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Building design dynamics effects on implementation and use of LCC during DGNB certification

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Denmark has in 2019 stated a new climate law aiming to reduce the CO2 emissions. The sustainability certification Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) is suggested to facilitate the required change in building design by balancing environmental, social and economic sustainability. DGNB requires implementation of life cycle costing (LCC) and use of the LCCbyg tool to achieve the economic sustainability. Recent literature suggests that LCC is often used to document the decisions when the design is finished, therefore missing the potential of using LCC to ensure economic sustainability. The present study aimed to understand how building design dynamics affect the implementation and use of LCC during DGNB certifications, to discuss the potentials and limitations of implementing and using LCC in future DGNB certified building projects. The present study concludes missing objectives to lower LCC, resulting in late involvement of the auditor and separation from the building design only using the auditor and LCCbyg tool to document the decisions. Furthermore, the auditor must mask the cost in the LCCbyg tool to comply with the competitive nature of the building design. The results can potentially direct further study of regulative and normative actions to create a shared objective towards implementing and using LCC during DGNB certifications of buildings.

Abstract

Denmark has in 2019 stated a new climate law aiming to reduce the CO2 emissions, and buildings are causing a considerable amount of the emissions, therefore subject to change. The sustainability certification Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) is suggested to facilitate the required change in building design by balancing environmental, social, and economic sustainability. DGNB requires implementation of life cycle costing (LCC) and use of the LCCbyg tool to achieve the economic sustainability. However recent literature suggests that LCC is often used to document the decisions when the design is finished, therefore missing the potential of using LCC to ensure the economic sustainability. The present study aimed to understand how building design dynamics affect the implementation and use of LCC during DGNB certifications to discuss the potentials and limitations of implementing and using LCC in future DGNB certified building projects. The cultural-historical activity theory was used as the theoretical framework to design the qualitative interviews with Danish DGNB auditors and Swiss LCC consultants, furthermore a Danish DGNB certified building case study. The case study was based on semi-structured qualitative interviews with the designing architect, cost calculator, DGNB auditor, design and project manager. The case study found missing objectives towards lowering future cost and challenges of informing cost data between the initial and future owner. The present study concludes the missing objectives to lower LCC, resulting in late involvement of the auditor and separation from the building design only using the auditor and LCCbyg tool to document the decisions. Furthermore, the auditor must mask the cost in the LCCbyg to comply with the competitive nature of the building design. The results can potentially direct further study of regulative and normative actions to create a shared objective towards implementing and using LCC during DGNB certifications of buildings.

Foreword

The present thesis is made as completion of the master's in management and informatics in the construction industry. The thesis was based on interviews with Danish DGNB auditors and Swiss LCC consultants, together with an architect, cost calculator, design manager and project manager. I would like to thank the informants for explaining their praxis experiences of implementing and using lifecycle costing in DGNB certificated building design. The informant's helpfulness and interest in the thesis has made it possible to understand how DGNB and building design are dynamically shaping each other and how lifecycle costing is implemented and used.

I would like to express my gratitude to my supervisor Kim Haugbølle for supporting me with professional and passionate supervision and helpfulness throughout the process of writing the present master thesis. Furthermore, I would like to thank the Danish construction knowledge center Molio for allowing me to participate in the LCCbyg course and DK-GBC for answering my questions regarding DGNB. Lastly, I would like to thank the research group at Aalborg university's BUILD department for conducting the education management and informatics in the construction industry. The master study has developed my professional and personal knowledge and made me understand the construction industry as a socio-technical interrelated system in which both technology and humans are reciprocally shaping each other and the surrounding context.

Table of content

1. Introduction

The world is experiencing climate changes caused by human pollution and the use of natural resources (World Meteorological Organization, 2020). Denmark has stated an ambitious climate law to lower the CO2 emissions by 70 percent before 2030 (Regeringen, 2019). Construction of buildings and the later use and maintenance have a high political interest because of the high amount of CO2 emissions (Transport&Boligstyrelsen, 2020b). The building design is when decisions about materials and solutions are defined, thereby defining a period where important decisions are made, with possibility to affect the CO2 emissions (FRI, 2019). The Danish Building Regulations are framing building design but have currently limited sustainable measures focusing on energy and indoor environment in recent years (Trafik-bygge-Boligstyrelsen, 2020a). Danish building owners and investors can go beyond the building regulations and argue a higher sustainability level by using volunteer sustainability certifications. Green building council Denmark (DK-GBC) adopted in 2012 the German sustainability certification Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) to the Danish norms and regulations (DK-GBC, 2020c). The DK-GBC-members, including public and private investors and architectural engineering and construction (AEC) companies, create an interdisciplinary network shaping Danish sustainable building design norms. DGNB is approaching sustainability with a holistic view balancing environmental, social, and economic parameters. A DGNB auditor is assigned to implement the multiple criteria into the building design and after that document, the level of fulfilment measured in bronze, silver, gold, and diamond (DK-GBC, 2020c).

Economic sustainability is crucial, as the building lifecycle's use and maintenance are causing approximately 80 percent of the life cycle cost (Dansk Facilities Management netværk, 2018) (Bygherreforeningen, 2018). If sustainable buildings are too expensive to use and maintain, the investors cannot afford to invest in sustainable buildings. DGNB promises that the certification differs from other sustainable certifications by including economic life cycle costing (LCC) (DK-GBC, 2020c). The DGNB auditor must calculate LCC with the digital tool LCCbyg and incorporate the results during building design. In contrast, the Danish Building Regulations do currently not require LCC, therefore, implementing LCC processes and tools in building design is a change of design praxis (Brunsgaard, 2016). LCC is calculated based on cost and quantities from the building design, thereby requiring corporative praxis. The building design process has undergone multiple changes, traditionally done by hand drawings and computer-aided design (2D CAD), but the last years changed towards using 3D building information models (BIM) (Transport&Boligstyrelsen, 2019). The BIM models can simulate the buildings in 3D and consist of both cost and quantity data, which is suggested to improve LCC implementation in the building design (Transport&Boligstyrelsen, 2019).

Crossdisciplinarity corporation makes the building design coordination highly complex, and the DGNB auditor must interact with different disciplines to incorporate LCC as part of the early decision making with (Collin et al., 2019). DGNB have achieved political and institutional expectation of ensuring sustainable buildings with LCC incorporated in early decision making, however recent literature suggests challenges. LCC is often not used as a methodology to inform the decision-making but as a tool to document decisions when building design is finished (Collin et al., 2019). Implementing LCC to document decisions after the building design is finished is also one of the most time-consuming tasks for the auditor (Selman et al., 2018). Brunsgaard describes a need to develop methods and further research in why LCC is often used in the final stages of design and not implemented to inform decision making (Brunsgaard & Bejder, 2017). The use of LCC as a documentation tool is not considered satisfying for the holistic DGNB promise to balance environmental, social, and economic parameters (Landgren & Jensen, 2018). There is a risk that the environmental and socially sustainable design will be extremely expensive to use and maintain if LCC is not considered. This emphasises the importance of considering the future cost of buildings and not only the initial cost, to ensure that buildings are economic, environmental, and social sustainable. Saridaki & Haugbølle describes multiple contradictions when LCC is implemented in building design and suggest research to understand the cooperative dynamics (Saridaki & Haugbølle, 2019). There is a need to create a further understanding of the contradictions and why LCC is often not used or considered in the early design process of DGNB certified buildings.

The present study objective is to understand the building design dynamics and its effects on the implementations and cooperative use of LCC. The study will use third-generation cultural-historical activity theory (AT). AT is useful for analysing dynamics between cooperate praxis and understand possible contradictions between rules, division of labour objectives, and the tools used to mediate the activities (Engeström, 2001). The present study was initiated with preliminary interviews with Danish DGNB auditors and Swiss DGNB consultants to understand LCC implementation and uses in a cultural, historical, and international perspective. The preliminary interviews were used to design and direct a Danish non-public DGNB certified office building case study. The case study was conducted with the use of qualitative interviews with five informants from the building design team, including architect, cost calculator design manager, project manager and the DGNB auditor.

2. Research question

How does building design dynamics affect the implementation and use of LCC during DGNB certification?

2.1 Research objectives

- Characterise how LCC was implemented and used in the design of a Danish DGNB certified building.
- Understand how building design dynamics were shaping implementation and use of LCC during the design of a Danish DGNB certified building.
- Discuss the potentials and limitations of implementing and using LCC in future DGNB certified building design.

2.1.1 Problem delimitation

The present study was focusing on the early building design, often consisting of architectural design solutions therefore was the technical installation and engineering departments not included in the data collection. The study of interest was the dynamics between building design actors and the DGNB auditor and therefore was the building owner, future investors, and tenant not interviewed. The present study is based on the DK-GBC 2016 DGNB manual because the case building was DGNB certified between 2016-2020.

3. State of the art

The state of the art section will introduce relevant concepts, terms, and information about the use and implementation of LCC and DGBN certifications, to create a deeper understanding and justification of the research question. First, will the LCC methodology's history and use be described, followed by an introduction to the fundamental concepts behind an LCC calculation. The standardised Danish and Swiss LCC tools will be presented. Furthermore, will DGNB and the specific LCC requirements will be introduced to understand the particular context the LCC methodology and the LCC tools are implemented and required in the present case study. Lastly, will the historically opportunities and limitations in using LCC during DGNB certifications be introduced.

3.1 The LCC methodology

LCC was introduced to the building design in the early 1960es by the US Défense as a methodology to evaluate the initial and future cost during the ownership of buildings (Marshall, 1987). LCC was further implemented in non-public building investment during the 1980s because the oil crisis required the building design to reduce the energy cost during ownership (Goh & Sun, 2016). The rising focus on energy savings was combined with an increasing environmental focus during the 1990s, resulted in new sustainable certifications and the use of LCC as a methodology to balance the environmental and social paraments of building design with the economic considerations during the building ownership (Goh & Sun, 2016).

LCC is a methodology to evaluate both the initial and future buildings' cost (Marshall, 1987). Buildings LCC is affected by multiple parameters such as building constructive solutions, the lifetime of the materials, and how expensive it is to recover and maintain the materials. The largest LCC expenses are often caused by the activities the buildings are designed to facilitate (Haugbølle & Raffnsøe, 2019). The buildings' flexibility and adaptability, together with the use and maintenance, should be part of the early LCC considerations in collaboration with the future owner and users (Haugbølle, 2016). The multiple parameters make the LCC methodology a cooperative activity combining cognitive skills and mathematical formulas (Sterner, 2000). The LCC methodology can include evaluation of the whole building or separate building components as the basis for design and procurement decision making (Ellram, 1993).

Multiple professions and organisations are part of the building design process, and are all delivering design solutions, making LCC a cooperate activity requiring close collaboration and communication (Cole & Sterner, 2000). Implementing LCC during early building design is suggested to change design praxis, traditionally focusing on the initial cost (Larsson & Clark, 2000). The building owner must understand the advantage of implementing LCC and pay the extra design cost towards lowering LCC during the long-term ownership (Cole & Sterner, 2000). Cole & Sterner describes the owner must state the LCC objectives contractually for the building design team (Cole & Sterner, 2000). LCC implementation's contractual agreement must define when LCC is implemented and used during design and to what detail level. The LCC calculation for a whole building is time-consuming (Bogenstätter, 2000). Therefore, small components of the building are suggested to be more realistic to calculate during the early building design (Cole & Sterner, 2000).

3.1.1 Implementation of LCC

Ellram describes that LCC is a philosophy and a change process that must be adopted by the top management; implementing the knowledge of the LCC methodology as a philosophy during the early design is the key to informing decisions regarding lowering LCC (Ellram, 1993). The building design is traditionally divided into phases initiated and finished with contractual deliveries. The timing of implementing LCC into the design phases has been argued of high importance (Bird, 1987). Larsson & Clark describes three main uses of LCC: 1) planning, conducted in the early design phases, 2) analysis, and 3) management, documenting the building LCC when the design decisions is taken (Larsson & Clark, 2000). Design solutions are discussed in the early phases, drawn on sketches and written in building programs, and it is therefore possible and relatively cheap to change the design and to evaluate multiple options (Samani et al., 2018). Norman argues that at the end of the concept and definition phase, over 70 percent of the decisions are locked, it is therefore in the initial phases the largest possibility to affect and plan the LCC (Norman, 1990).

Furthermore, Norman argues that 90 percent of the LCC is decided when the design and development phase is finished, leaving the limited possibility to influence the LCC after the design and development phase (Norman, 1990). If the LCC calculation is applied during the later phases, it would be to document the building LCC not influencing the design. The possibility to affect the building is in the early phases, and the LCC planning should, therefore, be conducted as an integrated part of the building design team (Norman, 1990).

3.2 LCC calculations

An essential part of the LCC methodology is the LCC calculations to inform the decisions makers about the LCC consequences of the building design (Gluch & Baumann, 2004). The LCC methodology is including multiple cooperative processes such as defining what should be part of the LCC calculation, the collection of data, and performing the LCC calculation, after that the evaluation and implementation of the results (Harris & Fitzgerald, 2017). The LCC calculations can be divided into two different detail levels, the whole building LCC or building component LCC. The details level decisions define how much data there must be included in the calculations and therefore how much data there must be collected, calculated, analysed in the LCC calculations (Haugbølle, 2016). The following will describe the concepts, detail levels, and necessary data included in the LCC calculations.

3.2.1 Whole building LCC

The whole LCC calculation includes most of the expenses caused by the initial construction and during the building's lifetime. The whole LCC are including data from multiple cost groups such as Initial construction and site costs, Initial consultant costs, recovery costs of building components, operating and maintenance, including cleaning and supply costs (DK-GBC, 2020b). The LCC data is spread to multiple professions and organisations, making the data collection a highly interdependent cooperative process (Brunsgaard & Bejder, 2017).

3.2.2 Component LCC

The Component LCC calculation often includes comparison of two or more alternative building components to define which one has the lowest cost during the lifetime of the building (Haugbølle, 2016). Component LCC includes some of the same cost groups as the whole LCC, but because the LCC calculations are done on specific components, the data collection is much faster. Component LCC can be done during the early design when the primary building components such as façades, roofs, and floors are suggested and is recommended to be made as components LCC calculations (Harris & Fitzgerald, 2017).

3.2.3 The quantity data

The quantity data is important for the LCC calculation and must be collected from the multiple professions and organisations during the building design. The quantity data collection of the whole LCC is naturally much more time consuming than the component LCC data collection (Haugbølle, 2016).

3.2.4 Calculation period

The calculation period is defining how many years the LCC calculation should include. Investors will often evaluate if the building investment is profitable in a specific period called the investment horizon (Haugbølle, 2016). Some investors are expecting to own buildings for five years and others 100 years, the calculation period is central because it defines how much future cost the LCC calculation should include.

3.2.5 Initial costs

The initial cost is among other the design and construction cost of the building. LCC calculations can be used to evaluate if it is profitable to pay a higher initial cost and then save money during the building's ownership. The initial cost data can be collected from the building budgets and bidding documents, or it can be estimated based on experience or by using generic cost data in Denmark available from the V&S price books (Haugbølle, 2016).

3.2.6 Future cost

The building's future cost is an essential part of the LCC. The LCC calculation often considering the lifespan of building components and the supply, recovery, operation, use, and maintenance cost. To evaluate LCC, the future cost must be calculated back in time in today’s prices, the method is called discounting to a net present value (NPV) (Haugbølle, 2016). The discounting of future cost to NPV is done with a mathematical formula based on a discount rate percentage. The sum of all the future costs to an NPV at a specific time, will inform the building owner how much money it is necessary to put aside for being able to pay the future costs (Haugbølle, 2016). The NPV sum can also be divided as an annual cost to evaluate how much money the owner must expect to pay every year. Development of future cost of energy supply, materials, and the labour cost of cleaning and maintenance greatly influences the LCC. The discount rate includes the expectations of cost development by including inflation, the interest of bank loans, and risk (Haugbølle, 2016). Combining initial and future costs to a total NPV sum makes it possible to compare building components or the whole buildings LCC with other buildings.

Lifespan and recovery rates

The building components' lifespan defines when there must be made costly recovery of the components and have a high influence on the future cost of the building. Buildings can often last 100 years, but the building's future cost depends on when components must be changed (Aagaard, 2013). The Danish research institute (SBI) has developed generic lifespan values of the most used materials, the lifespan values can be uses in the LCC calculations (Aagaard et al., 2013). The recovery cost can be estimated based on experience, or it can be defined as a percentage of the initial cost (Haugbølle, 2016).

Operation and maintenance cost

The LCC calculation must include the future cost of operating and maintaining the building and its components. It can often be difficult to accurately define the cost data on operating and maintenance of the building, and the cost has, therefore, a high uncertainty. The operation and maintenance cost can be estimated based on experiences data, or it can be defined by generic cost data from the V&S price books as a percentage of the initial cost of the building components (Haugbølle, 2016). When building components operating and maintenance costs are compared with the initial cost, the initial cost is often only constituting a small proportion of the total LCC. For example, cleaning is usually not part of the design consideration but expensive during building ownership; therefore, it is an essential part of the LCC calculation (Haugbølle & Raffnsøe, 2019).

3.2.7 LCC data uncertainty

When LCC is implemented in the early design phases to compare alternative solutions, there is often a limited amount of data available (Arja et al., 2009). The limited amount of data requires estimating of the cost and quantity data, based on previous experience or generic cost data (Flanagan et al., 1987). Marshall describes a resistance towards LCC use in early building design (Marshall, 1987). Uncertainty and low trust in the LCC calculations have been described as historical limitations in LCC use (Flanagan et al., 1987). The building design including multiple professional disciplines delivering their part to the design, the interrelated dependency creates a natural data uncertainty integrated into the design praxis (Dwaikat & Ali, 2018). The LCC methodology is based on using the data uncertainty as an advantage, the value of the LCC methodology is suggested to be the teamwork and collaborative task of discussing future LCC, not only the results of the LCC calculations (Gluch & Baumann, 2004).

"[…] An indirect benefit from performing LCC for a building investment decision is that it may not be the actual monetary figures that provide the decision maker with insight, but instead the actual involvement in the process of carrying out LCC […]" (Gluch & Baumann, 2004).

The suggested value of LCC as the cooperative activity of discussing the future cost should encourage the use of LCC as a collaborative activity and not an isolated LCC calculation. The LCC calculations can initiate discussions among the design team about future cost, cognitive skills, and the cooperation of preparing, analysing, and implementing the results is the LCC methodology's values.

It has been suggested to develop LCC tools that standardize the LCC methodology and calculation methods so that it is possible to compare the LCC performance of buildings (Cole & Sterner, 2000). The following pages will present the Danish and Swiss LCC tools there have standardized the LCC calculations. The two LCC tools is required to be implemented and used in the building design of Danish and swiss DGNB certified buildings.

3.3 LCC tools

3.3.1 IFMA LCC

Swiss Sustainable Building Council (SGNI) is the Swiss DGNB council established in 2010 (DGNB GmbH, 2020). Like the Danish DK-GBC, the SGNI council is a non-profit organization composed of multiple members of the country's AEC industry. The members contribute to adjusting the DGNB certification manual to the country-specific norms and regulations (DGNB GmbH, 2020). SGNI requires, like DK-GBC, the use of a specific LCC tool, the required LCC tool is developed in cooperation between SGNI and the International Facility Management Association (IFMA) (DGNB Schweiz, 2020). IFMA is one of the world's largest facility management organisations, with many thousand members worldwide (IFMA, 2020). IFMA Swiss chapter developed in 2011 the LCC tool called IFMA LCC (IFMA, 2011). To standardise the DGNB LCC calculations SGNI required the use of the IFMA LCC tool to document the building LCC during Swiss DGNB certifications (DGNB Schweiz, 2020). The IFMA LCC tool is Excel-based and the LCC calculations can be made in different detail levels based on the building design phases development (IFMA, 2011).

3.3.2 LCCbyg

In 2013, the Danish government stated the requirements of using LCC in public building design. The LCC implementation in Denmark was made by using multiple Excel-based LCC calculation tools. The use of multiple LCC tools and methods can make the results difficult to compare (Cole & Sterner, 2000). To standardize the LCC calculations and methods sponsored the Danish ministry of traffic building and housing in 2015 the development of the LCCbyg tool (Haugbølle, 2020). LCCbyg is updated several times a year to ensure that the LCC calculations are made based on the newest standardised data model and structure to facilitate LCC comparison and benchmarking (Haugbølle, 2020). In 2016 DK-GBC required the use of LCCbyg in all Danish DGNB certified buildings, and

LCCbyg has, therefore, a DGNB template prepared for the required LCC calculations (DK-GBC, 2016).

The LCCbyg calculation

The LCCbyg tool can be used to calculate LCC for the whole building or components of the building (Haugbølle, 2016). The first step of the LCCbyg calculation is, therefore, to define what the calculation should include. The LCCbyg tool is divided into the three main pages data entry, prerequisites, and rapports shown in figure 1. The data entry page consists of the top bar in which it is possible to define the different LCC alternatives or building components followed by the calculation period. At the data entry page's right side is the cost groups structured after the Swedish SFB classification system. The cost groups consist of predefined building components; there can be dragged and dropped to the middle of the data entry page. The components and cost groups consist of predefined future cost calculation values. In the middle section is the building components quantity and initial cost data typed. The bottom part of the data entry page consists of the predefined values of building components to calculate the future cost, including the lifespan, recovery rates, operation, and maintenance data. The lifespan data is based on, SBI lifespan table from 2013, the recovery rate is predefined to be 125 percent of the initial cost (Haugbølle, 2016). Operation and maintenance costs are also predefined values in the building components in LCCbyg based on the Danish V&S price books (Haugbølle, 2016).

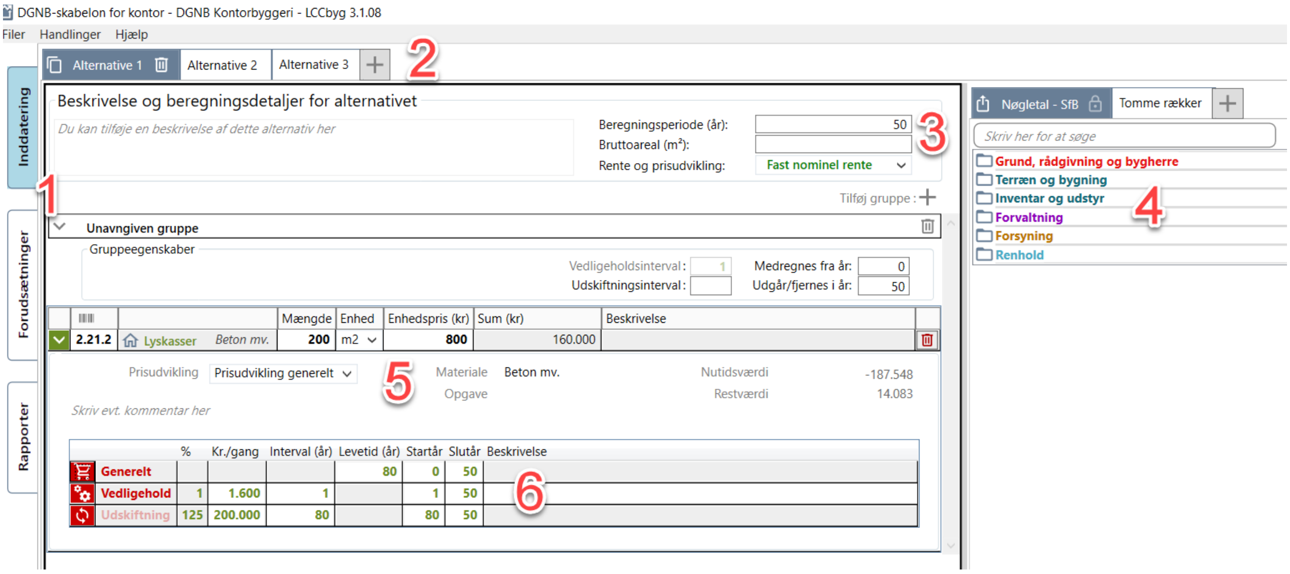

Figure 1: LCCbyg user interface. Note: 1. Data entry, prerequisites and rapports. 2. Alternatives. 3. Calculation period, gross area and the interest and price development assumptions. 4. Cost groups 5. The building components quantity and initial cost data. 6. future cost Lifespan, recovery rates operation and maintenance data. Own LCCbyg calculation based on (Haugbølle, 2020).

LCCbyg calculation report

The results of the LCCbyg calculation can be presented in multiple diagrams. Figure 2 describes an example of three façade alternatives over a 50 years calculation period, where the colors in the columns indicate different cost. Blue initial cost, yellow operation and maintenance, grey recovery cost and orange cleaning cost. The comparison in figure 2 shows that alternative two has a 17 million DKK lower NPV than alternative three during the 50-year calculation period, mainly caused by a lower cleaning cost. The comparison is an example of how different cost groups get visible and comparable when calculated back in time to NPV. The auditor could inform the building design team about the LCC results when choosing the building façade.

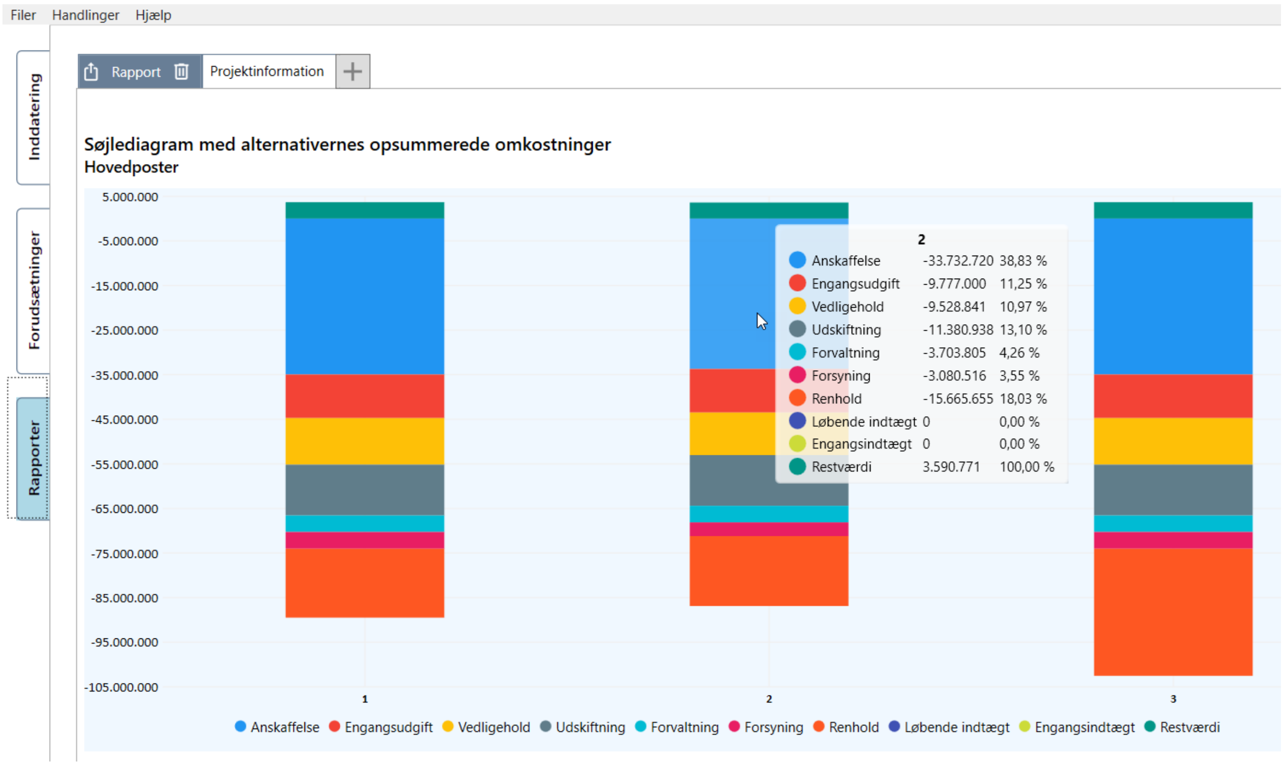

Figure 2: LCCbyg calculation report of three façade alternatives, own LCCbyg calculation based on (Haugbølle, 2020).

3.4 DGNB

DGNB is a methodology to plan and, after that, document the sustainability efforts of buildings. The process breaks the traditional interfaces between professions and organizations and requires collaboration across the design teams. The national DGNB councils educate DGNB auditors to implement, manage, and document the DGNB certification process (DK-GBC, 2020c).

3.4.1 Holistic sustainability

The DGNB certification is based on the United Nations RIO declaration balancing sustainability between social, environmental, and economic parameters (DK-GBC, 2020c). The DGNB qualities are divided into five key areas: Social, environmental, economic, technical, and process, with individually weighted percentages. **Social 22.5%,** indoor environment, safety, accessibility, and architecture. **Environmental 22.5%,** energy and water use, natural resource, and waste handling. **Economic 22.5%,** LCC and security of the financial future of the building. **Technically 22.5%,** fire safety, acoustic, material quality, and the technical system's performance. **Process 10%,** the implementation of DGNB in the planning, design and construction phases (DK-GBC, 2016).

3.4.2 Sustainability on a formula

The five DGNB qualities are further divided into 40 sub-criteria's, each with specific objectives of fulfilment measured in a percentage. The evaluation of the criteria's is made based on a checklist with points, written in an evaluation matrix. The overall degree of fulfilment is presented as silver, gold, and platinum, requiring 50 %, 65%, and 80% fulfilment, respectively. A precertification can be used during the early design process to ensure that the building will fulfil the criteria. The results of the DGNB certification are used to benchmark the building and define a common definition of how sustainable buildings should perform (DK-GBC, 2016).

3.4.3 Calculation and documentation tools

The DGNB certification is a complex process for the auditor to understand and manage. The ongoing design changes are shaping the contexts of the solutions and the derived consequences regarding sustainability. To continually inform the design management, the auditor must calculate and document the fulfilment level with multiple calculation tools provided by the DGNB councils. The DGNB auditor must balance the multiple criteria's and use different tools incorporated in the design praxis, and document them in the evaluation matrix (DK-GBC, 2016). DK-GBC requires the use of LCCbyg, and SGNI requires the use of IFMA LCC to document economic sustainability during DGNB certifications.

3.4.4 Economic sustainability

Economic sustainability is counting 25 % of the overall DGNB score, and the main objective is to minimize the LCC of the buildings. The Danish DGNB manual 2016-2020 was dividing the economic sustainability evaluation between the following four sub criteria's: **ECO 1.1 LCC (9.6%),** consisting of LCC calculations using the LCCbyg tool. **ECO 2.1 Flexibility and adaptability (6.4%)** ensure the building can be changed and adapted to tenant and owner requirements throughout the building lifetime. **ECO 2.2 Robustness (6.4%)** ensures the materials are made robust and chosen regarding the use and environmental wear and tear without causing high future cost for the owner. The Flexibility, adaptability, and robustness will influence how much the building is costing during the ownership and is therefore highly interrelated with the LCC methodology. Besides the ECO criteria's the sub-criteria **PRO 1.3** contributes as 1.7 % of the total DGNB score divided between 8 different process initiatives, including early LCC assessment of alternative components (DK-GBC, 2016).

3.4.5 ECO 1.1 LCC Requirement

The ECO 1.1 criteria require using LCCbyg to make a whole LCC calculation over a 50-year calculation period with a 5 percent discounting rate (DK-GBC, 2016). The ECO 1.1 whole LCC calculation should include the initial site, construction and consultant costs. The initial cost should be based on unit prices from the bidding/tender documents and the construction accounts (DK-GBC, 2016). The collection of initial cost data requires the auditor to cooperate with the turnkey contractor to collect the building's cost data. The future cost exclusive supply is calculated based on the initial cost and part of the DGNB LCCbyg template, including recovering, operating and maintenance, and cleaning cost by the predefined values and methods previously described LCCbyg section (DK-GBC, 2016). The auditor must document and calculate the LCC based on the quantity of building components, and area data, including gross, net, and cleaning areas. The LCCbyg results give a total NPV sum compared with a DGNB specified reference values in a DGNB evaluation matrix. It is not required to do LCC calculations during pre-certification. The ECO 1.1 is performance-based, if the LCCbyg calculation fits within the DGNB reference value, it can be approved. To earn the maximum of 100 checklist points, the building NPV must be 50 percent lower than the reference value defined in the DGNB evaluation matrix (DK-GBC, 2016).

3.4.6 Implementing and using LCC during DGNB certifications

DGNB is introducing new regulations, norms requiring a change of the traditional design praxis. LCC is suggested to be another way of thinking about design by including the future cost in the design considerations. The DGNB auditor must manage the implementation of LCC together with multiple other DGNB criteria's making the implementation a considerable interruption of traditional design praxis (Brunsgaard & Bejder, 2017).

The LCC tools are designed with a purpose and understanding of how the LCC activities should be performed. The LCC tools are possibly interrupting the traditional building design activities, and there is a need to analyse the LCC implementation and use of the LCC tools (Collin et al., 2019). The DGNB auditor cannot perform the whole LCC alone, there must be interaction with multiple actors from the building design team. The unit of the present study analyse is, therefore, the cooperative LCC activity. The present study will expand the view of LCC implementation and use from the individual actor level to understand the historical and social context of design praxis as a cooperative system of activities.

4. Activity theory

This section will introduce the present study theoretical framework, Cultural-historical activity theory (AT), including the key concepts and terms. The section aims to create an understanding of why AT was chosen as an analytical framework to understand how building design dynamics affect the implementation and use of LCC.

AT is a theoretical framework used to analyse human individual and cooperative activities (Johansen, 2002). AT is developed in Russia in the early 1900s by the Russian psychologist Lev Vygotsky and aiming to understanding human activity as shaped by the social and materialistic context, it is performed within (Johansen, 2002). The initial focus was on how tools mediating individual activity towards an objective. The tools are central in AT and include physical and mental artifacts mediating activities towards objectives. Vygotsky died in 1934, and his student Leontjev was educated to develop AT further. Leontjev realised limitations in the narrow focus on individual activities and changed the AT focus towards understanding activities as shaped by cultural and social stimulation (Johansen, 2002). The Finish professor Yrjö Engeström developed in the 1980s a revised third generation of AT and included the division of labour, rules, and social communities as important social mediators of human activities shown in figure 3 (Johansen, 2002). Engeström introduced the understanding of activities as multiple systems interrelating during cooperative activities towards shared objectives (Engeström, 2001). Recent literature suggests the AT as a useful theoretical framework to study building designs corporative activities when culturally developed tools are introduced (Bonneau, 2013).

4.1 Activity systems

Engeström developed a third generation of AT theoretical framework and depicted the concepts in a triangle model shown in figure 3. The model consists of the subject, which is the person or group conducting an activity towards an objective, the top of the triangle is the mediating artefacts developed or used to achieve to objective (Engeström, 2001). The bottom part of the AT triangle is the social mediation of the activity systems, including rules, community, and division of labour, all socially mediating the activities' patterns and interrelated shaping of the activity systems dynamics (Foot et al., 2014).

The third generation activity theory can facilitate analyse of the dynamics between the different interrelated and collaborative activity systems (Engeström, 2001). In-between the activity systems, there is an invisible room where the social worlds meets and collaborate to frame the objectives and possibly reframe new meanings (Engeström, 2001). The analysis between two or more activity systems makes it possible to analyse inter-organizational challenges between activity systems. The activity theory can be used to realize patterns and systems in the human behaviour, Furthermore, the relations between the objectives (Engeström, 2001). Language is one of the tools to mediate between the activity systems, therefore, an essential object to analyse because the language can create systems of changing and transforming the specific discourse between the activity systems (Bonneau, 2013).

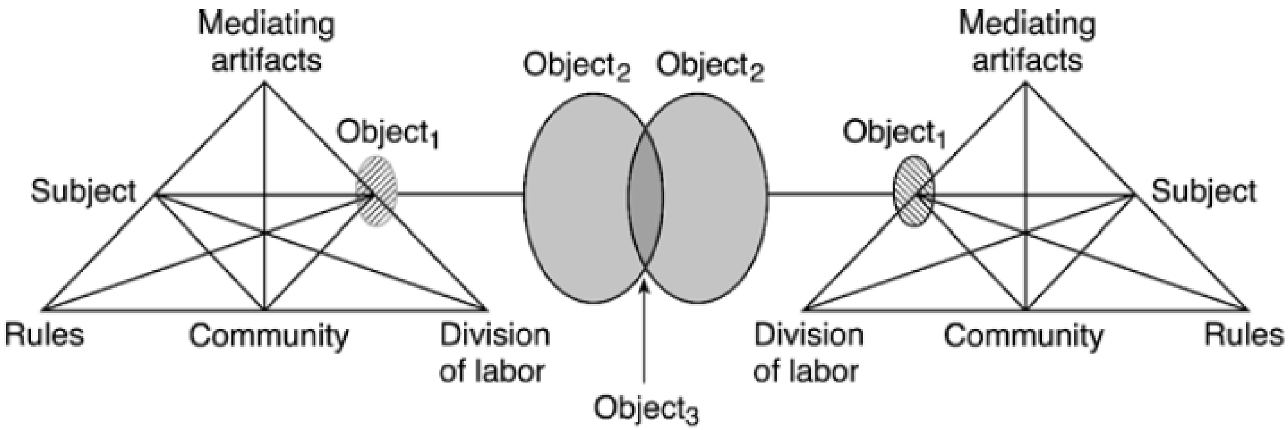

Figure 3: Interacting activity systems (Engeström, 2001).

4.2 Activity theoretical concepts

The AT framework used in the present study consist of multiple concepts there will be further described in the following.

Objectives

The objectives initiate collective actions, and cooperative work and can be shared between the activity systems. Dynamics in the activity systems are grounded in the social practice and shaped by the socio-historical influence on the objectives. The objectives are dynamic and can change over time because humans understand objectives from different perspectives (Engeström, 2001).

Tools

Tools are the mediating artifacts inside and between the activity systems. The tools are historically developed and based on the cultural and social context, shaping the human's activity in an interrelation of reciprocally shaping (Engeström, 2001).

Rules

The rules are the mediating boundaries framing the regulative constraints of the activity. Society can often shape the rules the activity is acting within. Rules can regulate the use of a mediating tool, and all other part of the activity systems, a new rule can change the activity systems (Engeström, 2001).

Community

The community is a multi-voiced system the activity systems integrate with during the cooperative activity. The Community has a mediating social effect on the activity system, it can shape the norms, traditions, and formative rules affecting the individual and social praxis traditions (Engeström, 2001).

Division of labour

The division of labour reflects a social praxis tradition. If there are changes in the activity system, the traditional roles can be displaced, and new divisions of labour are made. The activity system is dynamic, and replacement of tools can cause a change in the division of labour. (Engeström, 2001).

The AT concepts are highly interrelated, a change in the rules can affects the tools, or a norm in the community can influence the creation of a new rule which might affect the division of labour. In between the AT concepts and activity systems, multiple dynamics are continually shaping the activities and objectives, making the study of all elements important and not only focusing on one of the AT concepts (Engeström 2001).

4.3 Contradictions

The activity systems are connected and often entangled social systems, and contradictions between the activity systems can initiate change and innovation (Engeström 2001). Repeatedly interventions of actions are part of the dynamics in the activity systems. Interventions in the socio-historic institutionalized practices can cause internal or external tensions between the activity systems (Engeström 2001). The tension can cause human cognitive processes to search for changes or improvement of the situation. Contradictions are not damaging; instead, the room where parts of the activity system can shape a possibility for improvement so that the activity system's objectives can be reached (Engeström 2001). The change process can take days or many years, but contradictions can be the initiator to shift of the situation. Both the discursive in language and materialistic mediators are subject to analysing contradictions (Engeström 2001). Analysing contradictions makes it possible to understand how humans interact and how they change their mediating materialistic tools towards fulfilling the objectives. The patterns of the interactions, communication, and management styles are part of the analysis and understanding of organizational changes (Engeström 2001).

The activity system is not closed from the outside, power dynamics shapes the transformative process (Engeström 2001). For example, a new rule is introduced, causing the tools to be changed or shaped differently. The contradictions are a researcher's window to understand where there is room for improvement in the socio-historical practices, and innovations can be initiated. Foot et,al describes four levels of macro to micro dynamics, these will potentially be overseen by looking at contradictions as one hole (Foot et,al 2014). Opening contradictions and studying them at different levels makes the analysis much more in-depth and visualizing the dynamics. By studying the tensions between the four levels of contradictions, it is possible to make descriptions and an understandable presentation of the contradictions' reasons and relations. The reconstruction and representation of the contradictions can reshape the activity systems and the systemic analysis of contradictions can forecast and predict future challenges in the activity systems (Engeström 2001).

4.3.1 Primary contradictions

The primary contradictions are based on the tension in the capitalistic society between value and exchange value (Foot et,al 2014). The tension arises because everybody in the society has an embedded value and, at the same time, the trading value is shaped by the socio-economic dynamics (Foot et,al 2014). Primary contradictions could arise in an analysis of the activity systems of banking companies and clients. The bank advisor helps the clients in their investment, there is trust between the client and the advisor. At the same time, the bank is earning money from an interest in bank loans.

The bank pays the adviser a bonus for each loan while having a financial benefit for making the client make the loan as large as possible. The client is a source of income for the bank advisor and part of a socio-economic system that trades his service for financial compensation regarding the interest rate that enables the bank to sustain its operations. The bank advisor is potentially prone to socio-economic dynamics between the objectives to make the loan as high as possible ensuring profit for himself and the bank while his professional objective is to make good advisory for the client.

4.3.2 Secondary contradictions

The secondary contradictions are often related to the primary contradiction and placed between different involved parts of the activity system (Foot et,al 2014). If the above example is continued, the bank could, because of public critics, make a rule that demands the advisor cannot receive a bonus linked with the number of client loans he can sign. This could make a contradiction between traditional work praxis and the new reshaped praxis. The bank advisor could potentially change objectives from signing new loans with high interest towards making the best loan for the client with low interest.

4.3.3 Tertiary contradictions

The tertiary contradictions can arise when new objectives are integrated into the existing activity systems, the new objectives are often introduced to change previous secondary contradictions (Foot et,al 2014). During this tertiary contradiction phase, there is often reformulated new objectives, and a more extensive change process is transforming and reshaping the dynamics of the activity systems (Foot et,al 2014). It can be members of a cooperative activity system introducing their objectives into other activity systems, the change can possibly displace the management and power of having control (Engeström 2001). The previous role for the bank advisor was a seller of loans, the promotion was more significant if the interest of loans were high. New objectives could be introduced to the activity systems if the bank shifted strategy towards another advisory style and promoted the bank advisor based on client satisfaction. The new objective could possibly change the division of labour, there might be fewer selling objectives, and the bank management chooses the more social understanding advisors. Displacement of objectives and roles can make the activity systems undergo large displacements. The shift from selling loans with high interest to make good advisory reformulate the work praxis and the activity systems need to find new stability.

4.3.4 Quaternary contradictions

Quaternary contradictions occur between the activity systems. Communication is the power of the activity systems and makes them collaborative towards being productive systems (Foot et,al 2014). There is a surgent discourse in the communication between the activity systems, this is essential to understand and analyse (Foot et,al 2014). Mediating tools and linguistic mediation are the foundation of the productive activity systems and a source of contradictions (Engeström 2001). The discourse can change the use and trust in the mediating tools, the discourse can be a factor in changing the culture and working praxis of using the tools and the belief in them as good mediators to reach the objective (Engeström 2001). Quaternary contradictions could arise between cooperating banks activity systems if one bank continued focusing on higher the interest and promoted the advisors of sell loans with high interest and the other bank promoted by client satisfaction.

5. Methodology

The present study used the AT theoretical framework to direct the methodological choices towards understand the four levels of contradictions between building design and DGNB activity systems when LCC is implemented and used. This section will present the methodological considerations, including the study design, informants, and organisations, together with the considerations there is done regarding the data analysis and strategy.

5.1 Initial design considerations

The present study is based on the DGNB auditors' task of implementing and using LCC during the DGNB certifications of buildings. The analysing unit is the dynamics that shape the cooperative activity when the building design team must include LCC in their design praxis.

The challenges of the LCC implementation and use during DGNB certifications of buildings was firstly realized by studying literature. When the initial problem was defined, the AT was chosen as a theoretical framework because AT is suggested to be used for analysing the human's praxis, including the contexts and tools mediating cooperate activities (Engeström 2001). Because the analyse unit is the cooperate LCC activity between the activity systems of building design and DGNB, a case study was chosen to include informants from both activity systems. The qualitative case study can be used as explanatory studies to explain the real-life environment (Flyvbjerg, 2006). The case study is thereby a strategy to identify propositions and hypotheses by investigation of human praxis and experience in real life (Yin, 1994). A case study of a DGNB certified building makes it possible to use the AT framework and study dynamics shaped by possible contradictions in the division of labour, use of tools, rules, and the communities between the building design and DGNB auditor's activity systems. The case study can expand the study from an individual activity to include the building design context the auditor cooperates with during the implementation and use of LCC.

To prepare and continuously direct the case study design towards answering the present study objectives, preliminary qualitative interviews with Danish and Swiss DGNB consultants were done. The interviews were used to understand the auditor's experiences of implementing and using LCC. The preliminary interviews were intended to narrow the research objectives and strategically select the informants for the case study. The preliminary interviews and case study were designed with a narrative structure, including the context and chronological order of building design. The narrative structure was chosen because the study of contradictions between the activity systems is embedded in the routines and norms situated in the corporative praxis.

5.1.1 Preliminary interviews

There was conducted three preliminary interviews with Danish DGNB auditors and two with Swiss LCC consultancies shown in figure 4. The preliminary interviews were intended to create knowledge about the DGNB auditors' experiences when implementing and using LCC. The knowledge about the DGNB auditors' experiences was used to identify contradictions between building design and the DGNB praxis. The identification of contradictions was used to understand which professions and organisations from the building design activity systems there could be relevant to include in the case study.

The three Danish DGNB auditors are currently and previously employed in engineer, architect, and turnkey contractor companies and described their experiences from multiple DGNB certification projects and organisation types. It was a strategic decision to interview DGNB auditors employed in different organisation types to understand possible diversity in the contradictions related to the organizational structures. The results based on the preliminary interviews was not used to generalize the contradictions rather to direct the case study.

After finishing the Danish interviews, two interviews with Swiss LCC consultancies were conducted in Switzerland's capital Zurich. The two Swiss LCC consultants are working in two different international engineering companies, and they have experiences with implementing LCC and using the IFMA LCC tool on multiple DGNB certificated buildings. The interviews were made to expand the view of the research objectives and create a wider international perspective as the basis of the later discussion of the potentials and limitations of implementing and using LCC in future DGNB certified building design.

Organization	**Country**	**Profession**	**Pseudonym**	**Number of interviews**	**Appendix**
Architect company	Denmark	DGNB auditor	Auditor 1	1	F
Engineer consultancy	Denmark	DGNB auditor	Auditor 2	1	G
Engineer consultancy	Denmark	DGNB auditor	Auditor 3	1	H
Engineer consultancy	Switzerland	LCC consultant	LCC 1	1	No appendix
Engineer consultancy	Switzerland	LCC consultant	LCC 2	1	No appendix

Figure 4: Preliminary interviews informants and organisations, own figure.

5.2 Case study design

A single case study of a DGNB certified building was conducted. The case study intends to get a level deeper than the preliminary interviews allowed, in understanding the dynamics and contradictions between the activity systems. Therefore, includes the case study members of both building design and DGNB activity systems in the context of a specific DGNB building design shown in figure 5, Multiple members of the activity system could thereby explain their praxis experiences of the implementation and use of LCC.

The present case study is based on an information-oriented selection strategy. The information-oriented selection is made because the case is predicted to provide specific information, there can be related to similar cases and used by a wider group with the same contextual reality (Flyvbjerg, 2006). Most DGNB buildings are office buildings (DK-GBC, 2020a). Furthermore, the preliminary interviews indicated that the DGNB auditors experience contradictions implementing and using LCC with non-public turnkey contractors with short-term ownerships. Therefore, the present study has chosen an office building with a non-public turnkey contractor with a short-term ownership. The turnkey contractor is premium member of the institution DK-GBC, and the activity systems are therefore closely interrelated in the same institutional communities. LCC is suggested to have the largest effect in the early design phases, and the five chosen informants are therefore part of the early design, shown in figure 5.

Organization	**Country**	**Profession**	**Pseudonym**	**Number of interviews**	**Appendix**
Turnkey contractor (TKC)	Denmark	DGNB auditor	Auditor	2	A & A.2
Architect (ARC)	Denmark	Architect	ARC	1	B
Turnkey contractor (TKC)	Denmark	Cost calculator tender	CC	1	C
Turnkey contractor (TKC)	Denmark	Design manager	DM	1	D
Turnkey contractor (TKC)	Denmark	Project manager	PM	1	E

Figure 5: Case study informants and organisations, own figure.

5.3 Interviews

The present study is using a qualitative interview method to collect data from the preliminary interviews and the case study. The qualitative interview method makes it possible to identify the experienced human world of life and, after that, analyse and convey it so that others can understand it (Brinkmann & Tanggaard, 2015).

5.3.1 Semi structured interviews

In the present study, semi-structured interviews are used because there are many new experiences during the implementation and use of LCC, which is essential to let the interviewed persons explain and describe with their own words. A semi-structured qualitative interview is a method where the interview can be directed by the informant's experience and not a predefined understanding of the situation (Brinkmann & Tanggaard, 2015). The dynamics and contradictions between building design and DGNB activity systems cannot be predefined, the interviews must be directed by how the informants experience their reality.

The qualitative interview guide was designed based on the AT framework with questions about objectives, use of tools, the division of labour, and the rules mediating the activities. The interview guide was designed to study the implementation and use of LCC from the start to the end of building design in a chronological order shown in figure 6. The chronological order is called a Narrative structure (Brinkmann & Tanggaard, 2015). The Narrative structure is chosen to understand the project history with the focus on when and how contradictions between the activity systems are experienced, because the context is an essential part of understanding dynamics between the activity systems. For the sake of the informants and the organizations, all names of companies, informants as well as buildings, are pseudonymous. The interviews were recorded and later transcribed and sent to the informants' approval before they were used in the present study analyse.

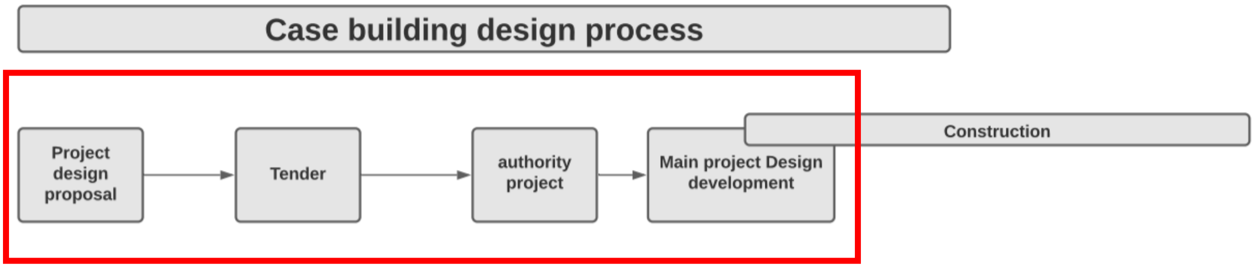

Figure 6: The studied phases and project delimitation, own figure.

5.4 Transcriptions

In the present study, nine interviews were audio-recorded, transcribed ad verbatim, and attached as appendixes. The transcriptions were made with a number system, as shown in figure 7. The number system was made so that the interviews could be coded, and the citations used in the analysis can be tracked to the appendix. The quotations are translated from Danish to English. If there was a need to explain words, they were made in brackets (…..) and without cursive. The transcribed interviews were sent to the informants and approved to ensure the data's validity before the data was used in the analyse. The Informants approval ensured that that the transcriptions was written as the informants wanted to express themselves and ensured there was no misunderstandings.

Appendix title:

Appendix Z_Profession_Organisation

Initials:

Interviewer = LS

Informants = XX

Transcription:

1 LS: Question ……………………………………

2 XX: Answer ……………………………………

Quotation in report

Z_002: "[…] Answer …………………………………… *[…]" (XX)*

Figure 7: Transcription and quotation methods, own figure.

5.5 Data Analysis

The present study was initiated with a coding and analysis strategy based on the AT framework to answer the research objectives. The analysis strategy was identified before the interview was initiated, as it was essential that the interview data could be coded and analysed with the chosen strategy (Brinkmann & Tanggaard, 2015). After transcribing the interviews, they were coded, and the most important statements were categorized. The coding was made based on the chosen themes from the AT framework towards understanding possible contradictions between the activity systems. Therefore, both the questions and the coding are designed to make the data analysable using the AT framework. Manually collar coding of the transcription was performed in Microsoft Word and based on predefined AT theoretical categories shown in figure 8. There was special attention to the contradictions between the activity systems. The contradictions are by AT considered to be important contributors to theorize events and thereby to explain the dynamics. In a qualitative study, these important theorizing events can be called plots (Brinkmann & Tanggaard 2015).

”[…] Plotting means creating a structure that allows for the creation of meaning in the events depicted […]” (Brinkmann & Tanggaard 2015 p,289).

The contradictions were analysed as plots, deeply analysed to make it possible to see a pattern in the dynamics there was shaping the cooperative praxis of implementing and using LCC.

Collar coding list:

Green= objectives
Blue=Tools
Grey= Community
Purple= Division of labour
Reed=Rules
Pink Corporative activities

Primary Contradictions

Secondary Contradictions

Tertiary Contradictions

Quaternary Contradictions

Figure 8: Collar coding list inspired by the AT concepts (Engeström 2001).

5.6 Analysis strategy

A narrative structure was used to characterise how LCC is implemented and used in the design of a Danish DGNB certified building. The AT concepts of contradictions was used to the theorizing of events and understand how building design dynamics were shaping implementation and use of LCC during the design of Danish DGNB certified buildings.

Narrative structure

The timing of implementing LCC is critical, the analysis was therefore structured to illustrate when and how LCC was implemented and how it was used during the building design phases. The case study analysis was a deconstruction of the history following a timeline and the social construction aiming to help the reader make sense of the case study. The AT is based on understanding the activity in the social and historical contexts its takes place (Engeström, 2001). The building design is a developing process with continuously changing professions and organisations involved. The narrative structure is an analysis reported as events there is told in an understandable chronological order making the time and place of the event logically structured (Brinkmann & Tanggaard 2015). To explain the context of building design, the analysis was be described in the phases shaping the contextual reality the DGNB auditor interacted within. The actors were described with their functions and the events connected with the phase model timeline to create the case study's narrative explanation as the actors experience the LCC implementation and use.

6. Analysis

The present case study was performed to characterise how LCC was implemented and used during the design of a DGNB certified building and to understand how building design dynamics were shaping the implementation and use of LCC. The result of the analyses provides the basis for the discussion of the potentials and limitations of implementing and using LCC in future DGNB certified building design. The analysis is explained in a narrative chronological order divided into the building design phases, to study how contradictions develop over time and thereby shape dynamics between the activity systems. The study is based on qualitative interviews with the following subjects. Architect (ARC) Design manager (DM), Project manager (PM), Cost calculator (CC), and the DGNB auditor. DM, PM, CC, and the auditor are employed in different departments by the turnkey contract company here named the Pseudonym TKC. The ARC is employed in an external architect company.

DGNB certified case building

The building analysed in the present case study is DGNB gold certificated by the 2016 DK-GBC manual for office buildings. The case building is an office building forming one thousand employees' working environment. The turnkey contract company TKC was the initial owner of the building and designed and constructed the building**.** TKC includes construction, cost calculation, and property development departments. TKC property development department (TKC PD) is often signing a turnkey contract with the TKC construction department (TKC CON) when they do investment projects. The case building was a short-term investment building developed by TKC PD. TKC PD's objective was to rent the building to a tenant and later sell it to a long-term investor. The TKC company guidelines required TKC PD to find a tenant before the detailed design was initiated. A tenant secures TKC PD an income and makes it easier to sell the building to a long-term investor.

6.1 Project design proposal

The first phase of the case building design was the project design proposal (PDP), TKC PD had invested in a building plot and wanted to define the case building's design. The PDP phase aimed to produce drawings and technical descriptions of the building's overall requirements and architecture. TKC PD was developing the building for their own money, the objective of the PDP phase was to prepare a building design attractive for a tenant to rent. The building design activity system was from the beginning of the PDP phase consisting of TKC PD and the architect. The building design had to comply with the local area plan to be approved at the local municipality. The early design was consequently framed by coordination with the municipality assigned architect there should approve the architecture and material choices of the façades. The PDP phase was the period in which many of the important design decisions was made. There was no DGNB auditor assigned to the building design in the PDP phase. The following description is therefore based on the ARC, DM, and PM descriptions of the early design development of the case building. Figure 9 shows the process.

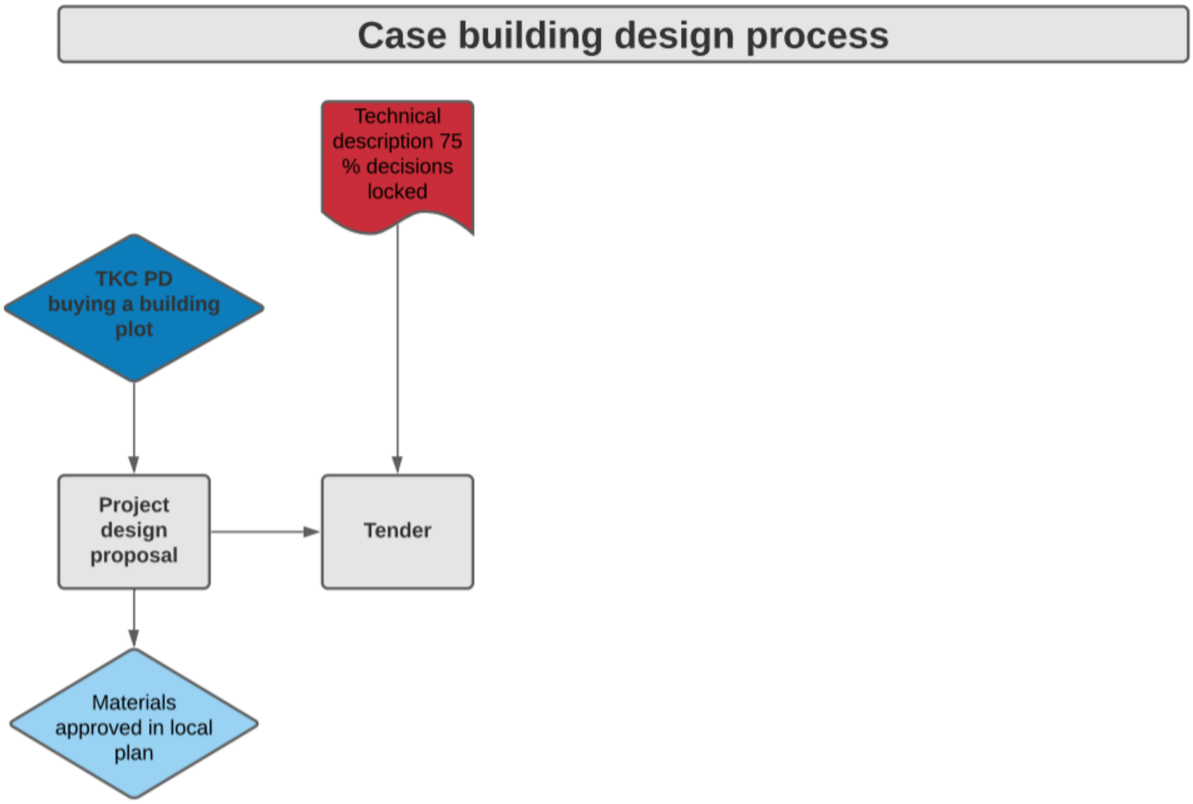

Figure 9: Project design proposal phase, own figure.

6.1.1 Building design objectives

TKC PD was the investor, designer, and project manager advised by the chosen architect. The initial technical description was prepared between the architect and TKC PD and was the documentation of the design decisions. The architect used 2D computer-aided design (2D CAD) for making the initial drawings, and TKC PD wrote the technical descriptions in MS word. The 2D CAD drawings and MS word were the primary mediating tools between the architect and TKC PD.

The initial design was directed towards TKC PD short-term objective of profit, the long-term investor would be the new owner and responsible for the future cost of the external building envelope, such as façade and window cleaning. The future tenant rents the building and would be responsible for the maintenance and cleaning cost of the inner surface, such as floors and walls. The short-term ownership influenced TKC PD objectives, the PM describes:

E_006: "[…] (The case building) *is a here and now profit for* (TKC PD) *within a manageable number of years, and they are responsible five years, it is* (TKC PD) *most extended perspective on these buildings. There is rarely a look at the long-term ownership perspectives concerning the choice of building materials […]" (Project manager)*

The PM describes TKC PD short-term perspective on the building design, resulting in a limited focus on the future cost during the early design of the case building. There was no DGNB auditor assigned during the PDP phase, and thereby was the auditor not able to implement the LCC methodology. The building's handover between TKC PD and the future owner would be a handover of the building design's future cost. The future owner and tenant were not part of the PDP phase, the future cost of the materials and solution choices were therefore not discussed with the owner, and the user there had to pay the future cost.

6.1.2 Early decision making

The technical description's development was framed by the building design's approval and compliance with the local area plan. Restrictions about the architecture and materials choices were described in the local plan and, therefore, an essential regulative framework for the early design process. The ARC describes the façade material's decisions as an example of decision making made without calculating the LCC consequences. During the PDP phase, the ARC purposes anodized aluminium used as a façade material, and the argument was that the architectural look of the building would fit into the local architecture. TKC PD decided that the anodized aluminium could be used and described in the application to the city architect. The city architect approved the anodized aluminium façade components, and the building design could continue. ARC describes that no DGNB auditor was assigned resulted in a limited focus on sustainability or lowering the future cost. The LCCbyg tool was not used to calculate LCC on the anodized aluminium materials the ARC describes:

B_080: "[...] Because the entire local plan had been prepared and described the way the building should look, decisions were locked at that time also because the project was basically designed before choosing to DGNB certify the building [...]" (Architect)

The decision of DGNB certify the case building was made at the end of the PDP phase when many of the materials and design decisions were written in the technical description and applied by the local municipality. The PDP phase defined a large part of the design decisions with no point of return when approved by the local municipality. DM describes that 75 percent of the material choices were made when the technical description was finalized at the end of the PDP phase.

D_027: "[...] A large part of the material decisions were made when we made the turnkey contract, and it is approx. Day 0 of our phase. When we make a turnkey contract, there is a technical description and the more accurate it is the better, and on the (Case building) *I think that 75% of the materials was locked when we had made the technical description [...]" (Design manager)*

The architect had the objective to make a unique architectural design and had a limited focus on future cost perspectives on the proposed materials. Simultaneously, TKC PD expected the architect to lower the initial cost during design before an DGNB auditor was assigned to the project. When the TKC PD had objectives about the low initial cost, sustainability and the LCC considerations were not the primary design objective and were first introduced as a design requirement.

Engeström describes that every productive activity system is affected by socioeconomic dynamics and tensions between the exchange and use-value of the produced product (Engeström, 2001). TKC PD is DGNB certifying the case building promising a sustainable product balancing environmental, social, and economic sustainability. Opposite a low initial cost gives a higher profit for TKC PD. There are primary contradictions between locking 75 percent of the design decisions in a DGNB gold-certified building without engaging a DGNB auditor to the project. The DGNB certification, including the LCC methodology, is a change process suggested to be incorporated in the early building design to inform and direct the design towards sustainability balanced with future costs.

6.2 Tender phase

After finalizing the PDP phase, a contract with a tenant was signed, and the tender phase could begin. The tender phase (TP) is when sub-contractors can bid on executing construction work of specific parts of the building. TKC PD has the requirement that 95 percent of the initial building cost must be calculated, and bids received from the sub-contractors before further design. TKC cost calculator (CC) was responsible for calculating the initial cost of the building and dividing the building into build contracts. The CC receives the technical description from TKC PD, and the 2D plan, façade, and section drawings from the architect. Based on the technical descriptions and drawings, CC measured the materials' quantities and after that calculated an initial cost of the building; it typically takes 4-8 weeks. When 95 percent of the building's initial cost is calculated, and the bids from the sub-contractors are received, TKC PD has an overview of the initial cost of designing and constructing the building. At the end of the tender phase, the initial cost will be the basis for a design and construction budget between TKC PD and TKC CON department, figure 10 shows the process.

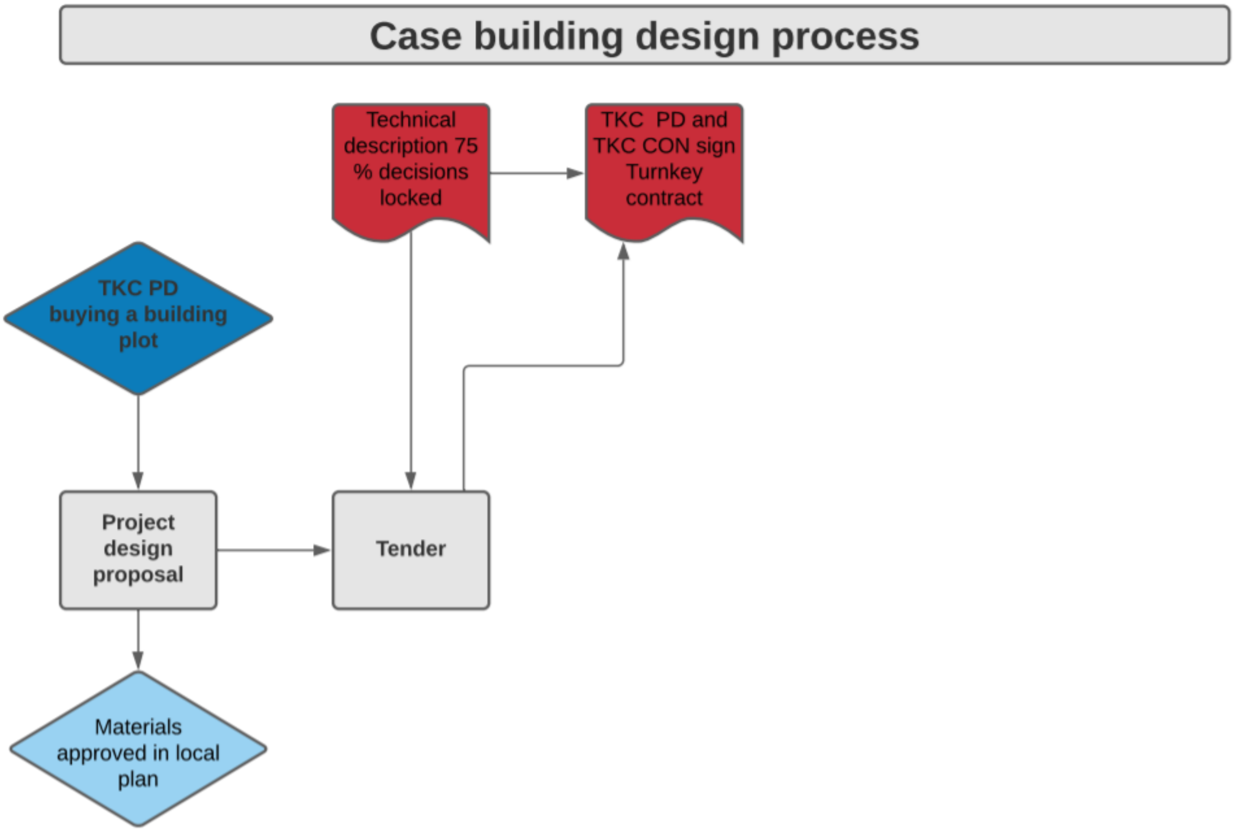

Figure 10: Tender phase, own figure.

6.2.1 Cost calculations

To prepare the tender documents for the bidding subcontractors, CC divides the building into work specific areas in build contracts. The technical descriptions and 2D drawings were the mediating tools there made it possible for CC to understand the building geometry and calculate the quantities. CC used the software blue beam to measure quantities from the 2D drawings. During the TP, there is no DGNB auditor assigned to the project, the cost calculation is therefore made without considering the DGNB and LCC requirements CC describes:

C_046: "[…] At this project we were not that far with the DGNB certification when we calculated it, we assigned a DGNB auditor late, but at other buildings, the DGNB auditor is included early […]" (Cost calculator)

CC calculated the building cost with the use of the TKC developed Excel tool MAP. The MAP tool includes TKC historical data on initial cost and has a predefined organization for the bidding lists later sent to the sub-contractors. The Map tool, including historical cost data, was used to consider the bids from the sub-contractors and evaluate early design costs. The bidding sub-contractors were chosen based on low initial cost requirements. Therefore, the MAP tool is designed to fit the TKC cost calculation praxis, focusing on lowering the initial cost.

The auditor was not assigned during the early cost calculations; therefore, the auditor could not implement LCC nor inform the early decision-making of the design solutions sent to the bidding sub-contractors. The cost calculation was done with a division of labour between TKC PD and CC, the auditor had later to understand the cost calculations and implement LCC, including the use of LCCbyg. DGNB requires the auditor to extract the cost from the build contracts, therefore the auditor had later to translate the cost made in the MAP tool into building components cost in LCCbyg.

Secondary contradictions arise inside the activity systems when the building is calculated with the MAP tool without introducing the DGNB auditor to the building design. The Map tool was using historical data based on the initial cost and does not include the future cost. The organization and detail level of the bidding list was not the same as required in LCCbyg. The MAP tool was designed to fit the traditional TKC cost praxis, and the LCCbyg tool was designed to think calculation in a different way, including future costs.

CC describes limited experience of working together with the DGNB auditors and is not introduced or educated in the use of the LCCbyg tool. CC uses the TKC calculation department's own developed LCC calculations tool when required by the clients. The TKC LCC tool is an Excel document with predefined calculation values. CC describes TKC PD had no requirements of using LCC tools during the case building's tender calculation.

C_038: "[...] I have not heard the name (LCCbyg) *before. We use our own LCC tool when requested. But it is usually the public investors, they sometimes ask for an LCC calculation. We have our sheet we sit and put the numbers into and then it calculates it for us [...]" (Cost calculator)*

Tertiary contradictions arise when the CC is not educated and informed about the DGNB process of implementing LCC. The cost calculations are not reconfigured to the DGNB process, and TKC had not been educating CC about the new mediating tools such as LCCbyg and how they change the division of labour and require displacements of roles. Suppose the design activity system is not educated to understand how their praxis must be changed to facilitate the DGNB process, it can be difficult for the auditor to manage the later implementation of LCC.

6.3 Authority project

The authority project (AP) phase aims to develop the design detail level concerning submitting a building permit application. At the start of the AP phase, TKC PD and TKC-CON were signing a turnkey contract. TKC CON had after that the responsibility of the architect and design management. The technical description and drawings were the basis for the contractual agreement describing what TKC CON, as a turnkey contractor, was obligated to deliver to TKC PD. The TKC CON department was represented by two employees, DM and PM. The DGNB auditor was assigned to the building design at the start of the AP phase to pre-certify and later certify the case building to the DGNB gold level, including the LCC calculations. The tenant and the tenant consultancy were involved in the AP phase to fit the user requirements. The AP phase was a transition of including the DGNB activity system and, at the same time, redesign parts of the building to fit the tenant requirements shown in figure 11. DM and PM had to balance the TKC objective of creating profit, implementing the DGNB processes, and integrate the redesign based on the tenant requirements.

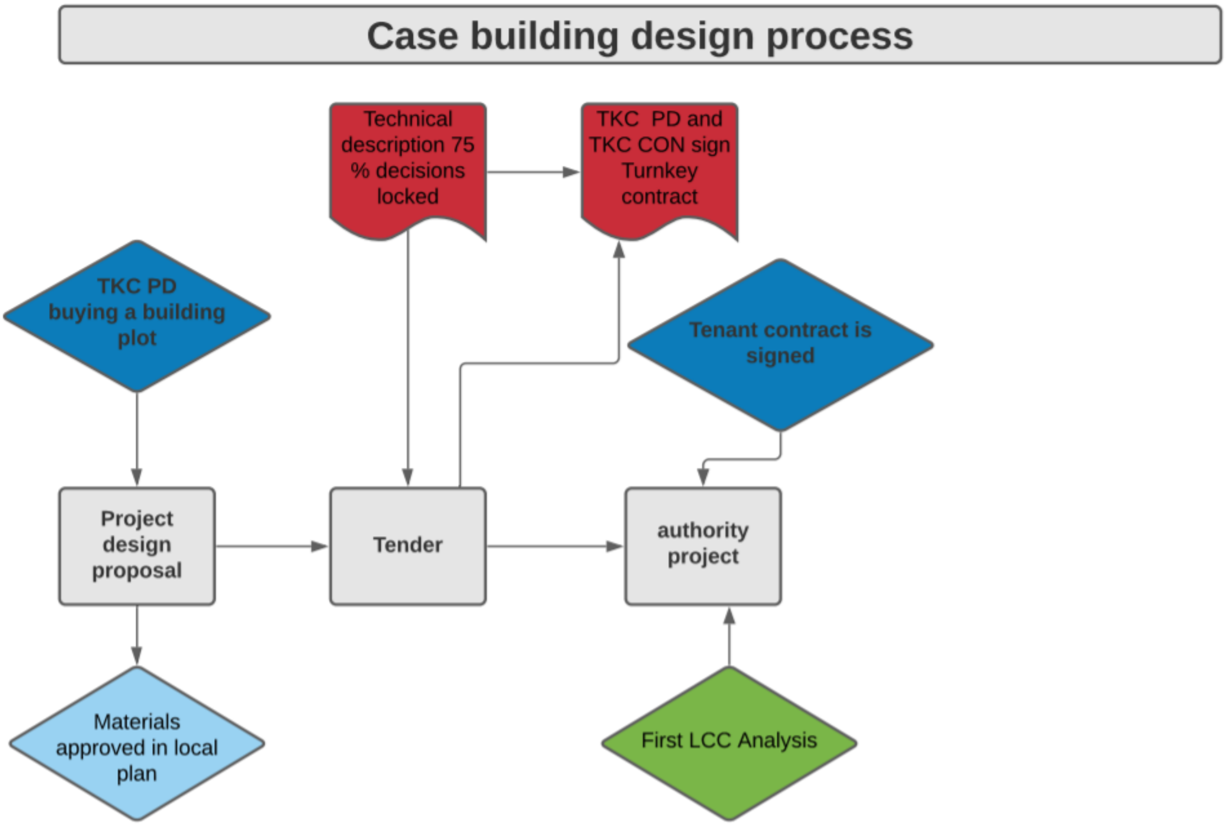

Figure 11: Authority project phase own figure.

6.3.1 The DGNB auditor is assigned

The auditor was assigned to the building design at the start of the AP phase, TKC PD decided that the building both should be DGNB pre-certified and later DGNB gold certified. The auditor was assigned into the case building design when over 75 percent of the design decisions was locked, the auditor had to manage a change process and incorporate the LCC methodology. DM and PM were managing the building design to lower the initial cost and make a profit for TKC PD, introducing DGNB, including LCC created a shared objective between the building design activity systems shown in figure 12. The PM describes the implementation of DGNB as time-consuming and costly, driven by the overall strategic objective of making it easier to sell the building to a long term-investor.

E_024: "[…] Management and handling of DGNB is costly. We would like to save it away because it would be 1.5 million DKK more on the (TKC PD) *bottom line. But to get interest from investors abroad and in Denmark, it is best to have a DGNB certified building […]" (Project manager)*

The DGNB auditor was managing the DGNB process and tried to implement the LCC methodology into a building design activity system driven by the strategic objective to sell the building as fast as possible with the highest possible profit. The auditor was interrupting DM and PM's traditional design praxis by introducing a new process which was not necessary to design the building but only to achieve the DGNB certificate.

TKC PD was by requiring the implementation of DGNB, forcing a new set of design rules into DM and PMs project management praxis, and the auditor had to manage the compliance of the multiple DGNB criteria's. The DGNB manual was directing a strategy and order of building design tasks for DM and PM, which was usually framed by the Danish building regulations. Multiple DGNB requirements obligated the DM and PM to open their praxis and involve the auditor, including the LCC ECO 1.1 requirements. As an example, the LCC calculations in LCCbyg required the auditor to get access to the budgets managed by the PM. TKC PD required the DM and PM to manage the building design and lower the initial cost while DGNB certifying the building when many of the decisions already was locked. The multiple contradictions were caused by the multi-directional objectives between building design and the DGNB activity systems shown in figure 12.

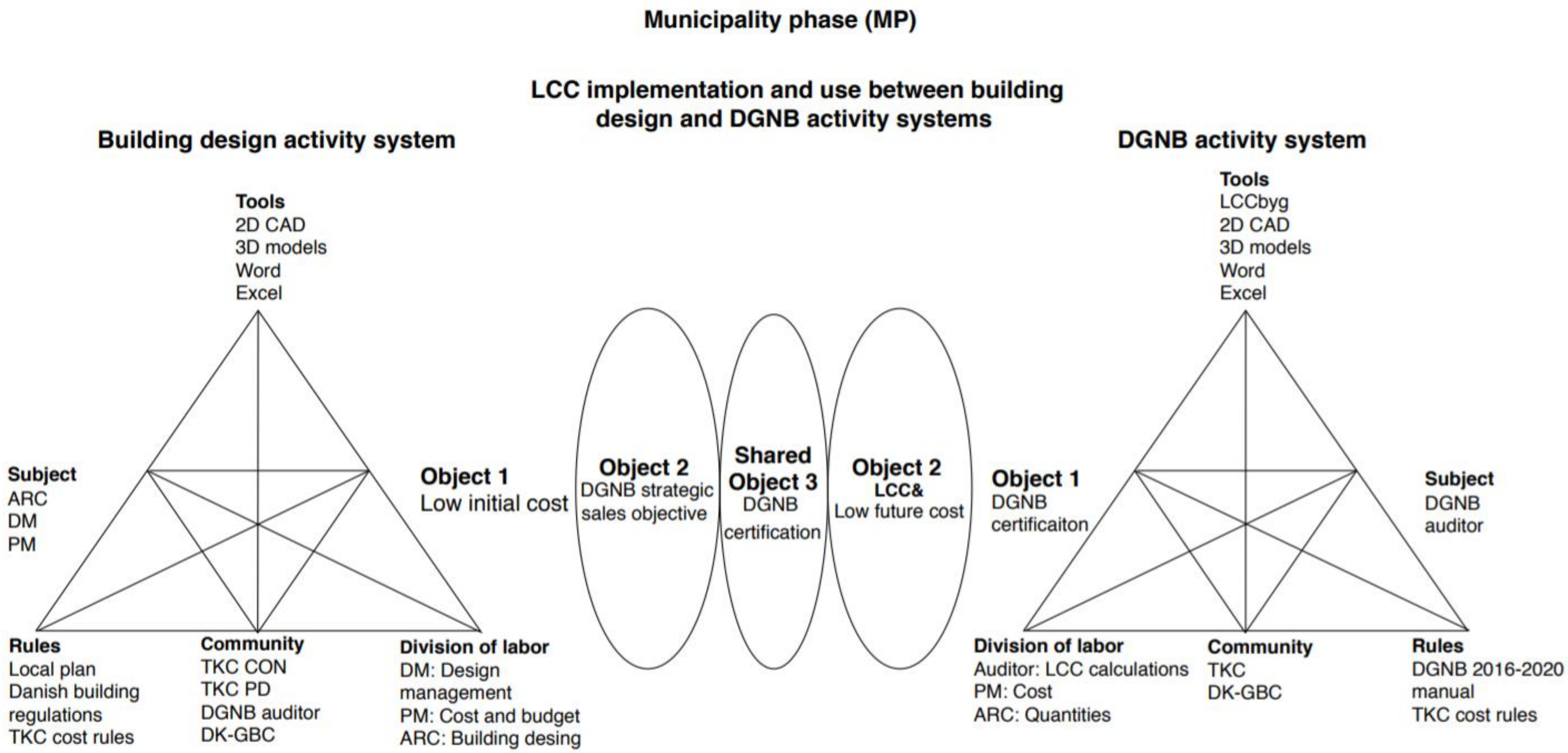

Figure 12: LCC implementation and use between building design and DGNB activity systems, own figure based on (Engeström 2001).

6.3.2 Design changes

During the AP phase, the tenant changed the building's room design and inner surface materials, the DM coordinated the design changes, and the PM ensured the design could stay within the budget. The tenant used an external architect consultancy to critically question the internal building design and implement their user requirements in the technical description. The DM describes how the technical description mediated the design decisions:

D_037: "[…] The technical description is the basis for the agreement that is made between (TKC CON and TCK PD) *and is the basis for what* (TKC PD) *makes an agreement with the* (tenant) *[…]" (Design manager).*

Despite many locked decisions from the previous phases, the tenant created design changes, and opened a window of opportunity to include the DGNB auditor and, thereby, the LCC methodology. The multiple DGNB criteria's could continuously be assessed against the proposed design changes, and the DGNB certification could influence the building sustainability. The design changes had undeniably many consequences regarding LCC, but no LCC calculations or comparison of alternatives was made of the design changes. Despite the possibility to implement LCC and use the LCC calculations to evaluate the future cost the DM and PM decided that the auditor should postpone the implementation of LCC until the end of the AP phase, the auditor describes:

A.2_010: "[…] We assessed the LCC analysis could not influence the choice of materials or choice of constructions. Therefore, (DM and PM) *thought it was a waste of time to do the analysis where you compare materials, so you would rather spend the time and resources on something else […]" (DGNB auditor).*

There was considerable interest from the DM in getting the tenant design changes finalized as early as possible during the AP phase. When DM had locked the design decisions in the technical description, it was difficult for the auditor to implement all the different DGNB calculations, including LCC there, as a result, was not implemented. The DM describes the reasons behind the interest in finalizing the design early during the AP phase:

D_025: "[…] The earlier you can get the end-user out (of the design process) *so* (the user) *does not have to be asked more about what they want here and what they want there. We are then more free and able to complete the project […]" (Design manager).*

There are Quaternary contradictions between the DM objective of finalizing design as fast as possible, and then the auditor objective of implementing DGNB to evaluate multiple criteria before making the design decisions. The rushed schedule created tension between the DM design objectives and the auditor's objective of considering multiple sustainable parameters, including LCC. The limited possibility of delaying the design and implementing DGNB evaluations was visible during the design meetings. DM describes how the initial design meetings were conducted and how the auditor was included:

D_061: "[...] The DGNB auditor participated not every time on design meetings, it was an assessment if there was some questions regarding DGNB it is referenced in the minutes and when we think there was relevant questions enough then we asked DGNB auditor to come to the next design meeting. We took the questions that was to the Auditor as the first and then she could leave again [...]" (Design manager)

The DM was conducting the design meetings as traditional design meetings and invited the auditor in an external consultancy role, even though they were both employed in TKC. DGNB was not applied as an integrated praxis, and the division of labour was not displaced and fitted to the DGNB praxis. The auditor had to try interacting with the decisions but was detached from large parts of the design discussions, leaving the auditor separated from the important cost considerations and thereby the possibility to implement LCC as a methodology.

The tenant would not be the building's future owner and had to keep the design changes within the initial budget. PM and DM made an ongoing evaluation of how the design changes affected the initial cost, schedule, and the solutions' buildability. TKC PD had possible limited ownership considerations about how the design changes would affect the future cost. The DM describes the challenges in deviation of building ownership:

D_013: "[...] Typically, it is the investor who is responsible for external maintenance and also the outer part of the building envelope and green areas. While the tenant has everything inside, there may be some conflicts concerning what it is they subsequently have to pay for ...]" (Design manager).

The tenant was not the building owner and had been agreeing on a rental cost with TKC PD. The tenant tried to change and optimize the design within the budget constant and dynamically, affecting the future cost. The auditor was interested in influencing the building design and using the LCCbyg as an active tool to improve the building LCC. Despite the interest the auditor was never at the same meetings as the tenant participated in. When the auditor was not informed about the design consideration and decisions, the auditor had no possibility to influence the design with LCC, the auditor describes:

A.2_030: "[...] The tenant and the tenant's architect's consultant did not attend the design meetings I attended. I imagine that it has been the case that the (TKC PD) *has talked to the tenant and then the tenant has expressed inputs for design to the* (TKC PD) *as the* (TKC PD) *has then taken to the* (PM and DM). *It has been a flow that has been kept around me. There is a hierarchy around how to talk to each other and my experience is that so far the* (TKC PD) *is in contact with the tenant, I rarely have anything to do with the tenant [...]" (DGNB auditor).*

The auditor was not involved in the budget updates and was not calculating LCC on the design changes. This indicates that no one in the design activity system had the long term LCC objective because the new owner would first be involved after the design. Because the auditor was not dynamically updated on the budget and material changes in collaboration with PM and DM, the LCC seem to be a static and fragmented process separated from the design economy management in the present case study.

6.3.3 Material decisions

Floors

During the early design meetings, the Tenant described a wish about choosing white oil-treated floors. The floor solution requires maintenance with oil four times each year, and the maintenance was an extra expense compared with other floor solutions; there can be maintained once a year. DM and PM were interested in keeping the maintenance cost down because the building needs to be attractive for tenants in the future. PM and DM tried to explain to the tenant and tenant advisor about the extra maintenance cost, but the tenant wanted to add the white oil-treated floors to the technical description. Despite several DM and PM warnings, the white oil-treated floors were accepted and written in the technical description. The LCCbyg tool was not used to compare the floor materials, and the future cost was not part of the decision making, even though DGNB auditor was working on the project and advising the design. The PM describes the long-term consequences for the tenant:

E_022: "[...] The floors was chosen, (the tenant) *then later went in themselves and tried if they could wax treat the* (floor), *but they failed so they have a higher* (LCC) *expense than they had expected [...]" (Project manager).*

The auditor was assigned to the project and could do an LCC calculation on the floor solutions. Comparing alternatives using LCCbyg could potentially have been showing the tenant that the white oil-treated floors were much more expensive than alternatives. The auditor was not part of the discussion and could not use the LCC knowledge and the LCCbyg tool to inform the decision-making. The auditor describes that there could have been made several material comparisons with the use of LCCbyg during the AP phase:

A.2_038: "[...] Such as floor and wall surfaces and ceiling surfaces that were not locked at the time it could well have been worked on in relation to the LCC analysis [...]" (DGNB auditor).

The PM and DM were not to using the auditor's competence and LCCbyg tool to consider LCC during the discussion about the floor with the tenant. The active decisions of not involving the auditor even if the competence and tool were present, can be caused by the TKC PD primary objective of making the initial cost low, there can also be limited knowledge about the possibilities of LCC. When LCCbyg is not used to compare alternatives, it can only be used to document the chosen solutions. Another example of limited LCC implementation is the façade material decisions.

Facades

The case building façade design was made so a large part of the building cannot be cleaned without using a crane or rappelling from the roof, as an alternative to cleaning from the ground. During the AP phase, the TKC PD realized the chosen anodized aluminium facade material could be a potential problem regarding maintenance and cleaning cost. Anodized aluminium has a well-known weakness regarding bird excrements because it changes its surface collar and gives a filthy architectural look. To keep the façade, clean from bird excrements, the architect suggested installing spikes and sound solutions, but the different solutions would change the look of the facade and potentially add initial construction cost. TKC PD suggested changing the anodized aluminium façade to another material, but it was already described in the technical description and approved by the municipality and agreed in the local plan. The ARC describes the situation:

B_078: "[...] The architect had proposed anodized aluminium, later (TKC PD) tried *to change it in the local plan. The local authority would not approve anything other than what was described in the local plan, and thus there should be used anodized aluminium façades [...]" (Architect)*

The city architect would not approve a change of the façade material. Implementing the LCC analysis during the PDP phase, could maybe have been important for the design decision by showing potential extra cleaning cost for the future building owner. The DM and PM were not part of the PDP phase and early façade decisions but had praxis knowledge and knew that the anodized aluminium facade would be costly therefore advised TKC PD to change the facade. The Auditor describes that the LCCbyg tool was not used as an active mediating tool to compare alternative materials:

A.2_008: "[…] No alternatives have been calculated in the LCC calculation during the authority project. You can say at the time when you submit to the authorities, the project is fairly fixed, at least to some extent. The thing about having alternatives in the LCC calculation, we have not really used in the LCC calculation during the DGNB certification for the case project […]" (DGNB auditor).

6.3.4 The LCC calculation

The auditor made the first LCCbyg calculation at the end of the AP phase based on the updated design budget and the quantities from the architectural drawings. The LCC calculation was made to document the whole building LCC, thereby fulfilling the DGNB ECO 1.1 criteria. The LCCbyg calculation is requiring the quantity and cost data on building components. As preparation, for the LCCbyg calculation the auditor made a therefore large amount of cost and quantity data collection.

Quantity data

The architect was drawing the façade, plan, and section drawings with 2D CAD software. TKC PD required 3D models as part of the design deliveries at the end of the AP phase, the architect had therefore to translate the initial drawings from 2D to 3D drawings. The design activity system used multiple 2D, and 3D tools, which was part of their traditional praxis, but the DGNB documentation and LCCbyg calculation require a large amount of quantity data, which can easily be extracted automatically from the 3D models. The architectural 2D CAD drawings required extra coordination, the PM describes the challenges:

E_044: "[…] TKC CON has the main constructions drawn before the authority project starts so it will be some of the requirements that need to be looked at more concerning the architects and get them to start the 3D model up much earlier, they spend a lot of time drawing in 2D, in the beginning, to find out what the layout should be like and then they draw the 3D model at once it is a bit too late concerning our processes […]" (Project manager).

The 3D models and the technical descriptions were the mediating tools between the building design and the DGNB activity systems to make the LCC calculation at the end of the AP phase. The auditor had to understand the design and make an estimate of the building component quantities, the translated quantities were typed in excel, structured by the SFB classification system before it was typed in LCCbyg shown in figure 13. The auditor had a similar praxis as the CC previously had during the TP phase when the technical descriptions and the drawings were translated into a quantity cost. CC was using the time to understand the drawings and estimate the cost and quantities of the design. The auditor must further divide the quantity into the component cost of the different building components. With no collaboration and cost handover between CC and the auditor, important cost knowledge could have been lost during the shifting between design phases and cost responsibilities.

Cost data

The PM had been updating the budget during the AP phase based on the build contracts signed in the tender phase. The auditor had to translate the build contracts into component cost structured by the SFB classification system. The auditor describes that it was time-consuming and difficult to merge the build contracts and quantities into the component cost LCCbyg requires:

A.2_014: "[…] Sometimes I receive a façade (cost) *in a large lump and divide a facade into sandwich elements and windows and doors and whatever else could be. It can be very different and sometimes it is also about the actual calculation that there may also be some underlying Excel sheets there properly does, but it will not be included or will not be specified in the calculation I receive. […]" (DGNB auditor).*

The CC, PM, DM, and the auditor do not collaborate during the case project preparation of the whole LCC calculation. The knowledge about the cost calculations was not shared with the auditor, and the auditor does not have a specialized economic background. It was a considerable challenge for the auditor to understand the build contracts and the drawings regarding estimating the component cost. During the case project, the auditor realized that the translation of the build contracts into component cost was time-consuming and prone to errors. The auditor went to the TKC calculation department and tried to change the cost calculation department's use of the MAP tool instead of organizing build contracts into specified components costs by the SFB classification. If the same SFB system organized both the build contracts and LCCbyg tool, the auditor's data input would be less time-consuming. The auditor experienced considerable resistance:

A.2_016: "[…] I was new and just started in (TKC) *where I thought I should influence how these calculations are set up and they should instead be calculated according to SFB numbers, but I would say I got wiser […]" (DGNB auditor).*

The TKC calculation department was not interested in change, and the traditional build contracts were delivered to the auditor. During the AP phase, the whole LCC calculation took the auditor over two weeks of work due to a large amount of estimating and translating cost and quantity data into the component structure in the LCCbyg tool. The conflict between the cost calculation and the auditor manifests the contradictions between the build contracts and the component cost in LCCbyg. When the auditor tried to change the TKC cost calculation department praxis from large build contract into building component cost, a tension was made. The auditor could not change the CC calculation praxis and seems to accept the situation. Institutional innovation to reconfiguration the cost praxis to fit the LCCbyg tool was suggested by the auditor but rejected.

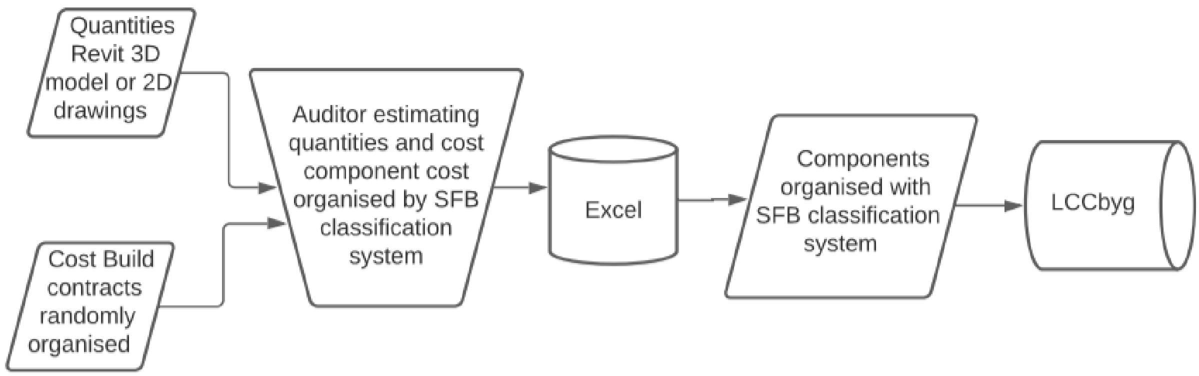

Figure 13: LCC data translations into LCCbyg calculations, own figure.

6.3.5 Masking of cost

Another factor that made the auditors LCCbyg calculations challenging was the traditional building design dynamics of keeping the cost a secret. TKC PD was not interested in opening the cost books and letting the future owner or tenant know how much profit there was made on the building. The auditor did know the TKC internal norms of hiding the cost and was therefore obligated to mask the cost when it was written in the LCCbyg shown in figure 14, the auditor describes:

A.2_020: "[…] It was necessary to mask the cost of the case building. What happens to me in practice is that I get our calculation and it reflects the cost that we have used. It is clear that we must also earn something, so there is a gap between what the investor ends up paying and what has actually been the cost. […]" (DGNB auditor).

The auditor could not write the correct cost into the LCCbyg tool when the cost was received from the PM's updated calculations. Due to the TKC company norms, the DGNB auditor needed to do masking of cost so that the tenant and future owner could not see what TKC was earning on the project components. The auditor describes how the cost was distributed between the building components:

A_011: "[…] The cost that we can pass on will most likely have the percentage we have to earn distributed on the different building components. We do not have an internal guideline for how we do this, but typically it will probably just be that you took the remaining amount that is profit and then just distributed it evenly on all building component items […]" (DGNB auditor)

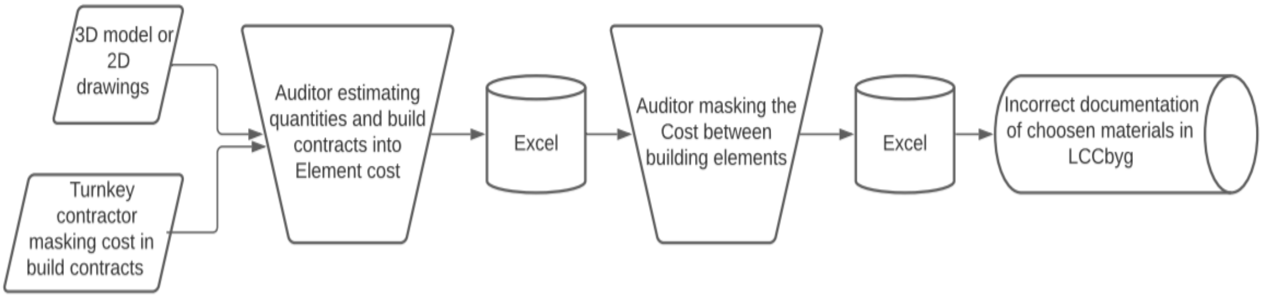

Figure 14: Masking of cost, own figure.

The LCCbyg tool was a cost mediating tool introduced into the design activity systems by the auditor. The LCCbyg tool created tertiary contradictions by compromising and visualizing the traditional secret cost. The contradictions placed the auditor in a dilemma of making an accurate LCC calculation or complying with the TKC company guidelines of masking the cost. The present study cannot assess how much the cost masking was influencing the accuracy of the LCCbyg calculation there was used to document the case building LCC and thereby to fulfil the DGNB ECO 1.1. criteria.

6.4 Main project

The main project (MP) phase determines and describes a building with a detail level that can be used as basis for construction. In the present study, the technical description and the drawings was updated regarding the tenant requirements during the AP phase. The MP phase was starting when the building permit was received. TKC is often initiating the construction before the design is finalized, causing the design and construction to be overlapping. The second whole LCC calculation of the case building was made during the end of the MP phase. At the end of the phase, a new investor was found for the building, and there was a transition of ownership from TKC PD to the long-term investor shown in figure 15.

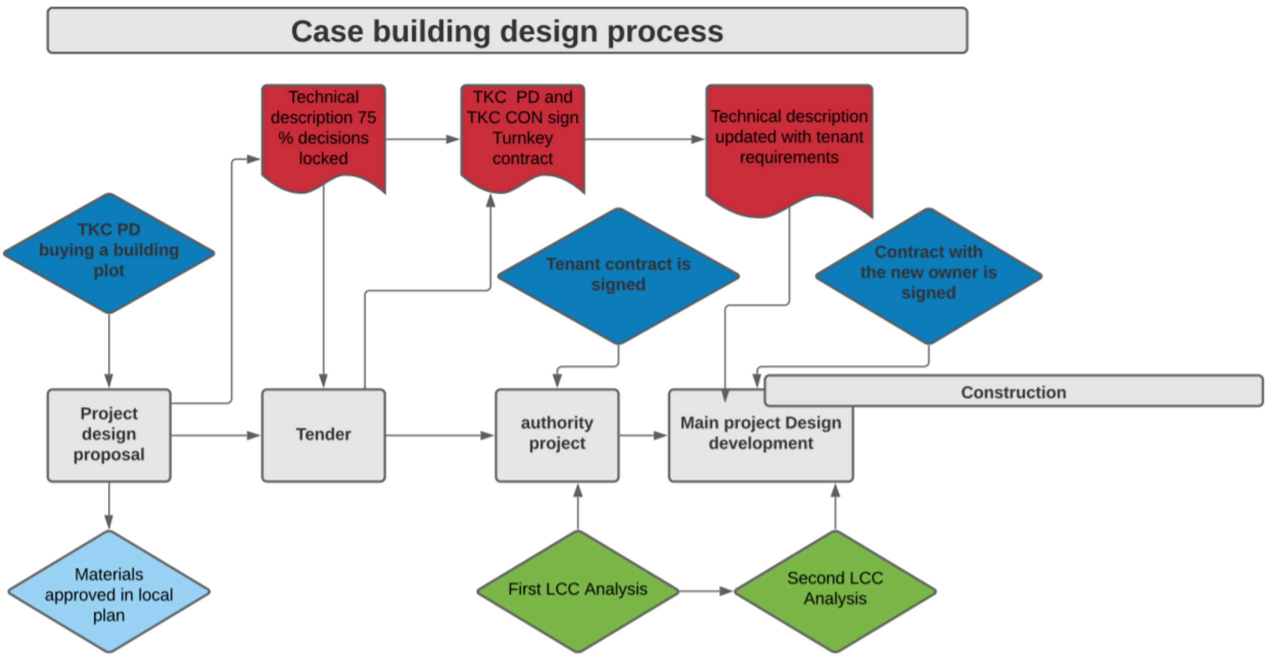

Figure 15: Main Project phase, own figure.

6.4.1 Window cleaning decisions

The MP phase was designed based on the finalized agreements between the tenant and TKC PD. During the MP phase, the architect realizes that the building geometry would cause the windows to be cleaned with a huge crane. The metro company and police must be announced when the cleaning is done because the crane must be placed on the road. The architect was suggesting installing anchors on the roof to avoid the use of a crane. Anchors could be used to enable manually cleaning of windows from a rope and thereby lower the cleaning cost significantly. The cleaning solutions were discussed in design meetings by the design activity systems. The auditor was not making LCC calculations on the cleaning solutions, but it was obviously much cheaper regarding the future cost to install an anchor in the roof instead of depending on a crane for window cleaning. The installation of anchors would raise the initial construction cost and, therefore, exposure of the design objectives, ARC describes:

B_44: "[…] If it was me who owned the building I would not get a crane (for window cleaning) *it is a very big cost and very cumbersome regarding to the police and the metro, I would think that it was a good expense to spend a little more money in the beginning of the project but in the long run significantly less hassle and significantly less cost […]" (Architect).*

Cranes are using diesel and would affect the cleaning cost and environmentally sustainable criteria in the DGNB certification. The auditor was not part of the window cleaning discussion, and the LCCbyg tool was not used to calculate the difference in LCC between the crane and manual rappelling cleaning. At the case project, the objective of lowering the initial cost seem to dominate the decision of not install anchors in the roof, even though they are aware of the future implications. The long-term building owner will pay for that decision in the following many years. When the DM was asked why the LCC analysis not was used for decision making during the design, the answers were:

D_065: "[…] If it's just facts you have to deal with, it's a bit of the same. If it is not possible to influence the decisions, then it (LCC calculations) *does not matter […]" (Design manager)*

The DM believed that LCC calculations could not influence decision, it could be because the building design had to stay within the initial design budget made by TKC PD. Maybe, The DM had to stay within the budget even if there was a possibility or an interest in lowering the future cost. The LCCbyg tool could possibly have been used to compare alternatives and document the LCC consequences within the discussed window cleaning decisions. Because the auditor was not involved in many design discussions, the auditor could only document the decisions using whole LCCbyg calculations at the end of the building design phases.

6.4.2 LCC documentation

The DM and PM describe a general understanding that by using traditional materials, there has been approved during previous DGNB projects, a low LCC could be achieved. The auditor describes the design activity systems furthermore assumes LCCbyg tool to be superfluous because the buildings are designed with well-known materials. The PM describes how the experience was used to make the building design comply with the DGNB LCC requirements without implementing LCC or using LCCbyg to inform the decisions:

E_032: "[…] I have not experienced many LCC calculations, it is rare we are down there and look at it. I have not tried so many of these LCC calculations because it is not so much what we go in and look at you have a lot of experience in advance, so you just use those materials […]" (Project manager)

The present case study cannot assess if the case building was good or bad performing regarding LCC. As PM argues, there could be many LCC considerations during the building design and the future cost lowered by choosing traditional materials with a well-known performance. However, the case study showed decisions where the LCCbyg tool could have been used actively to lower the future cost. The decision about not installing the anchors in the roof is not a matter of limited knowledge about the LCC consequences. The design activity system was informed that not installing anchors would higher the future cost for the future building owner. The objective of lowering the initial cost was considered most important. With the objective of lowering initial cost, an LCC calculation would possibly not influence the DM and PM decisions. LCC calculations would only make it more obvious that there were contradictions between lowering the initial cost and the DGNB process's objectives of reducing future cost. The auditor argues that the building design activity systems and TKC PD were missing objectives towards implementing LCC and lower the future cost among:

A_019: "[…] When we do LCC calculations during DGNB projects it is a reporting tool. I personally wish that we both internally in (TKC) *and in the industry in general used the LCC calculation to achieve some objectives […]" (DGNB auditor)*

When there were no objectives made for the building LCC, the initial cost was to be the primary design objectives framing the building design.

6.4.3 The second LCC calculation

The MP phase was finalized with a second whole LCCbyg calculation documenting the case building LCC performance. The auditor described that the second LCC calculations were only made to document the decisions and achieve the DGNB certificate. The auditor suggests that the LCC calculations were changed to be a shared activity between the auditor and the PM in future building design:

A_057: "[...] The LCC analysis is not applied to project meetings; (LCC) *is made for the DGNB certification. The project calculation is considered regularly at project meetings, but it's like going on in another loop, and there you could say, well, then LCC should maybe belong up with them, but the practice is that it does not. It belongs down with me [...]" (DGNB auditor)*

When the LCC calculations were not applied to the design meetings, it was a pseudo document, and only the auditor was informed about the results. The DM describes, similar to the auditor, that the LCC calculations were not used to inform the design decisions and LCCbyg calculations were done when the decisions were made:

D_067: "[...] I do not remember areas where one has looked at the LCC analysis and then made decisions. It is a question of a lot of quantities that must be extracted to do the LCC analysis, and it is usually late in the phases that you pull them out [...]" (Design manager)

The DM explains an understanding of LCC as it only can be made on the building design exact quantities and cost. The knowledge about LCC as able to make small comparative studies of building components is not visible in the described understanding of LCC. The present case study showed in general that the understanding of how LCC could be used to inform the design decisions making could be improved in the future. The building design activity system was required to use multiple digital tools. The late implementation of DGNB, and without the required education and information about the possibilities of LCCbyg and the LCC methodology, it is understandable, there was a sceptic towards making the LCCbyg tool directing the important design decision making.

7. Discussion

The following section will discuss the theoretical, practical, and political implications of the analysis findings, together with the potentials and limitations of implementing and using LCC in future DGNB certified building design.

7.1 Objectives

Cole & Sterner describes objectives of lowering the future cost as one of the main drivers to implement and use LCC with success (Cole & Sterner, 2000). The present case building design was fragmented due to individual responsibilities and the shift between the design phases. TKC PD had short-term ownership of the case building, and the LCC performance would not directly affect their profit. The short-term objectives were passed to CC, DM, and PM, they knew they did not get any credit for lowering the LCC neither extra time to incorporate the LCC methodology. DM and PM objectives were to lock the design decisions as fast as possible with the low initial cost, directly contracting with the DGNB process requiring extra time to implement the multiple sustainable criteria's including LCC. Clear objectives of lowering future costs have potential to reward CC, PM, and DM to reduce the future cost and give an incentive to open design praxis and cooperate with the auditor.

When the tenant was changing the design during the MP phase, there were several openings in which the auditor could be activated and thereby using the LCC knowledge and the LCCbyg tool. DM and PM were considering the LCC when they tried to convince the tenant about the high cost of floors, but they were possibly missing the objective to include the auditor and LCCbyg calculations. TKC PD assigned the auditor and the DGNB objective, but there was no expansion of objectives among the design activity systems to include the DGNB objectives of implementing LCC and lower the future cost. The DGNB auditor tried to use the DGNB manual as a mediating tool towards creating objectives of implementing LCC, but the auditor was affected by the multidirectional objectives focusing on lowering the initial cost. Successfully implementing LCC in the case building design would possibly require a shared LCC objectives between CC, PM, and the auditor.

The Swiss consultant (LCC 1) described that the building owner objectives is essential to create shared LCC objectives among the building design activity systems. LCC 1 describes that public clients in the Zurich region recently has been requiring LCC as part of the evaluation of turnkey contractors. The public building owner requirements resulted in LCC involvement from the early building design and could inform about the future cost related to the design. LCC 1 experiences could indicate that there must be created shared LCC objectives from outside the activity systems and not only depending on the auditor to create the shared LCC objectives. The buildings LCC 1 described were public owned which also resulted in the future cost responsibility placed among the initial public managed design team. The present case building is a private building short-term owned by TKC PD, there might be a need to create normative or regulative objectives for TKC PD to implement LCC since there is no economic benefit of lowering LCC, a long-term owner will pay the future cost.

7.2 LCC implementation in a traditional project flow

The present case study showed the building design was made like the traditional praxis without extending the design process and allowing more time to implement DGNB. The DGNB auditor was introduced to the project when 75 percent of the decisions were locked. Norman describes that it is only during early design the building LCC can be affected (Norman, 1990). When the auditor first was assigned to the case study during the AP phase, there was a limited possibility to implement sustainability and LCC. The auditor could only document the LCC of the already locked decisions, and LCC was therefore only a documentation process. The PM and DM agree to use LCC at the end of the AP phase because they assessed no possibility of informing the design decisions with LCC. The late implementation of DGNB and no extended time to implement the criteria, including LCC, indicates that LCC calculations were mainly performed to gain the DGNB certificate.

A possible opening would be to implement the auditor earlier during the building design. TKC PD was making decisions during the PDP and TP phase. The auditor was employed in TKC and could already have been involved to advise the building design from the PDP phase. The auditor could have been using LCCbyg to compare alternatives of the building, such as facades, to inform the architect about the consequences of the façade materials. Earlier implementation of the auditor and LCC would require extra cost and possibly require an extended design process. Increased cost and extension of the design period, considered necessary to fulfil the DGNB criteria, will most likely affect the price of the building and potentially the investors' interest. Implementing the LCC considerations in the early design would also require praxis changes, which was also shown to be a challenge in the present study.

The need for earlier implementation of DGNB and the extra cost required might indicate a need to higher the expectation of the cost of implementing DGNB. Suppose the investor had to pay more but in return, received a DGNB certified building where the future cost was considered during the early design. In that case, the extra cost might be worth and appreciated by the investors. The literature, preliminary interviews and the present case study indicates that building design praxis is generally not reconfigured to include economic sustainability (Saridaki et al., 2019), (Collin et al., 2019), (Selman et al., 2018), (Brunsgaard & Bejder, 2017). When it is possible to assign DGNB late and not implement and use LCC to inform the design decisions there can possibly arise a belief in LCC as an unnecessary process to consider in future DGNB certified buildings.

7.3 Masking of cost

The DGNB ECO 1.1 requires the whole LCC calculation based on budgets and bidding (DK-GBC, 2020b). The present case study showed contractionary dynamics when the auditor was required to mask the cost due to TKC norms and the traditional competitive nature of building design praxis. The preliminary interviews have all confirmed the need to mask the cost and describes this as a large challenge that needs to be solved. The preliminary interviews indicated two types of cost masking; the first type was when the turnkey contractor sent the cost to the auditor in one number with all cost groups included. The auditor must then try to estimate an initial cost of components types in LCCbyg. The second type of cost masking was indicated in the present case study when the auditor is employed by the turnkey contractor and agreeing about masking the cost due to the company rules.

The LCCbyg is calculating the use, maintenance, and recovery cost based on the initial cost. When the initial cost was masked between the building components, it changed the initial costing's realism, and the LCC calculations were possible imprecisely caused by the fixed numbers. The masking of cost in large build contracts numbers and the subjective evaluation of material costs make the LCCbyg estimation very uncertain. The cost-related challenges caused by competitive tradition in the building design praxis is likely to explain the observed time-consuming praxis for the auditor to calculate LCC. When the whole LCC calculations are masked, the results sent to DK-GBC are possibly incorrect when used for benchmarking and comparing the LCC against reference values in the ECO 1.1 evaluation matrix.

When the LCCbyg calculation most often is required masked by the turnkey contractors, the value of using their budgets as cost data in LCCbyg disappears. The LCCbyg tool makes the cost visual and is, therefore, a mediating tool that directly collides with design norms, and it requires a transformation. Instead of changing the cost traditions, DK-GBC could instead require the whole LCCbyg calculation to be made based on generic cost data from V&S price books. If the cost of DGNB buildings was calculated based on the same V&S generic cost data, it would be easier to compare and benchmark the building's LCC values. The DGNB process needs to be adjusted to the competitive reality the companies are facing in their praxis. LCC estimations based on generic data would improve the possibility to compare the LCC calculations with reference values. Early use of LCC based on generic cost data can create a learning process and engage cognitive knowledge in LCC discussions, thereby compensating for the data accuracy (Gluch & Baumann, 2004). The LCC methodology value is the activation of early LCC considerations and discussions, future cost will always be an estimate.

7.4 LCC data handover

Saridaki & Haugbølle has suggested the implementation of LCCbyg into building design without changing the division of labour is causing multiple contradictions in communication between the activity systems (Saridaki & Haugbølle, 2019). The present case study described similar contradictions when the auditor was collecting cost and quantity data. The auditor tried to change the cost calculation praxis and suggested the TKC build contracts organised to fit LCCbyg SFB structure, but the cost calculation department rejected the suggestion. The cost calculation department argued it would cause a large change process and considerable cost to require the TKC build contracts structured in the component cost structure as required in LCCbyg.

The auditor has an engineering background and, after that, a short course in the use of LCCbyg. With a relatively low economic experience, the auditor had to integrate the LCC praxis into a traditional economic praxis managed by people with many years of cost experience and routines. Cost is one of the most important parameters for the PM, interacting and trying to change the praxis was a huge change process for an auditor with a few years' experience. It can be questioned how realistic it generally is to place the responsibility for implementing LCC and changing the historically developed calculation praxis at the DGNB auditors, LCC possibly requires much more than an auditor.

The DGNB ECO 1.1 criteria require the LCC calculation based on the budget, it could be an advantage that the cost calculation department helped the auditor with translating cost into the component cost structure LCCbyg requires. Instead of changing the cost calculation praxis, cooperation, and sharing of the LCC tasks could help the auditors work and limit the high cost of data translation. The LCC calculations could possibly be performed by the CC and later by the PM during the building design. The cost and quantity data were translated from the drawings and technical descriptions as a mediating tool in the case study. Whenever a new person interprets the cost, new understandings were made, and knowledge was possibly lost from the previous calculation. In the present case study, it was expressed that the auditor must do all the LCC calculations as an individual task, and it makes a gap and separation between the auditor and design activity system. The LCC should possibly be implemented in the CC and PM daily praxis supervised by the auditor if LCC should have a real impact on the design decisions. When it is only the auditor who understands the LCC methodology, it is difficult to make the design activity system trust the LCC calculations, and there is no shared responsibility for the results. The use of the LCCbyg requires an opening of the design practice and use of LCCbyg tool to mediate towards a common objective of lowering the LCC (Goh & Sun, 2016).

7.5 New volunteer sustainability class requires LCC

The government and AEC industry has established a climate partnership to improve sustainability in the AEC industry (Transport&Boligstyrelsen, 2020a). One of the climate partnership results is a two-year test period of a volunteer sustainability class (VSC). The VSC test period will be a basis for possible sustainability requirements in the Danish building regulations from 2022 (Trafik-bygge-Boligstyrelsen, 2020b). The VSC is like DGNB divided into environmental, social, and economic parameters and requires the use of LCCbyg (Trafik-bygge-Boligstyrelsen, 2020b). The requirements of LCC in the VSC is making a shift towards LCC requirements in non-public building design. The VSC requirements are incorporated in the Danish 2020 DGNB manual (DK-GBC, 2020b). Thereby reciprocally shaping the future sustainability requirements and gives DK-GBC a strong institutional and political influence.

The present case study indicates that CC, PM, and DM are usually not required to do LCC as part of their praxis in non-public building design. DGNB has, by requiring LCC made it visible in the present case study that there is a gap between the interfaces of building design and building owner future cost considerations. The LCC requirements in the new VSC can be the move towards closing the gap between the building design and owner. A future permanent LCC requirement in the building regulation from 2022 would possibly be the change towards a common objective for the investor, building designer, and new owner to implement LCC from early building design.

In 2006, the Danish building regulations stated energy requirements, and a new energy label (Nielsen & Zetterström, 2006). Energy is today integrated into building design as a natural part of the design praxis (Brunsgaard, 2016). The 2006 regulations have possibly been an important factor and made the design activity system willing to opening their praxis and displace roles and responsibility for the energy engineers (Brunsgaard, 2016). The missing common objectives towards lowering LCC might not be possible for the auditor to change, as building design is driven by money, and LCC calculations are expensive. The DGNB manuals are historically fitted to local norms and regulations, however, the present study showed that the implementation and use of LCC is a complete change in non-public building design. If LCC labels were required in non-public building design by the building regulations, the LCC implementation would possibly be easier for the auditor. The building design activity systems would then be familiar with integrating the LCC process and LCCbyg on every project as a natural part of building design to achieve a good LCC label. Visualizing the building LCC performance by a labelling scheme would possible be a regulative creating the missing objectives among the building design activity system to lower future cost.

7.6 Improvement of BIM and the LCC tools

Current literature suggests integrating quantity data between 3D models and the LCC calculation tools as one of the solutions to improve the use of LCC (Selman et al., 2018). For this proposal to succeed in the present case, it would require a change in the implementation and use of 3D models. The present case study showed 2D drawings made the architectural design until the AP phase. The Danish Ministry of Transport and Housing (DMTH) stated in 2019, aims to make LCCbyg capable of importing quantities and price data from BIM models (Transport&Boligstyrelsen, 2019). Saridaki & Haugbølle have tested two methods of data integration between the BIM models, V&S generic cost data and LCCbyg, concluding obstacles of missing coding systems and lack of 3D model quality indicating the need for improvement of data management (Saridaki et al., 2019). In 2020 a Strategy for sustainable construction, described a belief that the LCC cooperative challenges still can be solved and LCC used in early design by simplifying the LCCbyg tool and creating BIM integrations (Transport&Boligstyrelsen, 2020b).

"[...] Total economic calculations (LCC) are mainly performed in the final design phases of construction. The analysis tools must be simplified so that they can be included in on an ongoing basis for design decision, including the early design phase. The starting point is BIM (Building Information Modeling) to make LCA and LCC calculations easier and more flexible to perform, and the complexity of the analyzes must be reduced through a better user interfaces [...]"
(Transport&Boligstyrelsen, 2020b).

Resolving the lack of implementation and use of LCC by improving BIM and simplifying the LCCbyg tool is not considered sufficient to make the necessary changes in practice observed in the present study. The present case study results cannot be generalized. There might be some building design projects with detailed 3D models during the early building design. In that case integration between LCCbyg, and the 3D models would be advantageous. However, the present case study and preliminary interviews indicate that BIM and LCCbyg integration are currently not the most critical problems to solve. LCC is suggested to be a methodology, not a digital tool, an improved connection between LCCbyg and the BIM models in the present case study could properly make faster documentation of the whole LCC at the end of the design, but probably not improve the early use of LCC. The design decisions were based on 2D sketches and written paper mediated by technical descriptions. To improve LCC implementation in the early decision-making, there is a need to enhance the cooperative praxis between auditor and design activity systems, LCCbyg is already able to facilitate early comparative studies of building components indicating the challenges are processual.

7.7 Change of ECO 1.1 criteria

The present case study shows the auditor complies with the ECO 1.1 criteria in the 2016-2020 DGNB manual by making two whole LCC calculations documenting the building LCC (DK-GBC, 2016). The present case study results indicate the possibility to fulfil the DGNB gold certification without implementing LCC to inform the decision making. Relevant LCC considerations could have been made based on past experiences, however, there was observed gaps between the promised holistic DGNB certification and the level of LCC implementation and use in the present case study building design. Expensive maintenance of facades, floors, and a diesel-driven crane required to clean the windows is not the expectation of the DGNB certification. The possibility of DGNB gold certify a building without implementing LCC in the decision-making can possibly result in a common understanding of LCC as a documentation process.

The DGNB 2020 manual is changed, PRO 1.3 is now included in the ECO 1.1 criteria (DK-GBC, 2020b). Bringing all the LCC criteria's together under ECO 1.1 is a potential improvement and signals that LCC should be used from the early phases. However, it can be questioned if the change of the 2020 manual is enough to ensure LCC is implemented and used from the beginning of building design. If the auditor first is assigned during the AP phase, as the present case study indicates, changing the point system would have a limited effect. The present study indicates that if DGNB should influence the building design, the auditor should be part of the project from the first day of design.

Collin (2019) suggests early use of LCC to compare alternatives during the rapid ongoing design (Collin et al., 2019). LCCbyg can be used to compare building components based on generic V&S

cost data, the challenge is to make LCC an integrated part of the design process during the early phases. The ECO 1.1 criteria are changed in 2020 to require a comparison of alternatives (DK-GBC, 2020b). If ECO 1.1 were further changed and required specific LCC performance based on reference values on primary components, there would be smaller measurable objectives to lower the future cost. A particular component LCC performance, such as the façade, would be possible to communicate to the investor. The whole LCC is extensive and depends on many variables that can be difficult to create an overview. DGNB LCC components labels describing the building LCC performance of façade, roof, windows, and floors could be combined with the present study's suggested implementation of LCC labels in the building regulations. Compliance of requirements between DGNB and the building regulations has previously shown to be creating shared energy design objectives between building design and DGNB activity systems during DGNB certifications (Brunsgaard, 2016).

8. Conclusion

The present study aimed to understand how building design dynamics affect LCC implementation and use during DGNB certification. The present study concludes the building design activity systems' dynamics of missing objectives to lowering future cost results in the auditor's late implementation of LCC and separation from the building design only using the auditor and LCCbyg tool to document decisions. Furthermore, the competitive nature of building design results in the auditor must mask the cost when calculated in LCCbyg, making the LCC documentation possibly inaccurate. The answer to the research question is based on answering the three research objectives described in the following.

8.1 Characterise how LCC was implemented and used in the design of a Danish DGNB certified building.

The present case study shows that LCC was implemented when over 75 percent of decisions were locked. The findings indicate that LCC was used to documenting the building design rather than informing. The tenant requirements created multiple openings where the auditor could use LCC to compare alternatives, but the DM and PM had purposely chosen not to implement LCC in the comparison of components. The auditor was only partly participating in the design meetings and not part of the tenant's design coordination.

8.2 Understand how building design dynamics were shaping implementation and use of LCC during the design of a Danish DGNB certified building.

DM and PM decisions of not implementing LCC could be shaped by TKC PD's restrictive objective of lowering the initial cost and finalizing the building design in the frame of a short time schedule not adjusted to implement the DGNB processes. Building design dynamics make gaps between cost calculator, the auditor, and project manager, clarified when cost data was not structured on component level and must be translated and masked, making the use of LCCbyg time-consuming and the results potential inaccurate. The present case study was managed without reconfiguring the praxis and integrating the auditor as a member of the design activity system resulting in the auditor not being able to inform of the decisions making about LCC consequences of the ongoing design.

8.3 Discuss the potentials and limitations of implementing and using LCC in future DGNB certified building design.

The present study has discussed the limitations caused by the building design activity systems' limited objectives of lowering future cost and which potentials there could be to create objectives towards implementing and using LCC.

Objectives towards implementing and using LCC would potentially be initiated if both the Danish building regulations and the DGNB manual required specific LCC performance based on reference values on component level. The building regulations could possibly require building LCC labels like the current energy labels. Regulative requirements beyond the DGNB criteria could potentially make it easier for the auditor to implement LCC. The ECO 1.1 criteria could similarly require specific LCC performance on selected components based on reference values. Requirements of smaller, more manageable LCC calculations on a component level could make the calculations easier to evaluate for the building design activity system and DK-GBC when the LCC calculations should be approved. ECO 1.1 requires the whole LCC calculation to be made based on the budgets, the turnkey contractors requiring the auditors to mask the cost. To resolve the contradictory dynamics, DGNB could require generic cost data from the V&S prices books, with the possibility to remove the need for masking cost and make it easier to perform and benchmark the LCC. Future research is suggested in the implementation of an LCC label as part of DGNB and the building regulations, DGNB ECO 1.1 requirements on component level based on specific reference values in the DGNB matrix and the requirements on ECO 1.1 whole LCC calculations made on generic V&S cost data and not on budgets or bidding lists.

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