Stockholm. Royal Institute of Technology, Sweden.

Stake, R. (1999) *A hierarchical classification of the reasons for dividing products into modules, A theoretical analysis of module drivers.* Licentiate thesis, Royal Institute of Technology, Sweden.

Suzuki, K. and Ohara, T. (2000) Development of the Infill System for SI Dwelling Houses (Demonstrative Experiment for the New Housing Structure Project). *Working paper for the Japan House project (5p).*