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Identifying Contradictions of Integrating Life-Cycle Costing in Design Practices

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Abstract

Purpose – The architecture, engineering and construction industry faces several challenges when performing life-cycle cost calculations. On the basis of activity theory, this study aims at improving our understanding of the current cost calculation in design practices as an activity system with a number of built-in contradictions.

Design/Methodology/Approach – Drawing on one of the authors' practical experience from a design office, the research design comprises a paradigmatic case study of a Danish architecture firm, in which data are gathered through documents, observations, interviews and physical artefacts. Moreover, this paper applies a literature review on barriers for adopting life-cycle costing.

Findings – The paper identifies a number of primary, secondary, tertiary and quaternary contradictions between practices of design, cost calculations and data management. Thus, hypotheses are formulated on how and to what extent these different contradictions shape cost calculations in design practices to obstruct or support the application of life cycle costing principles in design.

Research Limitations/Implications – This study is part of an ongoing research project. Thus, additional analysis is required before the authors may conclude on final results.

Practical Implications – This paper identifies a number of factors that obstruct or support the implementation of life cycle costing in current design practices.

Originality/Value – This paper provides new insights into the various contradictions that shape data management in architectural offices as a prerequisite for improving life cycle design practices.

Keywords Activity theory, Life Cycle Costing (LCC), Data management, BIM, Contradictions, Design practices

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1. Introduction

The increased interest for sustainable construction challenges the architecture, engineering and construction (AEC) industry to focus on not only the environmental performance of buildings but also the economic assessment of alternative solutions in the long term. The concept of life-cycle costing (LCC) is used as a decision-making tool in construction and proved its value for strategic management. Despite the increased literature on LCC in the past years, there is a gap between theory and practice, as the industry faces various challenges on adopting LCC in work practices (Cole and Sterner, 2000).

This study applies activity theory (AT) as a theoretical base for understanding the LCC calculation practices of a Danish architectural firm as the outcome of an activity system of building design with a number of built-in contradictions. AT has proven highly useful in studies of information systems and practices (Allen *et al.*, 2011). The cross-disciplinary framework of AT is currently used in the construction industry for describing and analysing the complexity and interaction in actions in projects and for development of tools and applications (Lu *et al.*, 2018). Studies include AT as a framework of redesigning work (Engeström, 2000); for identifying contradictions of using BIM in life-cycle construction projects (Hannele *et al.*, 2012); for identifying information sharing and interoperability issues (Allen *et al.*, 2014); for examining the use of BIM and corresponding issues in the construction site management (Maki and Kerosuo, 2015); for adoption of flow techniques in software development (Dennehy and Conboy, 2017); for developing information research system (Karanasios, 2018); and for analysing BIM use in building operation and management (Lu *et al.*, 2018).

Therefore, the present study investigates the following research question: "How does the activity system of building design facilitate or obstruct adequate life-cycle cost calculation among building professionals?" Through literature review and case study analysis, the study will identify and analyse the main contradictions that support or hamper LCC adoption in the AEC industry. AT is proven beneficial in this particular research as the identification and analysis of contradictions will help practitioners to understand the core causes of the problem and redefine their practices to include LCC (Bonneau, 2013).

2. Methodology

AT was initiated by the Russian psychologists Lev Vygotsky (Vygotsky, 1978) and Alexei Leont'ev (Leont'ev, 1978) in the 1920s and 1930s. The first-generation of AT focuses on the triadic relation between an individual (the Subject) and a raw material or problem space (the Object) mediated by Tools and signs (Miettinen *et al.*, 2009). Engeström expanded that triadic model by emphasizing the collective nature of human activity and introducing the terms Community, Division of Labour (DoL) and Rules as additional interacting key elements of the second-generation activity system (Engeström, 1987). Later, Engeström introduced a third-generation activity model in which at least two activity systems are interacting (Engeström, 2001).

Various terms and principles are used for understanding and analysing the human activity in an activity system, including the concept of contradictions. Contradictions are "historically accumulating structural tensions within and between activity systems"; however, they generate "disturbances and conflicts, but also innovative attempts to change the activity" (Engeström, 2001, pg. 137). In an activity system, there are four types of contradictions, namely, primary, secondary, tertiary and quaternary. Each of them describes the misfit within one or more element, between two elements, between different developmental phases of a single activity or between neighbouring activities, respectively

(Foot and Groleau, 2011). The identification of contradictions is essential as they are forces for motivation of a change and development (Engeström, 2001).

The research approach that is followed in this study for the identification of contradictions in the activity system of building design includes a literature review and a single case study analysis.

2.1. Literature review

A literature review was performed on current application of LCC in the industry with emphasis on barriers of limited adoption as well as the use of AT in relevant research. Studies were gathered by using Google Scholar and various literature databases. The main key words of the research were LCC in relation with implementation, barriers and use as well as activity theory.

2.2. Case-study analysis

A case-study approach is followed in this research, as case studies have proved valuable for handling "practice-based issues where the experiences of the actors are important and the context of actions is critical" (Benbasat *et al.*, 1987, pg. 369). The research design of this study comprises a paradigmatic case study (Flyvbjerg, 2006), where the case company is a Danish architecture firm. That firm is selected as a case study as (i) its type and size are fairly typical, (ii) the process applies a range of elements typical of cost calculations during design, and (iii) the firm and its projects expose central contradictions induced by LCC when applied in design. Thus, this single-case is particularly suitable for analysing the present research, allowing connections between constructs that will lead to theoretical insights (Eisenhardt and Graebner, 2007).

To identify patterns and contradictions in the current design practices of the case study, internal multiple sub-case analysis is used. Specifically, three case-projects are selected for analysis. To ensure maximum variation of case selection, the case selection criteria were based on the performance of LCC calculations. The first project is an extraordinary case, as successful calculations have been performed (Project A), the second project is a typical case, including typical calculation methods (Project B), while the third projects lacks LCC calculations (Project C). The present study draws on qualitative analysis of data from documents, direct observations, interviews and physical artefacts of the architectural firm (Yin, 2009).

3. Findings

The literature review and the case study identified a number of challenges with regard to LCC adoption related to all four types of contradictions in the activity system.

3.1. Primary contradictions

Primary contradictions are located *within* the central activity system in relation to the elements of: subject, tools and community.

Subject: In the literature review, Gluch and Baumann (2004) pinpointed the lack of understanding of LCC definitions and methods as a critical issue for the practical usability of LCC. This is confirmed in the case study analysis, in which it was observed that despite extensive initiatives on sustainability matters, only a small percentage of individuals working in the case company have the necessary knowledge to conduct an LCC analysis.

Tools: According to literature, there are a considerable number of tools for LCC calculations (Sørensen *et al.*, 2016). However, practitioners have difficulties finding accessible and reliable data required for the calculations (Underwood and Dehily, 2017). Although, in the case study, cost data are retrieved from a Danish cost database, the LCC practitioner of Project A remarked that those data differ from the data provided by EPDs.

Community: In the research by Olsson *et al.* (2015), the lack of knowledge on sustainability issues is recognized as an important barrier for limited adoption of LCC in the AEC industry. Through the case study analysis, it was recognized that many of the stakeholders involved in the projects, including major clients, showed little awareness on sustainability, and it was challenging to acknowledge the importance of LCC implementation. Moreover, through the literature review, it is also identified that there is limited understanding of the AEC industry on the benefits of using LCC in investment decisions (Gluch and Baumann, 2004), which is also confirmed in the case study analysis as several clients were considering only short-term costs.

3.2. Secondary contradictions

Secondary contradictions are located *between* the elements of the central activity systems especially between the elements: Subject versus Tools, Subject versus DoL and Subject versus Community.

Subject versus tools: The interviews in the case study analysis identified that the practitioners of LCC face difficulties in implementing LCC with regards to the available tools. The tools include the mathematical methodology but lacked automated procedures, requiring manual intensive work. In the case of Projects A and B, LCC users insert all data (material quantities, cost data, future maintenance activities, etc.) manually, spending much time and effort in generating results. An LCC practitioner in the case company characterizes the LCC calculations as “a complex and tedious task”. Thus, as it is also stated in the literature, the AEC industry lacks useable software (Goh and Sun, 2016) and the calculation of LCC is, currently, a time-consuming procedure, prone to human error (Fu *et al.*, 2007).

Subject versus DoL: In the case-study analysis, it was observed that the collaboration of the LCC practitioner and the rest of the project team was limited and not well structured. Specifically, in the case of Project A, it was observed that two LCC practitioners were involved in the calculations without having clearly divided tasks. Thereby, part of the procedure was executed twice due to the limited communication, while during that time, the communication with the design team was also limited. The LCC practitioners relied only on the information provided in the design model and were not aware about any change, thereby increasing the possibility of errors. The communication was still limited after the execution of the calculations as well as during the decision-making process.

Subject versus community: One additional contradiction of LCC application, which is identified in the literature and observed through the case study analysis, is the lack of standardized methodology for managing and exchanging life-cycle data (Monteiro and Martins, 2013). There is seldom information available about future maintenance activities, while manufacturers rarely provide guidelines for maintenance and renovation activities of the elements. Moreover, there is no standardized way of exchanging information between engineers, manufacturers and facility managers (Chiurugwi *et al.*, 2015). In the case study, the LCC practitioner of Project B emphasized that the LCC results are fluctuating depending on the price data that are used (data provided by either cost databases or manufacturers).

3.3. Tertiary contradictions

Tertiary contradictions occur when the object of a more advanced activity system is introduced to the central activity system, which was observed in this study between the elements of traditional design processes of the architectural firm and the current processes that include building information models (BIM) to facilitate LCC calculations.

The literature review noted that even though the use of BIM offers new technological opportunities for advanced life-cycle management (Xu *et al.*, 2014), there are still challenges in design practices to establish robust and reliable models (Edirisinghe *et al.*, 2017) because engineers and architects do not design the models with collaboration interchange in mind (Plume and Mitchell, 2007).

In the case-study analysis, contradictions with regard to design models and the use of BIM were identified in all case projects. In Projects A and C, the community resists using the BIM model, while in Projects B and C, the models lack reliable data for LCC calculation. More specifically, in Project C, 2D software was used by the project team to satisfy the need for highly detailed design, which is difficult to be represented by using 3D BIM software. However, 2D models do not include the appropriate information required for the LCC calculation, and thus, the implementation of LCC in those projects requires additional effort and time. Despite the use of BIM software in project B, the models are missing appropriate information, like the elements' materials, causing errors in the LCC results. Finally, in Project A, the stakeholders made use of software that does not support BIM models. However, for supporting the collaboration, the stakeholders conformed to the need of using BIM and thus facilitating the activity system of both model design and LCC calculation of the case company.

3.4. Quaternary contradictions

Quaternary contradictions occur between the elements of the central activity system and neighbouring activity systems, which were observed between the central activity of LCC application and the co-existing activities of project design in the architectural firm.

Through the case study analysis, it is recognized that even though the activity system of design practices has been improved in terms of information modelling to support the advanced requirements of LCC (BIM models are used in Projects A and B), the work allocation and work processes of co-existing design activities as well as the data management procedures have not been transformed yet to enable the decision-making process.

4. Conclusions

On the basis of a literature review and a case study analysis of a Danish architectural firm, this study uses activity theory to identify the factors that hampers or obstruct the implementation of LCC in design practices.

The findings pinpoint several contradictions in the activity system of design practices. In particular, the case study analysis revealed new insights to the limited adoption of LCC mostly related to secondary and quaternary contradictions. Specifically, the secondary contradiction between the elements of Subject versus DoL in the activity system expose that several errors in LCC calculation occur owing to the limited communication between the LCC practitioner and the design team as well as the unstructured division of tasks and responsibilities. Moreover, quaternary contradictions were observed when the activity system of work practices tries to move from design without to design with LCC calculations showing that the current way of collaboration and work allocation are barriers for realizing the benefits of LCC and impede its use as a decision-making tool for improved quality of design projects.

To conclude, the identification of contradictions may help AEC practitioners to understand the core causes of challenges in implementing LCC and redefining design practices, hence amplifying their motivation for change and development towards adoption of LCC in current design practices.

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