INFORMING EARLY STAGE DESIGN THROUGH LCC DATA

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Life cycle costing (LCC) has been proved to be a valuable decision-making tool for strategic facility management considering life cycle perspective of buildings. However, its application by the Architecture, Engineering and Construction industry is limited due to lack of available and reliable information. In order to overcome this challenge, researchers have proposed transferring information from operation of existing buildings to the design of new buildings. By using structured analysis methods and specifically, data flow diagram techniques, this study aims to explore how can data from existing social housing building projects with regard to cost drivers of LCC inform the design of new projects. To support the analysis, a social housing project in a Danish architecture firm is used as the case study, and data are gathered through physical artefacts and five semi-structured interviews in both the architect and building client organisation. The results indicate the availability of operational data in several of the processes in the data flow diagram of the case project. The discussion focusses on different ways that O&M data from existing buildings that are provided to the design team through a requirements' report when a new project is published, can be effectively used to identify cost drivers of LCC and inform the design of new projects. The consideration of cost drivers of LCC in early design stages will contribute to designing more economically sustainable constructions that are easy and affordable to operate and maintain.

Keywords: cost drivers, Life cycle Cost (LCC), social housing, structured analysis

INTRODUCTION

The past few years, the Architecture, Engineering and Construction (AEC) industry has shown increased interest in sustainability, focusing on the environmental performance, social quality and economic assessment of buildings in a long-term perspective. Life cycle costing (LCC) is a methodology that promotes life cycle perspective of buildings, considering not only construction costs, but also cost to operate and maintain them through their entire lifetime. Thus, LCC is used by architects and engineers as a decision-making tool to evaluate different design solutions that have different cost effect over time, based on several key factors like cost, quality and comfort (Haugbølle and Raffnsøe 2019).

Currently, there is an increased use of LCC in the design practices of the Danish AEC industry due to several new initiatives including the adoption of LCC by governmental regulations (Bygningsstyrelsen 2017) (Mortensen *et al.,* 2018), European procurement

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policies (European Commission 2014) and various certification schemes (DK-GBC 2012) (a detailed description can be found in the research by Saridaki *et al.,* (2019)).

Despite the increased application of LCC, there are still several challenges that obstruct the full integration of the concept. In a recent study by Saridaki and Haugbølle (2019), the authors conducted an extensive literature review and a case study analysis in a Danish architecture firm and identified several contradictions of integrating LCC in the Danish design practices. The results indicated that main contradictions are related to poor availability of data and the form of collaboration in the current design practices. Other researchers have also identified the lack of reliable data as a critical hindrance of applying LCC (Fu *et al.,* 2007, Gluch and Baumann 2004, Ruparathna and Hewage 2015).

In order to overcome the challenge of poor data availability, researchers and practitioners have proposed to transfer information and data from operation of existing buildings to the design of new projects. In their literature review, Rasmussen *et al.,* (2017) investigated different ways for transferring knowledge from operation to design, while Jensen (2009 and 2012) proposed different transfer mechanisms, like: codification of knowledge from building operation to increase awareness among designers, continuous briefing of facility managers and users during design process, project reviews to ensure that designers take considerations for building operation seriously as well as regulations to ensure that codified knowledge from building operation is used by the design team. However, several actors need to be involved in the process to successfully achieve knowledge transferring, including building clients to ensure knowledge transfer (Jensen 2009 and 2012), facility managers to provide great insights to new building projects (Jensen 2009 and 2012, Meng 2013) and buildings' users (Chandra and Loosemore 2012).

Throughout the practical experience of one of the authors in a Danish architecture firm, the authors recognize opportunities for transferring operational knowledge to design practices through social housing projects. Social housing (in Danish: Almen bolig), also known as affordable housing or non-profit housing, refers to residential houses owned by social housing organisations, which are characterised by a non-profit business. In Denmark, the social housing sector constitutes one fifth of the housing stock (Alves and Andersen 2015), as there are more than 600,000 social housing units that are distributed among 25 social housing organisations. Social housing organisations are, at the same time, building clients and facility managers as well as they also have close relationship with the buildings' users (tenants). Thereby, they are reasonably considered as critical actors for transferring operational knowledge to new building design.

The aim of this research is to explore the processes of social housing projects and identify cost-related data from operating existing social housing buildings floating between design processes that can be used as cost drivers with regard to LCC to inform the design of new building projects in relation to LCC. By using Structured Analysis (SA) methods, and in particular Data Flow Diagrams (DFDs) in a social housing project of a Danish architecture firm, the study aims to answer the following research question: "How can data from existing social housing projects with regard to cost drivers of LCC inform the design of new projects?"

This is the initial part of a research study that focuses on analysing the processes of social housing projects and identifying data with regards to cost drivers of LCC that can be used to inform the design. In future research, the authors aim to propose interventions to the system that support the use of cost drivers of LCC to inform the design of new projects.

METHODOLOGY

In order to analyse the processes and identify data floating between the processes of social housing projects that can be used as cost drivers of LCC, the authors use structured analysis (SA) as an information analysis methodology.

SA was developed in late 1960s by Ross and his colleagues who use it as a methodology to describe complex IT systems such as the US Air Force Computer-Aided Manufacturing Project (Ross 1977). The methodology was commercially introduced in 1973, and since then, it has been applied in various project in diverse industries (Congram and Epelman 1995).

SA is successfully used for analysing complex systems and business requirements by describing a system of activities from a perspective of data flowing through it. Congram and Epelman (1995) stated that SA is helpful to understand what happens in delivering of a service, and it is a well suited methodology to structurally providing significant attributes of service description, such as: (i) who and what performs the activity (mechanism), and (ii) what guides or limits the activity (controls).

Various modelling tools are used to analyse systems in SA methods including, among else, data flow diagrams (DFDs). A set of interrelated DFDs, which are decomposed with the top-down approach, is used to represent a system (Wang and Tzui 1991). The top diagram summarises the diagrams below, which are arranged hierarchically and become increasingly more detailed at each level. DFDs are usually underpinned by a data dictionary and a process description document.

DFDs show the relationship between processes and data by using the following component (see Figure 1) (DeMarco 1979).

Figure 1: Data flow diagrams' components (Source: Adapted after DeMarco 1979)

- External entities, which are represented by a rectangle, are related to elements of the outside world that communicates with the system. An external entity could be an organisation, a group of peoples, a department or even another system that the model system communicates with.
- Processes/Activities, which are represented by a cycle, an oval, or a rectangle with rounded corners, are part of the system that transforms inputs to outputs.
- Data flow, which is represented by an arrow, shows the transfer of information from one part of the system to another.
- Registers/Datastores, which are presented with two horizontal lines, represent the place where data are stored to the system.

The research approach that is used in this study for analysis the processes of social housing projects is a single case study analysis. The case company is a Danish architecture firm, located in Copenhagen, Denmark, and it is a frontrunner on sustainable design and constructions including LCC. The case company is strategically selected as a paradigmatic case study in the Danish AEC, since it is a typical Danish architecture firm in terms of type and size, and it has been involved in several social housing projects for different social housing organisations around Denmark.

To support the analysis, a typical social housing project is selected as the internal sub-case project. The case project is also a paradigmatic social housing project, managed by one of the bigger social housing organisations in Denmark. The project is designed by the case company, and it is now under operation since January 2019. In order to create DFDs of the case project, qualitative data were gathered though semi-structured interviews and collection of physical artefacts (as proposed by Yin 2009). Specifically, in total five interviews were conducted during autumn 2019; three of them were conducted internally in the case company, while the other two were conducted with employees of the social housing organisation that owns the project under examination. To support the interviews, physical artefacts of the case project were carefully collected, including several reports from both architects and the social housing organisation.

The collected data were used to create a set of DFDs for analysing the case project. Due to the limited space, this paper shows an initial part of the research study presenting the top two DFDs of the SA system, Level 0 and Level 1, underpinned by their process descriptions. More detailed levels will be reported in future studies. It is important to mention that the developed DFDs are structured from architect's point of view since architects should identify potential data that can be used to inform the design of new projects.

Findings

In this section, the results of the case project analysis by using SA are presented. More specifically, the DFDs of the top-two levels (level 0 to level 1) of the analysis are illustrated, followed by a process description in each level.

DFD - Level 0

The top-level diagram of the case project analysis indicates that there are three main recurrent processes throughout the social-housing projects' lifetime (see Figure 2).

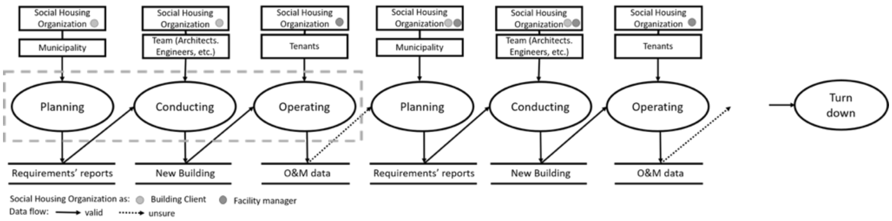

Figure 2: DFD of the case project - Level 0

As it is indicated in Figure 2, a social housing project begins with the planning process, which is initiated by the building client which is the social housing organisation and the municipality in which the project is located. The planning process results in a set of requirements' reports for the new building project which are used as input data for the next process, namely conducting the building project. The project is conducted mainly by a project team that consists of architects and engineers. Other actors are also involved in this process, including, among else, the social housing organisation, the municipality, tenants of social housing buildings, etc. When the project is executed, the new building is operated by the tenants. In the operating process, the social housing organisation is also involved having the role of the facility manager of the building that gathers several operational and maintenance (O&M)

data. Those three processes, namely planning, conducting and operating, constitute the main processes of social housing projects and are illustrated in Figure 2 with a dashed grey square. After several years of building operation, a renovation project is taken place and a new round of processes begins. Considering the performance and the O&M data of the existing building, a renovation project is, again, planned by the social housing organisation and the municipality, is conducted by a project team under the supervision of the social housing organisation, and the renovated building is operated by the tenants and managed by the social housing organisation. Those processes are repeated several times throughout the lifetime of the project until the building is turned down.

The DFD of level 0 indicates that the social housing organisation is involved in all processes of a social housing project throughout its lifetime, having different roles. Thereby, it can be reasonably assumed that social housing organisations have an overview of the building project's performance under all processes throughout its lifetime and thus, are considered as sources of plentiful data, including LCC related data. However, although the evident assumption of data sources, it is not yet fully recognizable how and in what volume those data are gathered, analysed and used in the recurrent processes of the same housing project or in similar processes of different projects in order to inform the design and improve performance of buildings. Nevertheless, is observed that the dataflow between processes of existing and new building projects is quite unstructured and this is indicated by a black dashed arrow in Figure 2.

DFD - Level 1

The DFD of level 1 is one step down in the hierarchy compared to the DFD of level 0, presenting a higher level of details. The case project that is used to map the DFD in level 1, is a completed new social housing building project, and thus, it is currently under the initial operating process, while the initial planning and conducting processes are already completed.

In this research, the authors are interested in how data for existing social housing project with regards to cost drivers of LCC can inform the design of new projects. Therefore, the analysis is focused on the sub-processes that occur at the end of planning and beginning of conducting process of level 0, in which the initial process of designing of the new project are taken place. The level 1- DFD is presented in Figure 3.

As illustrated in Figure 3, level 1 consists of four processes under examination: (a) public announcement of a new project, (b) competition process of the project, (c) evaluation of submitted projects, and (d) early design of building project.

In process (a), the social housing organisation in the role of building client announces the publication of the new project. The publication of the new project comes along with two reports that include some minimum requirements for the project submission. The one report, called Competition program, focuses on the competition procedures and describes, among else, the organisational and planning conditions, process prerequisites, requirements for tendering documents, competition theme, approval requirements, etc. The other report, called Standard Building program, focuses on the building and includes descriptions about the overall layout and architecture design, rooms' specifications, buildings' elements and materials, technical installations, electrical systems, outdoor areas as well as maintenance planning.

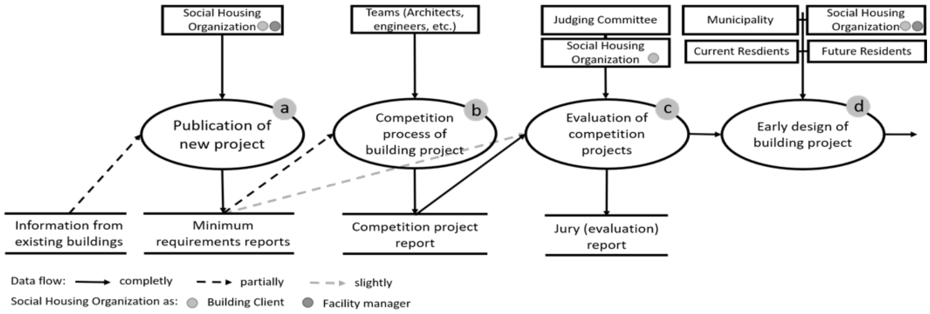

Figure 3: DFD of the case project -Level 1

Both reports include, among else, requirements for housing size, architecture quality, energy class calculations, indoor climate, daylight and sound conditions, etc. There are also several qualitative requirements in relation to LCC, like expected long lifetime of building components, low maintainability of materials and low operational costs. In addition, the Standard Building program report contains a detailed quantitative schedule of expected expenditures for maintenance activities for the upcoming 30 years of building operation (Figure 4). Specifically, the principle schedule for maintenance payments, as it is called, includes yearly expected payments for eighteen (18) maintenance activities for the first 30 years of operation (11 activities for external maintenance and 7 activities for internal maintenance). This maintenance schedule is arguably created based on cost data from other similar social housing projects; however, this is not yet clarified (illustrated by a dashed arrow between information from existing buildings datastore and process (a) in Figure 3). Thereby, it is also assumed that the social housing organisation is involved in this process of publication of the new project, having the role of facility manager of other social housing building.

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
*All amounts in DKK 1000																														
Exterior maintenance																														
Joint around windows	0	0	0	0	0	0	0	0	0	0	25	25	25	50	50	400	0	0	0	0	0	0	0	0	0	25	25	25	50	400
Replacing double-glazing units	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
Gutter repair	0	0	0	0	3	0	3	0	3	3	3	0	3	3	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Roof surface maintenance	0	10	10	10	10	10	15	10	10	15	10	10	15	10	10	15	10	10	15	10	10	15	10	10	15	10	10	15	10	15
Covering roof	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Exterior lighting	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Outdoor areas, paving/ asphalt	0	0	0	0	0	0	0	0	0	0	800	0	0	0	0	0	0	0	0	0	800	0	0	0	0	0	0	0	0	800

Figure 4: Part of the Principle schedule of maintenance payments (translation from Social Housing's Standard Building Program report)

In process (b), pre-qualified teams consisting of architects and engineers compete for winning the project. In this process, architects use the data from the minimum requirements reports of process (a) to develop an architectural proposal that satisfies those requirements and submit their competition project report (outcome of process (b)). The competition document of the case project includes a case analysis, several drawings along with building elements' specifications and various calculation results. However, it is observed that the competition document under examination does not include any information about the lifetime of the selected materials or their maintainability, or any other LCC information to support the architectural choices. This means that the data stored in the minimum requirements' reports as an outcome of process (a), are only partially used in process (b), and this is represented in Figure 3 by a dashed arrow.

The competition project report as an outcome of process (b) is used as an input in process (c), where several reports from different design teams are evaluated by the social housing organisation together with a judging committee. The judging committee consists of people from the local municipality as well as from other social housing organisations. In this case project, the main award criterion is the most economically advantageous tender; however, a number of sub-criteria are used for the evaluation. Those sub-criteria refer to: (1) The building system: Architecture idea, building technology and quality, variety of options and flexibility; (2) Price: compliance with given price per m2, unit price, price of advices; (3) Cooperation: the contract team and their organisation.

It is observed that, although the emphasis that is given on LCC related requirements in the initial reports of process (a), there is not any criterion that evaluates the consideration of long-term cost-effective design proposals in process (c). The grey dashed arrow between the datastore in process (a) and process (c) indicates that the minimum requirements' reports are slightly used as an input in process (c).

In this case project, the case company was part of the winning team, and thus it continued in process (d) working on early design of the project. During the early design process, the winning team had continuous communication with several external actors, who support the design by providing useful information in order to ensure high quality of the project. Those actors are the local municipality, the social housing organisation as well as current tenants of other existing social housing buildings and future tenants of this building project (represented as external entities of process (d) in Figure 3). The communication between the winning team and the external actors is performed through regular meeting, where information about the cost performance of existing buildings or unexpected operational and maintenance issues is transferred to the winning team through dialogue-based briefing processes. The dataflow between architects and social housing organisation apparently seems to be quite unstructured. In level 1, however is not yet visible if and how this LCC related knowledge is used by the architects.

DISCUSSION

Through the analysis, it is observed that in the DFD-level 1 of the case-project, there are few activities where LCC related data and knowledge from existing buildings are transferred to the design team. The discussion here, however, is focusing on the LCC related data that are stored after process (a) and specifically, the schedule of maintained payments that is part of the minimum requirements' report.

As a result of process (a), cost-related data are transferred explicitly to the design team through the 30-year maintenance payment schedule, which is part of the minimum requirements' report. As it mentioned-above the maintenance payment schedule includes LCC cost data for 18 maintenance activities that are expected to take place throughout the first 30 years of building's operation. According to Jensen (2012), this can be considered as codified knowledge from building operation that contributes to increase awareness among building designers. Since the social housing organisation provide this written specification report to the design team, it can be concluded that those cost data should be used by architects to drive the design of the new building, and therefore, they are fairly recognized as cost drivers.

However, the potentials of considering those cost drivers to inform the design of new project are not fully utilized in this case-study (data from the minimum requirement report are partially used in the competition process - dashed arrow in Figure 3). A reason for this might be the lack of criteria to evaluate the compliance of the competition project with the LCC related requirements in process (c). That indicates the lack of attention by social housing organisations to ensure that the design team will take consideration of the given data seriously. Another reason is that the design team fails to understand the value and the opportunities that are offered through this process.

However, answering the research question of this study, those cost drivers can be effectively used to inform the design of new projects. Firstly, the design team should propose alternative design solutions along with LCC calculation for a lifetime of 30 years including elements that their maintenance costs at the very least comply with the given maintenance schedule. In addition, by analysing the schedule of maintenance payments, the design team can also pinpoint the most critical cost drivers (the maintenance activities with the highest total cost throughout the 30 years) and propose alternative design solutions with lower LCC than expected. For example, in the case project's maintenance schedule report, the higher LCC in a lifetime of 30 years are related to the maintenance of the ventilation system, the paved/asphalt outdoor areas and the double-glazing units, indicating three critical cost drivers through buildings' operation. Those cost drivers of LCC can be used by the design team to inform the design of the new project, for instance, by proposing alternative design and maintenance strategies to improve long-term performance of ventilation systems, reducing the pavement in outdoor areas or designing solutions that can increase the lifetime of double-glazing units.

This is one activity that underlies valuable cost drivers of LCC that the architects may use to inform the design of the new project and propose solutions that are easy and affordable to operate and maintain. In addition, the case analysis reveals potentials also through other activities, for example through the inputs from external entities of process (d), where information from external actors about cost related performance or unexpected maintenance issues of existing social housing projects is communicated to the design team.

CONCLUSION

Life cycle costing has been proved to be a valuable decision-making tool for strategic facility management, considering life cycle perspective of buildings. Although several new initiatives have stimulated the increased use of LCC in the Danish AEC, its application in the design practices is still limited due to several challenges. One of the main challenges is the lack of available and reliable data, especially in early design stages. In order to overcome this challenge, research has proposed transferring information from the operation of existing buildings to the design of new buildings. Building client, facility managers and users are considered critical actors that can contribute on knowledge transferring.

This study focuses on social housing organisations in Denmark since they are at the same time the building clients and the facility managers of several residential buildings, as well as they have close relationship with the buildings' users (tenants). By using SA methods and specifically, data flow diagrams techniques, this study aims to identify how can data from existing social housing building projects with regards to cost drivers of LCC inform the design of new projects. To support the analysis, a social housing project from a Danish architecture firm is selected as the case project, and data are gathered through physical artefacts and five semi-structured interviews in both architects and building client organisations. The research data were used to create the DFDs of Level 0 and Level 1 of the SA system underpinned by their process descriptions. Through the analysis, it is observed that in the DFD-level 1 of the case-project, there are few activities where LCC related data and knowledge from existing buildings are transferred to the design team. However, the potentials of using this knowledge to inform design of new projects are not utilized by the design team.

The activity that is discussed in this study, refers to the outcome of the process of publication of a new project, where the social housing organisation publishes a payments' schedule of maintenance activities as part of the minimum requirements' report. The maintenance payments schedule includes yearly expected payments for 18 maintenance activities for the first 30 years of operation. Those activities are considered cost drivers for the operation of the building for the next 30 years, since the social housing organisation calls for a design that conforms to this payments schedule. In addition to that, by analysing the schedule of maintenance payments, the design team can pinpoint the most critical cost drivers (the maintenance activities with the highest cost) and propose more affordable design solutions with lower LCC than expected. For example, in the case project maintenance schedule, one of the most costly activities in a lifetime of 30 years is related to the maintenance of the ventilation system, so the design team can use this information as a cost driver and propose alternative design and maintenance strategies to improve long-term performance of ventilation systems and reduce the LCC that are related to the ventilation system.

The consideration of cost drivers of LCC when designing new projects will contribute on more sustainable constructions that are easy and affordable to operate and maintain. In future research, other activities that are disclosing potentials for identification of cost drivers with regards to LCC will be further analysed. Moreover, the authors will propose interventions in each of the processes of the SA system in order to ensure the integration of LCC in the processes of social housing projects contributing on better design of new projects with regards to LCC.

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