LIFE CYCLE COST CALCULATION MODELS FOR BUILDINGS & ADDRESSING UNCERTAINTIES ABOUT TIMBER HOUSING BY WHOLE LIFE COSTING

LIFE CYCLE COSTING FOR BUILDINGS: THEORY AND SUITABILITY FOR ADDRESSING UNCERTAINTIES ABOUT TIMBER HOUSING

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ABSTRACT

Most commonly, production cost is the main cost factor in construction and is often set to the minimum, which does not necessarily improve the lifetime performance of buildings. However, a higher production cost might decrease the total life cycle cost (LCC). It is important, therefore, to show the construction client in the early design phase the relationship between design choices and the resulting lifetime cost. Today, LCC calculation is used extensively for industrial products to minimise production cost and increase profit. Clearly, there are significant differences between an industrial product and a building from the life cycle perspective. The main differences are the life length of a building and the lack of industrialisation in the building process, especially during construction. These factors make calculating LCC for a building difficult early in the design process.

Increased cost and declining quality has resulted in a growing interest in industrialised construction. During the last twelve years around 20 000 apartments has been built in Sweden using industrialized timber housing techniques. Still, potential clients and building owners are uncertain of long-term financial costs and functional performance of timber houses.

This paper presents a state of the art analysis in the area of LCC for construction. It offers a structural overview of theoretical economic methods for LCC analyses and their restrictions as described in the literature. The paper also reveals the primary data which are required to carry out a LCC analysis and discusses limitations in the application of life cycle costing from the client's perspective. Furthermore, the paper investigates if the use of LCC calculations might become a tool for addressing the building owners' perceived uncertainties about timber frame housing. For this purpose a pilot interview study has been performed to obtain uncertainties expressed by Swedish building owners connected to multi-dwelling timber frame houses. In general, the results show that a tool must be able to handle not only economical factors but concurrently the effects of economical, technical, functional, cultural and human factors.

Keywords
Life cycle cost, life cycle costing, whole life cost, whole life costing, uncertainty, integrated life cycle design, timber frame housing, Sweden.

1. INTRODUCTION

In cold climate regions we spend a large amount of our time in buildings. The indoor environment of a building is therefore very important to us as it affects our wellbeing and health. Improvements of lifetime quality and cost effectiveness of buildings is consequently of common interest for the owner, the user and society. Life cycle cost (LCC) for buildings is therefore an important tool for involving the construction client better in early stage design decisions. However, regardless of its importance, life cycle costing has found limited application so far (Bakis et al., 2003).

An office building will consume about three times its initial capital cost over a 25 year period, but still far more attention is paid to the initial capital cost (Flanagan and Jewell, 2005). It should be considered that higher production costs can decrease the total LCC for a building. As stated by Kotaji et al. (2003) it is particularly important to show the relation between the design choices and the resulting lifetime cost (i.e. energy, maintenance, and operation cleaning) (Kotaji et al., 2003).

According to Ozsariyildiz and Tolman (1998), the construction industry is facing increased demands from society. Construction clients ask for high quality building, lower cost and shorter lead-time. The clients, who have to pay the bill, have actually very little influence over time, cost and quality (Ozsariyildiz and Tolman, 1998). Buildings represent a large and long-lasting investment in financial terms as well as in other resources (Öberg, 2005).

In recent years, industrialization of construction is put forward as an aid to decrease the building costs and increase the quality. The challenge for the sector is to understand what industrialization implies in terms of management, actors' roles etc. Industrialization of construction is also debated in literature (e.g. London and Kenley, 2001). Multi-family timber frame housing has been pointed out as an area for industrialized process development in Sweden. However, uncertainties are expressed by clients and building owners concerning long-term financial costs, technical performance and management of prefabricated timber frame houses (Höök, 2005). The construction industry is to a high extent project oriented and construction is therefore, at times, criticized to lack a systematic and strategic approach to change because of the project nature (Saad et al., 2002). Since the project orientation/culture is so strong, a method that incorporates uncertainties caused by e.g. housing industrialization must be able to work on a project level and at the same time capture long-term behaviour of the facility.

This paper presents a state of the art review in the area of LCC in construction. The aim is to describe the different advantages and disadvantages of the main theoretical economic evaluation methods for LCC calculation and show what relevant data and main sources are needed. Furthermore, the limited application of life cycle costing in the construction sector from the clients' perspective is discussed. Moreover, the paper presents the results of an interview study with Swedish building owners. The aim was to identify uncertainties about timber housing and investigate if life cycle costing can be used to address the uncertainties. In the context of this paper, timber housing is the industrialized production of multi-storey, multi-dwelling timber frame houses.

2. BACKGROUND

Because of the fact that an office building will consume about three times its initial cost over a 25-year period (Flanagan and Jewell, 2005), it can be essential for the construction client to use LCC as a decision making tool among alternative projects, designs or building components to reduce building running costs over the long term. Despite its importance, LCC has found limited application so far in the construction sector (Bakis et al., 2003).

LCC needs time and effort. For that reason, there has to be a clear output motive to use LCC techniques for it to be a worthwhile effort for the construction client (Raymond and Sterner, 2000). The availability of LCC data is today rather limited. One reason is the lack of a framework for collecting and storing data (Bakis et al., 2003). Construction clients often give a low priority to LCC as they are not aware of the benefits from it (Raymond and Sterner, 2000). Raymond and Sterner (2000) point out that for the construction client the initial cost can be determined easily and reliably but maintenance and operational costs are less predictable as they extend in the future. For that reason, initial cost is used as the main base for decision making today.

Among Swedish contractors there is currently a specialization trend towards an increased use of prefabrication and industrialisation in housing construction. The Swedish regulations adopted in 1995 a functional view that allows timber in multi-storey buildings. Of a special interest for this research is therefore the development of timber housing.

Timber volume element (TVE) prefabrication is examined since it displays several of the attributes that are important in the industrialization approach. The TVE's are prefabricated as "ready-to-use" housing volumes complete with electrical installations, flooring, cabinets, and finishing etc. TVE prefabrication is competitive on the Swedish detached house market but much less on the multi-storey market (≤ 10 % market share). The basis for this low acceptance of the TVE prefabrication was examined by Höök (2005). The attitudes of 35 building owners' organisations were:

- *Historical prejudice:* TVE prefabrication was connected to barracks and simple movable houses and hence to a historical prejudice about poor performance and low quality.

- *Lack of required technical information:* Technical solutions of TVE's and timber in itself were not believed to be able to fulfil all code based functional demands such as adequate sound insulation etc.

- *Low long-term economical performance:* The TVE building system and their manufacturers' capacity and intention to fulfil long-time quality and life-cycle costs were questioned.

- *Organizational or project management change:* The TVE management is more related to process than traditional project management. This necessitates new co-operative patterns between the client and the manufacturer.

Hence, the presumed beneficial effects of industrialisation seem to be limited for TVE prefabrication due to two combined effects. Firstly, organizational and technological changes seem to outmode the traditional construction management practices and place greater demands on the coordination between different organizations. The client has to take a more active role in coordinating the industrialised process and he/she apparently lacks knowledge or trust if the TVE system leads to an optimal life cycle performance. Secondly, in the eyes of the clients, there are too few actors to make the TVE system reliable comparable to other building techniques.

3. LITERATURE REVIEW

The research in this paper gives a state of the art analysis of life cycle costing in construction and considers the basis and implications for the perceived uncertainties regarding timber housing. Literature on life cycle costing, whole life costing (WLC) and whole life appraisal (WLA) is reviewed for definitions and usability in the construction sector. Integrated life cycle design is examined for life cycle design application. Literature on transaction costs is reviewed to understand the basis of the uncertainties.

3.1. Definition of LCC, WLC and WLA

Traditionally, focus in construction is on minimising the initial building cost. It has, however, since the 1930s become obvious that it is unfavourable to base the choice between alternatives solely on the initial cost alone (Kishk et al., 2003). This philosophy is today denominated differently by different authors. The different terms used in the literature today are "cost in use", "life cycle cost" (LCC), "whole life costing" (WLC) and "whole life appraisal" (WLA). Flanagan and Jewell (2005) define that the terminology has changed over the years from "cost in use" to "life cycle costing" and further to "whole life costing". They have defined the new term WLA which, according to the authors, is globally used today and which contains consideration of the cost benefits and performance of the facility/asset over its lifetime and defined as *"WLA is the total cost of a facility/asset over its operating life including initial acquisition costs and subsequent running costs"*.

The draft of the ISO Standard 15686-5 (ISO, 2005) instead makes a difference between the expressions WLC and LCC. Their contention is that WLC is equivalent to LCC plus external costs, thereby defining WLC as a broader term including within it life cycle costing and covering a wide range of analysis. Even in the ISO Standard it is admitted that sometimes all terms are used interchangeably, but the Standard does try to interpret those terms more narrowly. The Standard differentiates between LCC and "life cycle costing" by stating that LCC should be used to describe a limited analysis of a few components where instead "life cycle costing" should be understood as the cost calculations themselves. The Norwegian Standard 3454 (Ns, 2000) defines LCC as including both original costs and cost incurred throughout the whole functional lifetime including demolition.

Discussions about wording bring a lot of confusion in this field. In this article, LCC is used equivalent to WLC. LCC analysis is, in this context, to be understood as a broader analysis over the whole life cycle of a building. The term LCC is chosen as it is still the better known term today in practice.

3.2 Evaluation and procedure of LCC methods (rename!)

For input to the LCC calculation, future costs are converted to their current equivalent by using a suitable discount rate. A period of analysis is chosen and an appropriate economic evaluation method is applied. The literature shows a broad variation of economic evaluation methods for LCC analysis. They all have their advantages and disadvantages. The methods have been formed for different purposes and the user should be aware of their limitations. The reviewed literature is structured in table 1. The table illustrates the six main economic evaluation methods for LCC, their advantages and disadvantages and for what purposes they can be used. The literature shows that the most suitable approach for LCC in the construction industry is the net present value (NPV) method. According to Kishk et al. (2003), the NPV method is also the most employed.

A review of different mathematical LCC models revealed that most of the models use the same basic equation. However, what separates them is the breakdown of cost elements. Concerning the suitability for the construction sector, each of the models seemed to have some specific advantages and some specific disadvantages. (Kishk et al., 2003). The model from the American Society for Testing Materials (eqn. 1) for example, distinguishes between energy and other running cost, which is useful in adopting different discount rates for different cost items.

$$NPV = C + R - S + A + M + E \quad \ldots (1)$$

C = investment costs
R = replacement costs
S = the resale value at the end of study period
A = annually recurring operating, maintenance and repair costs (except energy costs)
M = non-annually recurring operating, maintenance and repair cost (except energy costs)
E = energy costs

As LCC, by definition, deals with the future and the future is unknown (Flanagan et al., 1989), a risk analysis should be carried out after the performed calculation.

Table 1. The advantages and disadvantages of economic evaluation methods for LCC

Method	What does it calculate	Advantage	Disadvantage	Usable for
Simple payback	Calculates the time required to return the initial investment. The investment with the shortest pay-back time is the most profitable one (Flanagan et al., 1989).	Quick and easy calculation. Result easy to interpret (Flanagan et al., 1989).	Does not take inflation, interest or cash flow into account (Öberg, 2005, Flanagan et al., 1989).	Rough estimation to see if the investment is profitable (Flanagan et al., 1989).
Discount payback method (DPP)	Basically the same as the simple payback method, it just takes the time value into account (Flanagan et al., 1989).	Takes the time value of money into account (Flanagan et al., 1989).	Ignores all cash flow outside the payback period (Flanagan et al., 1989)	Should only be used as a screening device, not as a decision advice (Flanagan et al., 1989).
Net present value (NPV)	NPV is the result of the application of discount factors, based on a required rate of return to each years projected cash flow, both in and out, so that the cash flows are discounted to present value. In general, if the NPV is positive it is worthwhile investing (Smullen and Hand, 2005). But as the focus in LCC is on cost rather than on income, the usual practice is to treat cost as positive and income as negative. Consequently, the best choice between two competing alternatives is the one with minimum NPV (Kishk et al., 2003).	Takes the time value of money into account. Generates the return equal to the market rate of interest. It uses all available data (Flanagan et al., 1989).	Not usable when the comparing alternatives have different life lengths. Not easy to interpret (Kishk et al., 2003).	Most LCC models utilize the NPV method (Kishk et al., 2003). Not usable if the alternatives have different life lengths (Flanagan et al., 1989).
Equivalent annual cost (ECA)	This method expresses the one time NPV of an alternative as a uniform equivalent annual cost. For that it takes the factor present worth of annuity into account (Kishk et al., 2003).	Different alternatives with different life lengths can be compared (ISO, 2004).	Just gives an average number. It does not indicate the actual cost during each year of the LCC (ISO, 2004).	Comparing different alternatives with different life lengths (ISO, 2004).
Internal rate of return (IRR)	The IRR is a discounted cash flow criterion which determines an average rate of return by reference to the condition that the values be reduced to zero at the initial point of time (Moles and Terry, 1997). It is possible to calculate the test discount rate that will generate an NPV of zero. The alternative with the highest IRR is the best alternative (ISO, 2004).	Result get presented in percent which gives an obvious interpretation (Flanagan et al., 1989).	Calculations need a trial and error procedure. IRR can only be calculated if the investments will generate an income (Flanagan et al., 1989).	Can only be used if the investments will generate an income, which is not always the case in the construction industry (Kishk et al., 2003).
Net saving (NS)	The NS is calculated as the difference between the present worth of the income generated by an investment and the amounted invested. The alternative with the highest net saving is the best (Kishk et al., 2003).	Easily understood investment appraisal technique (Kishk et al., 2003).	NS can only be used if the investment generates an income (Kishk et al., 2003).	Can be used to compare investment options (ISO, 2004). But only if the investment generates an income (Kishk et al., 2003).

3.3 Required data for life cycle cost calculations

The data requirements, according to the reviewed literature, for carrying out LCC analysis are categorised in figure 1. These different data influence the LCC in different stages of the life cycle.

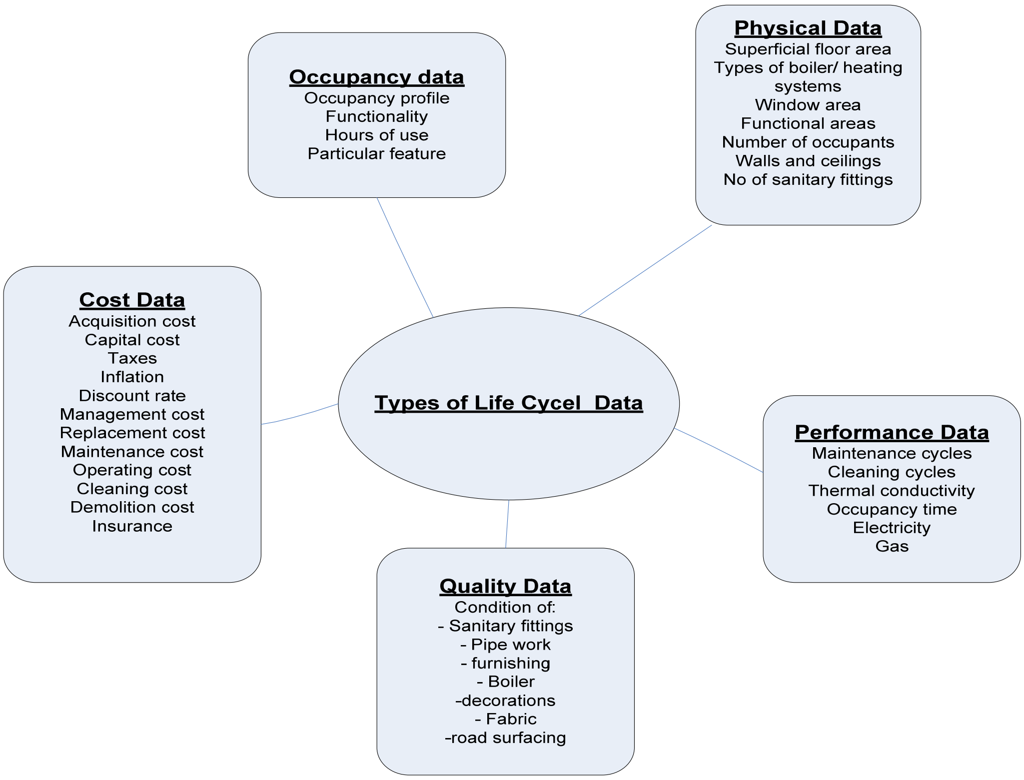

Figure 1. The required data categories for a life cycle cost analysis

The occupancy and physical data could be seen as the key factors in the early design stage. LCC estimation in this stage depends on data such as floor area and the requirements for the building. Flanagan et al (1989) stressed the importance of occupancy data as equally important key factors, especially for public buildings. Performance and quality data are rather influenced by policy decisions such as how well it should be maintained and the degree of cleanliness demanded (Kishk et al., 2003). Quality data are highly subjective and less readily accountable than cost data (Flanagan et al., 1989). In the more detailed design stage, life cycle cost estimation is based more on performance and cost data of a building (Bakis et al., 2003). Cost data are most essential for LCC research. However, cost data that are not complemented by other data types would be almost meaningless (Flanagan et al., 1989). These data need to be seen in the context of other data categories to obtain a correct interpretation of them (Kishk et al., 2003).

It should be considered that LCC is a decision making tool in the sense that it could be used to select among alternative projects, designs or building components. Consequently LCC data should be presented in a way that enables such comparison. For that reason the cost breakdown structure is an important concept for LCC (Bakis et al., 2003). There are several different standards (ISO 15686-5/ NS3454/ ASTM/ Australian/ New Zealand-Standard) available to guide a LCC analysis. All have different cost categories and slightly different cost breakdown structures.

3.4 Main sources of data

There are three main sources for data for LCC purposes.

- from the manufacturers, suppliers, contractors and testing specialists;
- historical data; and
- data from modelling techniques.

Data from manufacturers, suppliers, contractors and testing specialists can often be seen as a best guess. They may have a detailed knowledge of the performance and characteristics of their material and components, but do not have knowledge of the ways in which facilities are used (Flanagan and Jewell, 2005). However, extensive knowledge and experience of specialist manufacturers and suppliers are a valuable source for life cycle information. If the required data are not available, modelling techniques can be used. Mathematical models can be developed for analysing costs. Statistical techniques can be incorporated to address the uncertainties (Flanagan and Jewell, 2005). Data from existing buildings are used as historical data. Some of them are published as the BMI (Building Maintenance Information) occupancy cost. Other sources include clients' and surveyors' records, and journal papers (Flanagan et al., 1989).

The quality of decision-making derived from the use of LCC calculations is constrained by the availability of appropriate and accurate data, which Flanagan and Jewell (2005) refers to as the "data problem". Thus, data collection brings difficulties; however, LCC analysis is only accurate if the collected data are reliable (Emblemsvåg, 2003). Existing databases have their limitations; they do not record all necessary context information about the data being fed into them (Kishk et al., 2003). The data are usually expressed as units of cost which limits them to local use.

3.5 Integrated life cycle design

Apart from the difficulties with collecting data, the transition from understanding the theory of life cycle costing to practising it is not easy (Flanagan et al, 1989). In many cases, the intangibles (such as aesthetics) are in conflict with the results from LCC calculations (Kishk et al., 2003), also contributing to the difficulties facing the usefulness of the technique. To conjoin these objective techniques with more subjective ones, Flanagan et al. (1989) suggest using weighted evaluation matrices to handle the intangible costs and benefits. Despite the above mentioned attempt, Öberg (2005) states that the majority of the tools, such as LCC, durability of materials and environmental assessment (LCA), are limited to their specific purpose and cannot provide a holistic view of the issue. A general and holistic model combining different tools for an optimal life cycle design has been denoted *integrated life cycle design*, Sarja (2002). The model, with methodology and methods linked to it, makes it possible to handle the multiple needs desired by the owners, users and society in an optimised way during the entire life cycle of the building. The main aspects included in the model are displayed in figure 2. The model might be able to address several facets of uncertainties, going beyond a traditional LCC model. Notable, and important, is that LCC calculations are included in this model.

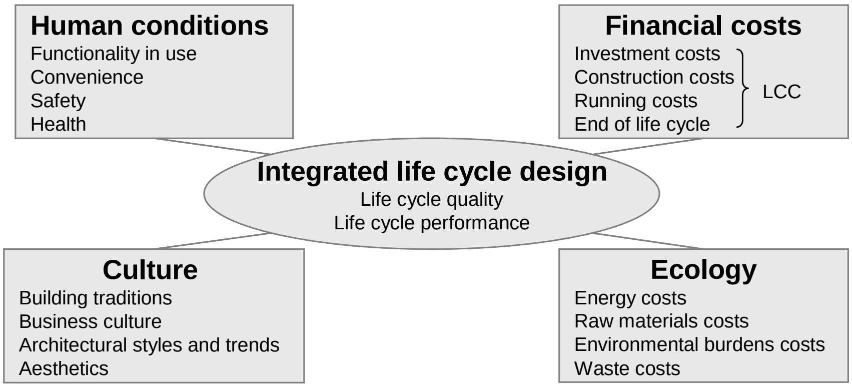

Figure 2: Main aspects of integrated life cycle design. After Sarja (2002).

3.6 Definition of uncertainty

Uncertainty is viewed in this paper as "*a business risk which cannot be measured and whose outcome cannot be predicted or insured against*". Uncertainty cannot be measured. However, two central contributors to uncertainty in a product development context are defined technology novelty/complexity and project complexity (Tatikonda and Rosenthal, 2000). Project complexity increases the degree of uncertainty as for a construction project with, e.g. new frame material, new actors or new type of co-operation. Technology novelty is, in a product development context, defined as "*the newness, to the development organisation, of the technologies employed*" (Tatikonda and Rosenthal, 2000). This opens the definition of technological novelty/complexity in construction e.g. to a broad range of attributes in industrialized timber housing. Knowledge about a new or altered production process and product design is needed as potential adopters' assumption of risk taking decreases with increased knowledge (Frambach, 1993).

Uncertainty has also been addressed in terms of the difficulties of task performance (e.g. Baccarini, 1996). Summing up, uncertainty is defined as "*the difference between the amount of information required to perform the task and the amount of information already possessed by the organization*" (Tatikonda and Rosenthal, 2000).The more uncertain the task, the greater the quantity and quality of information is needed to generate the knowledge necessary to complete the task.

3.7 Rationale for uncertainty

Transaction cost theory (TCT) was developed from transaction cost reasoning known through Oliver Williamson's *Transaction Cost Economics* (1975). The unit of analysis is the transaction, which "*occurs when a good or service is transferred across a technologically separate interface*" (Williamson 1985:1).

Two human and three environmental factors lead to transaction costs arising (Williamson, 1985:1). The two human/behavioural factors are:

- *Bounded rationality:* Humans are unlikely to have the abilities or resources to consider every state-contingent outcome associated with a transaction.
- *Opportunism:* Humans will act to further their own self-interests.

The three environmental factors are:

- *Uncertainty:* Uncertainty aggravates the problems that arise because of bounded rationality and opportunism.
- *Small numbers trading*: If only a small number of players exist in a market-place, there is little or no possibility of withdrawal and use of alternative players in the marketplace.
- *Asset specificity:* The value of an asset may be attached to a particular transaction that it supports. The possibility (threat) of a party acting opportunistically leads to a so-called "hold-up" problem. It refers to the extent to which a party is "tied in" a business relationship.

It is not until the human factors are combined with the environmental factors that problems arise (Williamson, 1975). Bounded rationality is a problem only when it is combined with situations perceived uncertain or complex for the party involved. As asset specificity and uncertainty increase, the risk of opportunism increases. Furthermore, human inclination for opportunism increases at a market with a small number of players, since opportunism brings its own punishment at a market with a large number of players (Williamson, 1975).

Transactions between organisations are controlled through contracts. This is especially true in construction since control of construction projects is based on firm contractual arrangements. However, the bounded rationality makes it impossible to regulate every matter within a contract, a phenomenon Williamson (1985:2) describes as contracts being unavoidably incomplete. In the relation between supplier and customer, trust will both facilitate the co-operation and prevent conflicts between the parties (Berggren and Lindkvist, 2005) and contracts can function both as a substitute and complement of trust (Klein Woolthuis et al., 2005). Prior experiences also play an important role in determining if and to what extent a partner can be trusted. Without long-term experiences it may not even be possible to submit the risk that one who is trusted may fail (Nooteboom, 2002).

4. RESEARCH QUESTIONS AND METHODOLOGY

Firstly, this paper aims to explore the different data that are needed to analyse LCC for buildings. It aims at a structural overview of existing theoretical economical methods for LCC analyses and their advantages and disadvantages. Furthermore, the objective is to point out the main data which are required to carry out a LCC analysis and to move away from the limited application of LCC to a position where LCC can properly inform the early stage of design decision making.

The incentive to the interview study, aroused by the earlier study by Höök (2005), is to deepen the understanding of the uncertainties and lack of trust expressed by building owners associated to timber housing. According to a market analysis presented by a Swedish commission, Industrifakta[1], clients are foreseen to receive increased power and a different role in a future industrialized building process in Sweden. A key factor for the clients is knowledge regarding long-term performance of the building systems. With a profound comprehension of the rationale for the uncertainties and lack of trust, the authors wish to investigate if and to what extent the uncertainties can be addressed by LCC considerations.

In this paper, we therefore formulated the following research questions:

- What are the different data needed to analyse LCC for buildings?
- What are the preferable methods for LCC analyses for the construction industry?

[1] In Swedish: Industrifakta, 2006: Konsekvenser av industrialiserat byggande.

- What is needed to increase the use of LCC calculations and application in the early design stage?
- What are the uncertainties expressed by Swedish building owners related to timber housing and what are their rationale?
- If and to what extent can aspects in integrated life cycle design be used to address the uncertainties?

4.1 Research methodology: Literature review

The literature review started with the focus on LCC models and required data for a LCC analysis. The start key words have been life cycle cost (LCC) and life cycle costing. The field of LCC is wide and to be able to keep focus on the construction sector all words have been combined with construction or building. This has narrowed the field. While reading the first literature it became clear that often terms like whole life cost and whole life costing is being used in the literature, as well as whole life appraisal (WLA). These words have been added to the list of key words. The main sources for the literature research were databases, such as Environmental Sciences, Emerald, Elsevier Science Direct, Compendix, Web of Science and Google Scholar. The search for articles was complemented with systematic search within libraries in Sweden through Libris.

4.2 Research methodology: Interview study

The investigation was designed as an exploratory study with a qualitative research approach. The data collection method was chosen as semi-structured interviews.

In-depth interviews are especially suitable when the problem is complex since the interviewer can rephrase the questions as well as pose related questions to penetrate the problem (Wiedersheim-Paul and Eriksson, 1989). With the possible difficulty involved concerning how to express uncertainties in mind, personal in-depth interviews were conducted. The possibility to adjust the questions to each individual was important in this case to reach the bottom of the viewpoints. The same questions, but from different angles, were asked thereby also reaching triangulation. In total, a number of seven in-depth interviews with five Swedish building owners were conducted. The interviews were held as semi-structured face to face-interviews.

The participating rental apartment building owners were selected from the features: geographical location of flats, size, type of ownership and whether they have experience of timber housing or not, see table 2.

Table 2. Characteristics of the participating companies

Location	No of rented flats	Ownership	Experience of timber housing
Luleå/Piteå	1100	Private-owned	Yes
Stockholm	5000	Cooperative economic association	No
Luleå	11500	Public-owned	No
All over Sweden	29000	Private-owned	Yes
Stockholm	43000	Public-owned	Yes

The interview data was analysed through *categorization*, taking into consideration the instructions by Dey (1993). Affinity diagram, (Foster, 2004) was used for grouping the data and the aspects in Sarja (2002) to combine the groups.

5. RESEARCH RESULTS AND ANALYSIS

5.1 Results of the literature review

Several cost-based LCC calculation methods are available for the construction sector. They all have their different advantages and disadvantages. According to the reviewed literature, the most suitable approach for LCC in the construction industry is the NPV method or, in the case of comparing alternative schemes with different lifetimes, the ECA. The NPV method is mainly used in existing LCC tools today. The user should bear in mind that different methods have been formed for different purposes. For example, in the case of a rough estimate, to distinguish if the investment is profitable or not, the payback method would be most suitable. Consequently, other methods shown in table 1 can be used if the proper purposes are considered.

The data can be divided into five main groups: occupancy data, physical data, performance data, quality data and cost data. All of them have to be taken into account for a LCC calculation. The importance of the different data depends upon the stage of planning in which the calculation is undertaken. LCC is a decision making tool to select among alternative projects, designs, or building components. Consequently, the LCC data should be presented in a way that enables such a comparison. The cost breakdown structure is in this case an important aspect.

Sources of data are manufacturers, suppliers, contractors and testing specialists' data, historical data and data from modelling techniques. However, all of them have limited use today according to the literature.

The reviewed literature indicates that LCC calculations need to be considered worthwhile for the construction client. Therefore, data access needs to be facilitated and, consequently, less time and money consuming.

According to the reviewed literature, the collection of the data is the main difficulty for calculating LCC for a building. This process can involve much time and money. To build databases seems to be a good alternative, and would save time and offer easier access to data. The limitations of databases, however, have to be recognised. Firstly, there is the local limitation and, secondly, there is often a need to normalize the data before adding to the database. Even so, building local databases would be a solution so long as there is regularly updating.

5.2 Results and analysis of the interview study

Analysing the interview data, a number of clusters of uncertainties were distinguished. Assorting the different groups of uncertainties under headlines constituted by the main aspects in of *integrated life cycle design* resulted in a number of groups falling outside the model by Sarja. These could, instead, be clustered under the headline *technical solutions*, identified by Höök (2005). The result of the categorization is displayed in table 3.

Table 3. The expressed uncertainties grouped and categorized

Financial costs	Technical solutions	Human conditions	Culture	Ecology
Energy consumption*	Motions*/Stability*	Sound insulation*/ perceived sound level*	Co-operation with partners*	Natural and sustainable materials
Long-term performance*	Risk of fire*	Security/ safety	Experience, history, tradition*	
Water damage, piping, installations*	Fulfilment of functional demands on actual location*	Comfort, well-being	Dry building process*	
Maintenance of wooden facades*	Timber as frame material*	Architecture, aesthetics		
Initial construction cost	Adaptability to new regulations and change			
Management- and life cycle economy*				
Stairwells and wooden staircases*				
Maintenance of: facades, roofs and windows				
Serviceability, accessability				
Wear				

The table shows the groups sorted under five headlines and divided into three levels. The groups in black squares are of highest importance as they are mentioned by four or more of the respondents. The groups on the second level, with grey filling, were mentioned by three or less and the third, the white, by one or two of the respondents. Notable is, no uncertainties were mentioned by four or more respondents under the headlines *culture* and *ecology*. The groups marked with an asterisk are uncertainties, or concerns, expressed especially about timber housing.

The most frequently mentioned uncertainties regarding *financial costs* are energy consumption, long-term performance and water damages. The respondents expressed a belief of higher energy consumption with a timber frame than for a traditional (concrete) frame, questions about the length of the building's physical life and particular concerns about the consequences of a water leakage in a timber frame house. All building owners except for one, expressed perceptions about motions (a technical solution) in the wooden frames causing, for example, cracks in wall paper. All respondents expressed doubts that the sound insulation, found under *human conditions*, is not good enough for timber housing. Their impression was that the living environment would be disturbed by noise making the building less attractive.

Most of the uncertainties are about financial costs. This finding clearly, and maybe not surprisingly, indicates that the long-term financial cost is the most crucial uncertainty to address. Furthermore, a salient observation from the interviews is that cost is the decisive factor in design decisions, but with shifting focus on short-term and long-term costs among the respondents. A difference could be discerned between private and public building owners. Consequently, many of the uncertainties of highest importance can be addressed by LCC calculations, although not all.

A conclusion drawn from table 3 is that the main grounds for the uncertainties about *technical solutions* originate from the TVE houses being a new product offer, a new frame material, with a novel construction method (industrialized production), all of which can be referred to as *technology novelty*. The technology novelty added with the facts that construction encompass high project complexity and that buildings incorporate a high degree of asset specificity and are of high economic value for the client makes it evident that human bounded rationality will influence the client's understanding of the transaction. Uncertainties concerning the technical solutions must therefore be addressed for the product to be trusted.

A building is a complex product delivered long after the contract has been signed. Due to this project complexity, the human bounded rationality is high in this type of transaction making trust an essential ingredient in the choice of contractor. No prior experience of the contractor will lead to an even higher perception of risk-taking from the client. Even more, if the client in addition has no prior experiences of either industrialised production or timber housing, there will be poor trust for all three inherent components in the choice of timber housing and little motivation to take the risk. The small number of manufacturers on the timber housing market further increases the perception of risk-taking. This can be explained by the increased inclination for opportunistic behaviour by the contractor, inevitably making the contractor perceived as less trust-worthy. Thus, creating distrust for the product and uncertainty about the delivery since the client has no possibility of withdrawal when there are no alternative contractors to engage.

To sum up, one can clearly derive many of the grounds for the expressed uncertainties related to timber housing, especially for the ones under the headlines *financial costs* and *culture* from Sarja (2002) and *technical solutions* coined by Höök (2005). Visible is, however, that most of the uncertainties can be embodied in the main aspects in *integrated life cycle design* by Sarja (2002). Though, with diverse weight given to the aspects since this study takes into consideration solely the perspective of the client resulting in the high importance given to the economical aspect and insignificant consideration of ecology. However, to address *all* uncertainties requires augmenting Sarja's model with the aspect *technical solutions*.

6. CONCLUSIONS

The choice of the right calculation method for LCC is easy and obvious if the advantages and disadvantages are appreciated. The calculation of LCC is not difficult and for structuring the main data, which need to be collected, help is available in the form of different standards such as ISO or the Norwegian standard. Nonetheless, data collection causes difficulties. Data need to be predictable if the LCC analysis is to be reliable. Regional databases are seldom available or usable. Collecting data by hand, takes much time and money. This is worthwhile if the project is big enough. When historical data are collected and updated over time, their use can become more reliable and the LCC analysis more trustworthy.

Data should be shared to avoid the duplicated effort of collecting them. If more clients demand LCC information and a proper check of the information against performance is done in the future, improvement in accuracy and reliability could be expected. When LCC is used more frequently, the construction client could judge LCC in the same manner as they do with estimated capital costs today. The construction client, and the end-user, could save much money in the long run, if LCC is adopted as a decision making tool. The lifetime quality and the cost effectiveness of buildings would improve by using LCC in the early stage design.

The most important features of timber housing, as a new product on the construction market produced with a new production process by relatively small and unknown manufacturers, generate uncertainties and scepticism among the potential clients and building owners. The grounds for the uncertainties related to timber housing are shown to a large extent to be found in the transaction cost theory and in the notions of technology novelty and project complexity. Knowledge of the rationale behind the perceived uncertainties makes it possible to address them. The study does, however, not reveal how this should be achieved since it was outside the scope of this paper.

The interviews in this pilot study show that uncertainties related to financial costs constitute the great majority of the uncertainties emphasized by building owners. Hence, a conclusion drawn is that LCC calculations will be able to address a large number of the perceived uncertainties about timber housing. Although, for the calculations to be applicable and accepted, the model must be broadened to include all aspects in integrated life cycle design. Furthermore, the characteristics of timber housing make it crucial to address the uncertainties about its technical solutions for the new product to be trusted by the clients.

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