

ULRIKA UOTILA

Managing the Early Project Phase of Municipal Building Refurbishment

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ACADEMIC DISSERTATION

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ABSTRACT

Municipalities all over the world encounter, currently, serious challenges in managing their building stocks. These apparent difficulties are shown by an extensive number of municipal buildings in a poor condition and with unfunctional facilities. Even if multiple refurbishment actions are implemented, they are often delayed, only partial or fail to reach the project targets.

The theory of the management of building refurbishment projects is broadly addressed in literature. However, the municipal environment as well as high uncertainty related to the implementation of these projects provide new features to be considered. Due to this apparent gap in the research domain, this dissertation aims to extend the understanding of management of the municipal building refurbishment project, focusing on school refurbishment. With this target, the research theme is addressed by combining the aspects of various disciplines, including the management of refurbishment projects, decision making, the municipal environment and hierarchy, and uncertainty related to refurbishment projects. This dissertation focuses on the early project phase since the most crucial project decisions are concluded then. For obtaining the target knowledge, qualitative methods, including a case study, an action research study, and interviews, were used.

This dissertation identifies multiple challenges in the current project management practices and processes of municipal building refurbishment, including multi-layered and inconsistent decision-making processes, and discontinuous municipal policy. Furthermore, a lack of competence in implementing timely actions to a proper extent was recognised to result in poor outcomes. The adoption of a long-term perspective when generating refurbishment alternatives and determining the key decisions and the targets on a high administrative level instead of the project level are, in this study, suggested as the methods to advance current management practises. Moreover, devoting a great effort to initial data acquisition of an existing building under refurbishment appears to be beneficial, as well as creating alternative proposals of project implementation instead on following a certain proposal, chosen already in the early project phase. The results of this dissertation may be beneficial for both municipal

practitioners and policymakers, as they highlight the current management challenges, and utilised to develop the management process of a municipal building refurbishment.

TIIVISTELMÄ

Kuntien rakennuskannan hallinnan on todettu olevan haasteellista monissa maissa. Tästä todisteena ovat lukuisat huonokuntoiset ja toiminnallisesti epäkäytännölliset kuntien rakennukset. Monesti rakennuksia pyritään korjaamaan, mutta korjaukset ovat vain osittaisia, toteutetaan viiveellä tai niillä ei saavuteta haluttua lopputulosta.

Korjausrakennushankkeiden hallintaa on selvitetty laajasti kirjallisuudessa, mutta kunnallinen toimintaympäristö sekä kuntien korjaushankkeisiin liittyvä epävarmuus luovat tutkimusaiheeseen uuden näkökulman. Tutkimusaukon täyttämiseksi tämä väitöskirja pyrkii lisäämään tietoa ja ymmärrystä kunnallisten korjausrakennushankkeiden hallinnasta. Tavoitteeseen pääsemiseksi aiheetta on tutkittu useista eri näkökulmista: niin korjaushankkeiden hallinnan, päätöksenteon, kunnallisen ympäristön ja hallinnon kuin korjaushankkeisiin liittyvien epävarmuuksienkin kautta. Korjaushankkeen merkittävimmät päätökset tehdään hankkeen alkuvaiheessa, minkä vuoksi väitöskirja keskittyy erityisesti tähän vaiheeseen. Tutkimuksessa käytettiin kirjallisuusselvitysten lisäksi useita laadullisia menetelmiä, joihin kuuluivat tapaustutkimus, toimintatutkimus ja haastattelut.

Väitöskirjassa tunnistetaan monia nykyisiä haasteita kunnallisten korjaushankkeiden hallinnassa ja käytänteissä. Ongelmat liittyvät erityisesti monitasoiseen ja epäselvään päätöksentekoon sekä epäjohtomukaiseen politiikkaan. Myös osaamisen puute korjaushankkeiden läpiviennissä aiheuttaa epätoivottuja lopputuloksia. Väitöskirja esittää kunnallisen korjaushankkeen kehittämiseksi pitkänaikavälin näkökulman korostamista korjausvaihtoehtoja tuotettaessa sekä hankkeiden päätavoitteiden ja -linjojen määrittämisestä korkeammilla hallinnollisilla portailla hanketason sijaan. Lisäksi lähtötietojen perusteellinen selvittäminen sekä eri korjausvaihtoehtojen rinnakkainen kehittäminen yhden jo aikaisessa hankevaiheessa päätetyn vaihtoehdon sijaan voi olla hyödyllistä. Väitöskirjan tulokset tuovat esiin kunnallisten korjaushankkeiden hallinnan haasteita ja voivat näin hyödyttää sekä kuntien rakennushankkeissa mukana olevia viranhaltioita että päättäjiä. Lisäksi tuloksia voi käyttää kunnallisten korjausrakennushankkeiden hallinnan kehittämiseen.

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Tampere, October 2021

Ulrika Uotila

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PUBLICATIONS

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Uotila, U., Saari, A. and Junnonen, J.-M, 2019, Municipal challenges in managing a building with noted health symptoms, *Facilities*, Vol. 38 No. 5/6, pp. 365-377. <https://doi.org/10.1108/F-07-2019-0073>

Publication II

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Publication IV

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Author's contribution to the publications

Publication I

The author was responsible for collecting the data by scrutinizing reports and other documents as well as performing the analysis. The research data was partly collected in collaboration with the co-authors. The author was responsible for writing the paper as the corresponding author. The co-authors provided valuable comments.

Publication II

The author was responsible for writing the article as the corresponding author. The research data was collected with the co-authors. In addition, the co-authors also presented valuable comments and suggestions to improve the paper.

Publication III

The author was responsible for doing the research and writing the paper. The co-authors provided valuable comments and suggestions to improve the paper.

Publication IV

The author was responsible for conducting the research by carrying out the interviews and writing the paper as the corresponding author. The co-authors presented valuable comments and suggested some improvements to the paper.

1 INTRODUCTION

In Finland, a major share of municipal buildings has been built before the early 1990s, including 85 per cent of schools (Korhonen *et al.*, 2018). Even though this building stock is aged and, often, also damaged, a large number of municipalities have postponed major repairs, which has increased the need for actions on a broader scale (Kero, 2011). Besides the repair needs, multiple municipal buildings require alterations in their facilities, as buildings' purposes of use have changed or the existing facilities do not meet the current technology or condition requirements.

Although there have been attempts to repair the defects and aged structures of municipal buildings, the projects have failed too often: project targets have not been achieved, the budget has been exceeded, or project implementation or schedule have been significantly delayed. Typically, building refurbishment projects are more complex than new building projects because of the features the existing building creates. These features produce unique challenges, such as increased uncertainty, since as-built data is often defective (Zolkafli *et al.*, 2012; Ali and Au-Yong, 2013), unavailable (Ali, 2010), or all the data cannot be discovered until demolishing work has begun (Oloke, 2017). In addition, feasible solutions are, often, unclear and estimations concerning schedule and cost are difficult to produce. Furthermore, safety issues, including hazardous materials and dangerous operations, generate challenges.

Typically, the management of a refurbishment of a municipality-owned building is challenging due to both the complicated nature of refurbishment projects and the characteristics that the municipal environment creates. Municipal authorities and politicians face public pressure to take action. However, limited appropriations and complicated decision-making processes hinder implementation. Moreover, uncertainty concerning the existing buildings, unclear or changing needs and requirements, as well as different interests of stakeholders, create an environment where it is difficult to make optimal decisions. The poor economic situation of many municipalities (Shen, Lo and Wang, 1998; Smith and Stewart, 2007) together with the high level of repair backlog in the municipal building stock (Støre-Valen,

Kathrine Larssen and Bjørberg, 2014; Korhonen *et al.*, 2018) make the situation even more demanding.

Irrespective of the complex nature of municipal building refurbishment, the management of these projects has not been properly studied in prior research. Generally, the management of building refurbishment projects has been studied by focusing on the management of the production performance in a refurbishment project (Wandahl and Skovbogaard, 2017; Kemmer, 2018; Kemmer and Koskela, 2020) and by addressing the challenges and opportunities of refurbishment management (Egbu, 1997; Arain, 2005). In addition, the characteristics of refurbishment projects have been examined by Ali, Kamaruzzaman and Salleh (2009), and many authors, including Reyers and Mansfield (2001), Ward and Chapman (2008), Mansfield (2009), Zolkafli *et al.* (2012), Noori *et al.* (2016) and Yacob *et al.* (2018), have addressed risks and uncertainty in them. Moreover, Egbu (1999) and Yacob *et al.* (2018) have focused on leadership of refurbishment projects, Chen *et al.* (2017), Egbu *et al.* (2002) and Oloke (2017) on management of safety and health issues, and Ali *et al.* (2018), Egbu *et al.* (1998) and Rahmat (1997) on planning and control processes and costs. Lee (2015), then, has studied management of client satisfaction, and Ekanayake *et al.* (2018) and Premachandra *et al.* (2018) problems in refurbishment projects. Mainly, the focus of these studies is limited to building refurbishment projects in the private sector. Due to the different nature of the private and the public sector, and the major challenges municipalities face with their building stock, the need for a better understanding of the management issues of municipal building refurbishment, in particular, is apparent. Increased knowledge of current practises and challenges in project management is urgently needed to improve the processes. Advanced management of municipal building refurbishment, especially in the early project phase, can be beneficial for the municipality and society in many ways, including financially and from the viewpoint of building history. But, it may also have a favourable impact on the health of municipal building occupants. Due to the aforementioned issues, this dissertation aims to obtain a better understanding of the management of the early project phase of a municipal building refurbishment project, in particular, focusing on refurbishment of a school building.

1.1 Aim and Research Questions

The primary aim of this study is to broaden the understanding of the management of a municipal building refurbishment project in the early project phase with the

purpose of improving the management of municipal building assets. The following research questions have been formulated to act as a guidance to achieve the research target:

- What challenges do municipalities have when refurbishing and managing municipality-owned buildings?
- How are decisions made in a municipal building refurbishment project in the early project phase?
- Where does uncertainty in the early phase of municipal building refurbishment projects originate from and how can it be identified and reduced?

1.2 Scope and Limitations of the Research

This study is limited to concern the management of building refurbishment projects of municipality-owned buildings, especially focusing on refurbishment of schools and day nurseries. A municipality, in this study, is defined as a town or a district that has a local government. In Finland, municipal governments are elected local authorities that provide services and facilities for local residents. As the results are limited to providing evidence only of the management practices of school campuses and day nurseries, much cannot be concluded regarding the refurbishment management of other municipality-owned buildings, for example, hospitals, offices, or municipal residential buildings.

The scope of the empirical studies of this dissertation mainly covers municipal building refurbishment projects in Finland. This national context has a major impact on the results, as each country has its distinctive organisation structures and procedures in municipal projects as well as cultural characteristics. However, as the municipal organisation and environment in Finland is rather similar to many countries, especially the Nordic countries, relevant studies are explored also internationally.

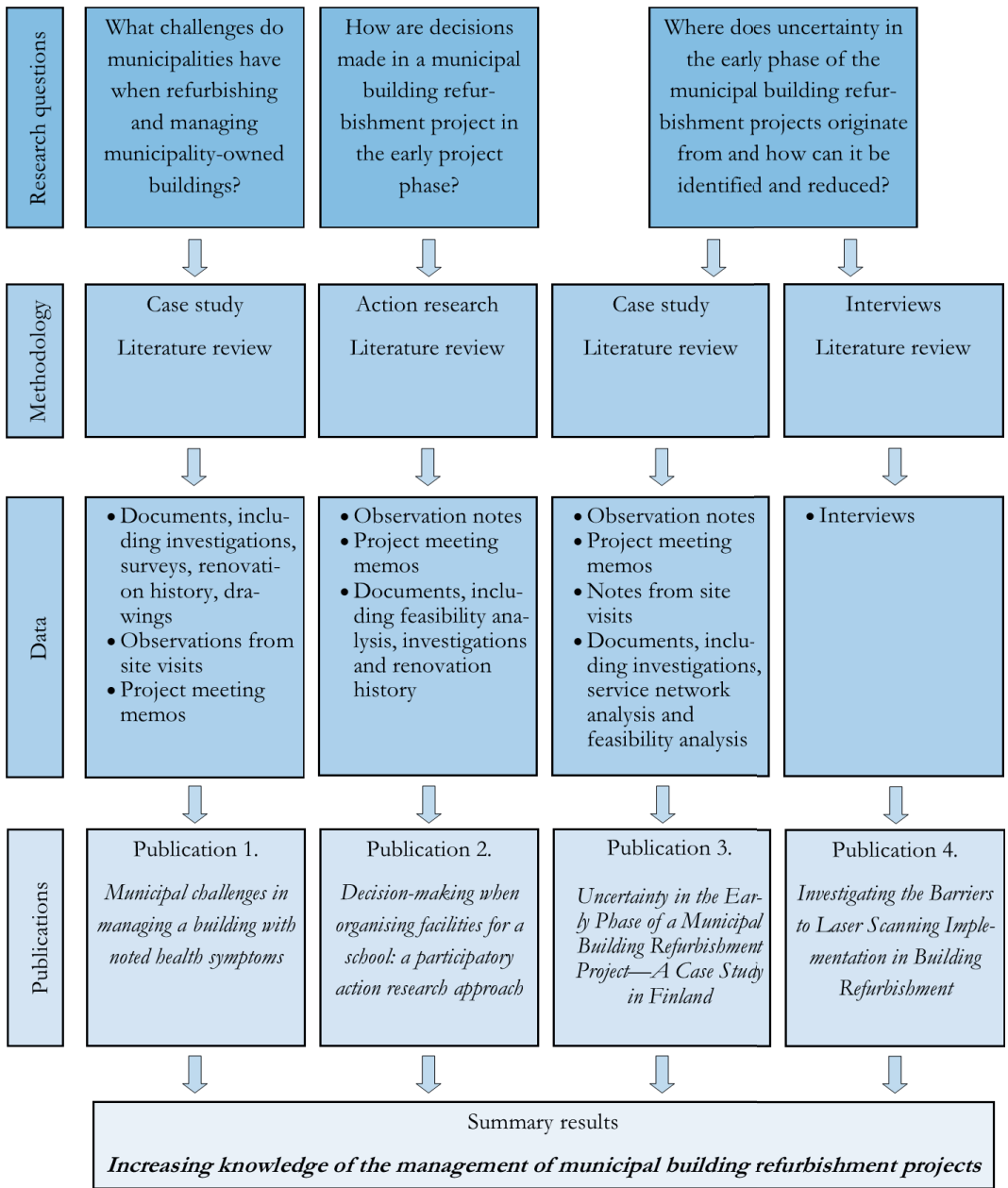
This research focuses particularly on complex building refurbishment projects, in which the complexity refers to refurbishment projects concerning a large-sized, structurally complicated or listed building; projects with an alteration to the intended use of the building; and the refurbishment of buildings with noted building-related

symptoms. The study is limited to the management issues in the early phase of the project, focusing especially on the project planning phase, whereas the implementation phase is mainly left outside of the scope. The early project stage is selected as it is the most crucial for the project due to the decisions concerning targets, budgets, schedules, and project characteristics made during this phase. The definition of refurbishment adopted in this research follows the interpretation by Egbu et al. (1998), according to which refurbishment refers to such works as improvements, adaptation, upgrading, rehabilitation, restoration, modernisation, conversion, retrofit, and repair that are carried out on existing buildings for a variety of reasons.

1.3 Research Process and Structure

To achieve the research goal of extending the understanding of the management of a municipal building refurbishment project in its early phase, this study is composed by addressing and bringing together several sub-categories of the research topic. Hence, the themes of the dissertation were formed step by step by collecting and analysing the data to reach conclusions. The research process, including the research questions and the publications, is presented in Figure 1.

Figure 1. The research process of this dissertation



In order to better understand the research problem, a literature review and empirical studies were conducted. The empirical studies were conducted to investigate the intrinsic characteristics of a municipal building refurbishment project as well as to

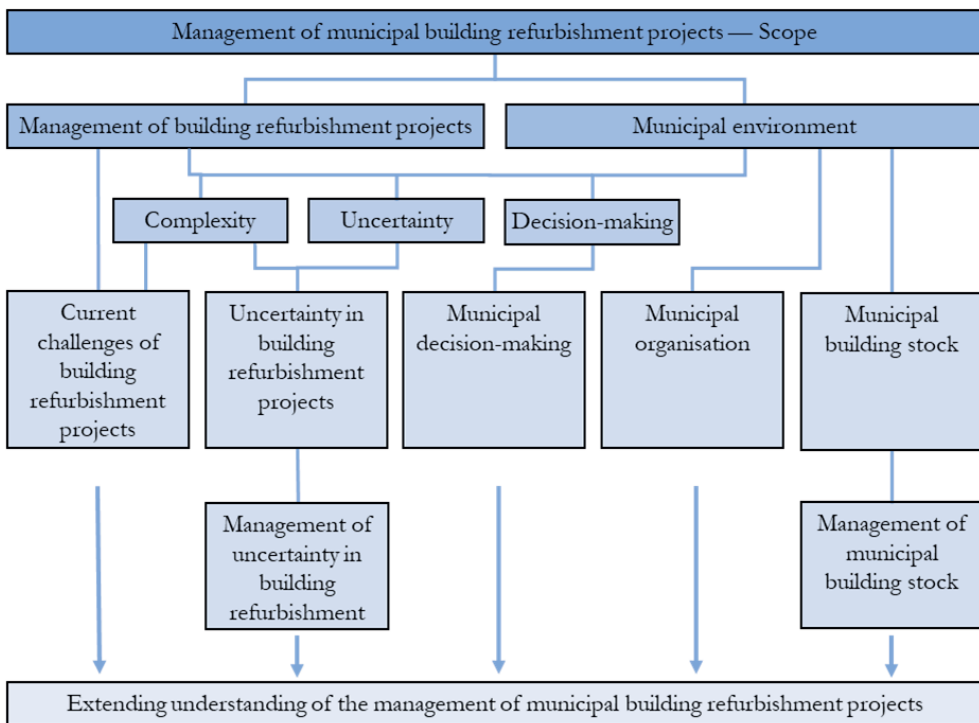
examine the current practises of municipal project and facility management. These studies addressed the problems and challenges faced in a municipal building refurbishment project as well as in facility management. Furthermore, the processes and decision-making in the early phase of a refurbishment project, uncertainty related to the project, and the features the municipal environment produces in the project were examined. In addition, tools and methods for improving the management processes, especially by decreasing uncertainty, were generated. The knowledge gained from these studies extended the understanding of the management of a municipal building refurbishment project.

2 THEORETICAL BACKGROUND

As the main intention of this dissertation is to understand the management of municipal building refurbishment, the theoretical background is addressed diversely. It covers various sub-categories and scientific disciplines under the umbrella of the research topic. The main sub-areas are divided into two categories: (1) the management of building refurbishment projects, including topics concerning management; project challenges; and the characteristics of refurbishment projects; and (2) the municipal environment, including the characteristics of a public building stock; the municipal decision-making process; organisational hierarchy; and the characteristics of a municipal building project. Commonly, building refurbishment projects are characterised as being of high uncertainty and complexity. As a lack of understanding of the complicated nature of refurbishment projects may lead to poor decisions and project performance (Kemmer and Koskela, 2020), theories of decision-making under uncertainty as well as the themes of complexity and uncertainty, in general, are also studied in this chapter.

Figure 2 shows how the addressed sub-areas support in achieving the research target. An examination of each sub-area was important for extending the understanding of the building refurbishment process in a municipal environment as well as for understanding its intricacy.

Figure 2. Sub-categories supporting the achievement of the research target



2.1 Characteristics of Municipal Building Refurbishment Projects

The municipal implementation process of a building refurbishment project differs from that of the private sector in several ways. In municipal projects, project preparation and decisions are made in separate phases and by different operational bodies, whereas in the private sector the implementation is typically a more straightforward process. In addition, municipal building refurbishment projects are, typically, rather challenging due to the building types the municipal property comprises. Often, the buildings are rather large in scale and contain demanding activities or technology. Municipal properties also include several listed buildings, and preservation generally complicates the process of refurbishment. Additionally, political issues cause uncertainties and difficulties for municipal building projects. Sometimes projects are hurried or implemented with deficient preparation or postponed for political purposes (Li and Wang, 2008; Hanis, Trigunarsyah and Susilawati, 2010; Aapaoja and Haapasalo, 2014). In addition, from an economic perspective, municipal building projects are not, traditionally, prioritised in an

optimal way in the long term, as decisions are often based on investment costs instead of life cycle costs.

Typically, the project targets of building refurbishment projects are generated based on the building condition. However, the municipal outlines and strategies, and estimates of the demands also need to be taken into account. These estimates are typically based on calculations of migration and population trends. Even if the key project targets would be clear, each project contains multiple targets on a smaller scale, such as project costs or duration, which might have a major impact on the entire project. Striving for seamless project implementation, the project stakeholders should reach a consensus on those issues. For facilitating this target setting, several methods have been generated. For example, prioritised weights of stakeholders' importance are used for targeting the project scope and evaluating the aims (Fageha and Aibinu, 2016). In addition, the stakeholders can address the weight of each element, and the total scores for the elements can be calculated by multiplying the scores with the importance weight for each stakeholder (Fageha and Aibinu, 2016).

Multiple stakeholders, including a project manager, experts such as condition assessment consultants, designers, representatives of various municipal departments, facility users, and councillors, are involved in a municipal refurbishment project. As the stakeholders, typically, have different interests regarding the scope and requirements of the municipal building project (Fageha and Aibinu, 2016), it is important to bring them to the project as early as possible (Burgdorff, 2011), and pay special attention to target setting.

Municipal facility management is not a systematic process that considers all the important aspects, such as economical, functional, cultural, safety, and ecological viewpoints. It is a process that is considerably influenced by effective phenomena, stakeholders' own interests (Österreicher and Geissler, 2016), and the political context (Borge and Hopland, 2012, 2017; Hopland and Kvamsdal, 2018). Therefore, decisions and implementations are not always made efficiently by reaching optimal solutions, and public money is not used in the most economic way.

2.2 Refurbishment Strategies

Refurbishment is typically needed when a building fails to perform as required (Ali, Kamaruzzaman and Salleh, 2009) or it is required to accommodate new uses (Fernandez, 2011). However, the type and extent of the refurbishment relies on multiple features, including client resources and expectations; building specific information; as well as policies and regulations (Ma *et al.*, 2012). In the literature, the types of refurbishments are categorised in multiple different ways. Arain (2005) divides the types and reasons for refurbishments as follows:

- Corrective refurbishment – Failure in buildings
- Space altering refurbishment – Change in use
- Optimising refurbishment – Optimisation of economic factors
- Pleasure refurbishment – Subjectiveness of the decisions of building owners
- Opportunity refurbishment – Change of circumstances

The selected refurbishment strategy is an important element of facility management, as it has a major impact on a building's profit and costs in the long term. If a building is poorly maintained and refurbishment actions are delayed, it progressively loses its value and utility (Chan, 2014). Even though routine maintenance reduces the deterioration, periodic refurbishment actions are needed to maintain the condition of the building at an acceptable level and to fulfil the needs.

Multiple tools and methods have been developed to assist decision-making in refurbishment actions to reach the optimal solution for each problem. Several authors (e.g. Caccavelli and Gugerli, 2002; Short *et al.*, 2010; Chidiac *et al.*, 2011; Asadi *et al.*, 2012; Ma *et al.*, 2012; Bull *et al.*, 2014; Passer *et al.*, 2016; Österreicher, 2018) have developed tools for assessing refurbishment actions from an energy-efficiency viewpoint. However, other aspects, including economic, health, aesthetics, longevity, and functionality, have been studied more limitedly. Only a few authors, such as Flourentzos *et al.* (2000), Juan *et al.* (2009), and Kaklauskas *et al.* (2005), have considered also these less studied aspects when developing tools and methods for decision-making for an optimal solution.

2.3 Management of a Building Refurbishment Project

A building refurbishment project is usually more challenging to manage than a new building project because of the circumstances and limitations the existing building imposes, as well as social, technological and legislative aspects (Ali, Rahmat and Hassan, 2008). Moreover, each refurbishment project is unique and typically contains a high level of risk and uncertainty (Holm, 2000; Egbu *et al.*, 2002; Rahmat and Ali, 2010; Bryde and Schulmeister, 2012; Noori *et al.*, 2016). As a consequence, in many refurbishment projects, project costs and duration exceed estimations, or project requirements and targets are not achieved (McKim, Hegazy and Attalla, 2000; Mills, 2001; Love and Edwards, 2004; Naaranoja and Uden, 2007; Roy and Kalidindi, 2017).

In order to achieve success in a refurbishment project, budget control and time management are important components of project management (Egbu, 1994, 1999), even though these are typically difficult to estimate accurately due to the high level of uncertainty and complexity. Furthermore, the management of project risks and uncertainties is, also, a vital part of refurbishment project management (Egbu, Young and Torrance, 1998). Typically, planning a refurbishment project is challenging because the exact scope of the work cannot be defined in advance, and the project needs to be carried out under high uncertainty (Okoroh, 1992). Furthermore, the initial data of an existing building is never complete; and multiple decisions as well as much planning need to be carried out during the construction work (Rahmat and Ali, 2010). In addition, the conditions and information may change dramatically during the refurbishment project. Therefore, the ability to cope with changes and unexpected issues (Egbu, 1994; Lee, 2015), and a flexible approach (Okoroh, 1992; Ishak, 2018; Yacob *et al.*, 2018; Garcés, 2020) are highly required in refurbishment project management.

While the number of participants in construction projects is high, it is, typically, even higher in refurbishment projects, as tenants, owners, condition surveyors etc. are involved in the project (Holm, 2000). Communication among stakeholders, including users, is considered to be a prerequisite for successful risk management (Nutt, Walters and McLennan, 1998) as well as having particular importance for meeting project targets (McKim, Hegazy and Attalla, 2000; Rahmat, Shabri Abd and Adnan, 2012). Project stakeholders' interest toward the project also has a remarkable effect on project success (Ali, Rahmat and Hassan, 2008; Lund *et al.*, 2016). As refurbishment projects are complicated, project leadership has a significant role in

project performance. Besides technical skills and experience, a project manager also needs communication and decision-making skills (Lee, 2015), as well as team building, planning and strategising skills (Egbu, 1999). Additionally, such characteristics as being empathetic, inspirational, flexible and having high motivation, are desired qualities in the leader of a building refurbishment project (Yacob, Saruwono and Ismail, 2018).

Often, refurbishment projects suffer from a lack of data concerning the condition of the building or as-built data (Zolkafli *et al.*, 2012; Oloke, 2017). This may cause design changes and increased costs and duration (Ali, Kamaruzzaman and Salleh, 2009). Hence, initial data gathering, including building condition investigations and as-built data, should be organised in a rather large scale already at the early phase of the project (Lund *et al.*, 2016). As key decisions are made in the early phase of the project, the accuracy of the initial data also has a major impact on decisions and, thus, the outcomes of the project. In addition, accurate information of the structures and materials is a key element in health and safety management (Egbu *et al.*, 2002). In refurbishment projects, health and safety risks need to be taken into account with a greater emphasis than in new construction, since working in an occupied building, in limited spaces, and with hazardous materials imposes additional challenges (Okoroh, 1992; Egbu, 1994; McKim, Hegazy and Attalla, 2000). Moreover, acquiring proper measurement data should be emphasised in the early project stage, as correctness and accuracy of that data has a significant effect on design performance. Generally, investing more resources into the early phase of a building refurbishment project is considered to have a positive effect on project outcomes (Egbu, Young and Torrance, 1998; Lund *et al.*, 2016). However, all the issues concerning, for example, the condition of the existing building, cannot be surveyed or discovered even with detailed surveys (Bryde and Schulmeister, 2012). Therefore, there is some level of uncertainty in every phase of each refurbishment project (Lund *et al.*, 2016).

In Finland, a building refurbishment project is, typically, roughly divided into eight stages: feasibility analysis; project planning; schematic design; design development; detailed design; construction; commissioning; and guarantee period (RT 10-11224, 2016). The early project phases are critical in project management, since the most significant decisions concerning the specific scope, budget, quality and schedule of the project, are made in those phases, particularly during the project planning phase (RT 10-11224, 2016). Thus, these phases need to be given sufficient time in order to gain all the required initial data and direct the project into the target

direction (Construction Industry Research and Information Association, 1994). After the project planning phase, the aim is to carry out the project targets within the set limits.

2.4 Project Complexity

Building refurbishment projects have particular challenges in project management due to the complex nature of the projects (Bryde and Schulmeister, 2012). As project complexity is associated with cost overruns (Qazi *et al.*, 2016; Luo *et al.*, 2017; Ma and Fu, 2020), delays (Qazi *et al.*, 2016; Luo *et al.*, 2017; Ma and Fu, 2020), and reduced quality (Luo *et al.*, 2017; Ma and Fu, 2020), complex projects have received increasing attention among scholars and practitioners, and there have been attempts to define, characterize, and manage project complexity. Even though this subject has been widely studied, there is still a lack of consensus on the definition of project complexity. Simon (2019) states that ‘how complex or simple a structure is depends critically upon the way in we describe it’. Hence, this so called perceived complexity considers complexity as subjective, which can be understood through the perception of an observer (Vidal and Marle, 2008). Vidal and Marle (2008) state that ‘project complexity is the property of a project which makes it difficult to understand, foresee and keep under control its overall behaviour’. Baccarini (1996) classifies project complexity into organisational complexity and technological complexity, and defines it as ‘consisting of many varied interrelated parts and can be operationalized in terms of differentiation and interdependence’. According to Williams (1999) ‘complexity is concerned with the underlying structure of the project’ Williams (1999) also divides complexity into two dimensions: structural uncertainty, and uncertainty. Even though project complexity is typically considered as a negative aspect, it has also a positive influence on the project as it may create opportunities (Vidal and Marle, 2008).

Complexity has been shown to take various forms, including organisational (Baccarini, 1996); social (de Bruijn, van Twist and Verheul, 1996; Jaafari, 2003; Girmscheid and Brockmann, 2008); technological (Baccarini, 1996; de Bruijn, van Twist and Verheul, 1996); cultural (Girmscheid and Brockmann, 2008; Brockmann and Kähkönen, 2012); and environmental (Luo *et al.*, 2017; Gao *et al.*, 2018). Organisational complexity in construction projects refers to the numerous elements related to the organisations, including number of stakeholders, objectives, and departments involved the project; decisions to be made (Vidal and Marle, 2008); and

people interactions (Whelton, 2004). In addition, the hierarchical structure of the organisation is a distinctive feature, which complicates, especially, a municipal refurbishment project. Furthermore, a project may have numerous customers, which use the building in different ways, and have different, also conflicting, needs and interest towards the building (Bascoul, 2017), which increase the complexity. According to Mulholland and Christian (1999) the organisational aspect is the most important component resulting complexity of construction project. Social complexity is related to the number and diversity of project stakeholders, and their impact, including interest and power towards the project (Brockmann and Kähkönen, 2012). Technological complexity in construction projects deals with the difficulty of the various technologies required during the project implementation (Bosch-Rekvelde *et al.*, 2011). Cultural complexity refers to the stakeholders' cultural diversity, which requires coordination of different cognitive maps (Brockmann, 2009). Girmscheid and Brockmann (2008) divided this complexity into three categories: national enculturation, industrial culture and organizational culture. Environmental complexity deals with the various physical and social environmental factors, including natural, political, economic, and regulatory factors (Luo *et al.*, 2017; Gao *et al.*, 2018).

Tools and methods to manage complexity is presented in the literature of project management. Baccarani (1996) has suggested integration as a tool for complexity management, Lehtiranta (2011) and Fang and Marle (2013) risk modelling and mitigation strategies, Yang *et al.* (2018) stakeholder network analysis, and Nguyen and Mohamed (2018) stakeholder management. In addition, Thomas and Mengel (2008) have proposed project management training and education, Brady and Davies (2014) recommended cultivating adaptability and innovative approaches, and Bascoul (2017) suggested to use Lean principles and methods to manage project complexity.

Besides to the ambiguous definitions and classifications of project complexity, also coherence between uncertainty and complexity is vague. Some authors, including Atkinson *et al.* (2006) consider complexity as an element of uncertainty, whereas Geraldi and Adlbrecht (2007) and Geraldi *et al.* (2011) present uncertainty as an element of complexity. Moreover, Sommer and Loch (2004) treat complexity and uncertainty as separate constructs.

2.5 Uncertainty

According to Mulholland and Christian (1999), uncertainty is one of the possibly negative consequences of construction project complexity. Compared to new building projects, refurbishment projects, generally, include more sources of uncertainty due to the circumstances and features the existing building produces (Zolkafli *et al.*, 2012). These uncertainties significantly affect decisions and project management and are strongly related to project performance (Egbu, 1999; Yacob *et al.*, 2018). As building refurbishment projects often fail (Mills, 2001; Love and Edwards, 2004; Naaranoja and Uden, 2007; Roy and Kalidindi, 2017) and their complexity increases (Baccarini, 1996; Zwikael and Ahn, 2011), efficient management of uncertainty and risks is considered to be an important element when seeking to improve project performance (Ward and Chapman, 2008; Zwikael and Ahn, 2011) and upgrade the outcomes of complex projects (Mawby and Stupples, 2000).

Uncertainty is defined as ‘a lack of certainty’ and can be related to cost, duration, required information, or quality (Ward and Chapman, 2003). It can be classified according to the issues a decision maker is uncertain about, including outcomes; situation; and alternatives, and according to the sources that cause the uncertainty, including incomplete information; inadequate understanding; and undifferentiated alternatives (Lipshitz and Strauss, 1997). Even though uncertainty appears in different forms, the common aspect of these appearances is a lack of knowledge about some key aspect of the project (Cleden, 2012). Uncertainty can be reduced by using several procedures such as collecting additional information to be processed before decision-making (Galbraith, 1974); deferring decisions until the required information is available (Hirst and Schweitzer, 1990); eliminating sources of uncertainty (Allaire and Firsirotu, 1989); and improving predictability through shortening time-horizons (Cyert and March, 1963).

Even though a large group of scholars defines uncertainty as a risk or a risk as uncertainty, more often these are categorised as two different concepts (Mehr and Cammack, 1972; Philippe, 2001). The key difference between these concepts is that the outcomes of risks are known, whereas the outcomes of uncertainty are unknown (Knight, 1921). In addition, risks are usually considered as events, whereas uncertainty is based on more general sources and needs to be examined in a broader perspective. Risks are easier to manage compared to uncertainty, as the outcomes and probabilities of risks can be estimated, whereas uncertainty is more blurred.

However, uncertainty can, sometimes, be transformed into a risk by gathering more information and knowledge. Building refurbishment projects contain multiple risks, but due to the complex nature of the projects, uncertainty is a special characteristic of these projects, as it has a major impact on project performance and it needs to be taken into account on a large scale.

2.5.1 Uncertainty in a Building Refurbishment Project

The sources of uncertainty are unique in every building refurbishment project. However, also, multiple common sources exist in these projects, as presented in Table 1.

Table 1. The sources of uncertainty in building refurbishment projects

Source of Uncertainty in a Building Refurbishment Project	Authors
Unforeseen site conditions, lack of drawings, lack of design information	McKim, Hegazy and Attalla, 2000; Arain, 2005; Singh, 2007; Rahmat and Ali, 2010; Zolkafli <i>et al.</i> , 2012; Ali and Au-Yong, 2013; Nibbelink, Sutrisna and Zaman, 2017; Oloke, 2017; Yacob <i>et al.</i> , 2017; Ekanayake, Sandanayke and Ramachandra, 2018
Lack of predictability of costs	Reyers and Mansfield, 2001
A tight budget, lack of funds	McKim, Hegazy and Attalla, 2000; Reyers and Mansfield, 2001; Arain, 2005; Rahmat and Ali, 2010; Babangida, 2014; Ali, Azmi and Baaki, 2018; Ekanayake, Sandanayke and Ramachandra, 2018
A tight schedule	McKim, Hegazy and Attalla, 2000; Reyers and Mansfield, 2001; Arain, 2005; Rahmat and Ali, 2010; Yacob <i>et al.</i> , 2017; Ekanayake, Sandanayke and Ramachandra, 2018
Lack of availability of materials	Zolkafli <i>et al.</i> , 2012; Babangida, 2014; Ali, Azmi and Baaki, 2018
Occupants in the building during the refurbishment work	Babangida, 2014; Yacob <i>et al.</i> , 2017
Lack of availability of working space on site	Babangida, 2014; Yacob <i>et al.</i> , 2017
Lack of involvement of key participants in the project and poor communication among project participants	Rahmat, Torrance and Young, 1998; Rahmat and Ali, 2010; Nibbelink, Sutrisna and Zaman, 2017; Ekanayake, Sandanayke and Ramachandra, 2018
Legislation requirements	Holm, 2000; Ali and Zakaria, 2012
Human factors, including leadership qualities, skills and decision-making	Egbu, 1999; Yacob <i>et al.</i> , 2017

Uncertainty is faced in every phase of a refurbishment project, but it typically reduces during the project: The level of uncertainty is the highest in the beginning of the project, mainly, because of a lack of knowledge and information, and reduces

progressively towards the end of the project, as more information and knowledge is gathered (Pender, 2001). Because of the limited information and knowledge the stakeholders have in the beginning of the project, the main decisions concerning the project are made under uncertainty. Therefore, the decision-makers' own assumptions and views have a major impact on the decisions.

2.5.2 Uncertainty Management in a Building Refurbishment Project

The aim of uncertainty management is to understand where and why uncertainty is important and unimportant in the project context (Ward and Chapman, 2003). Several authors (Green, 2001; Ramgopal, 2003; Ward and Chapman, 2003) have criticised the project risk management process for paying too little attention to uncertainty. In addition, typically, practitioners are rather unfamiliar with uncertainty management (Kähkönen, 2006), whereas, they usually are well-informed of risk management practices and use these practices in projects (Kähkönen, 2006). Risk management tends to improve a project's performance by decreasing the probability and impact of negative events and increasing the probability and impact of positive events (Ramgopal, 2003; Project Management Institute, 2013). Additionally, risks are sought to be reduced or maintained on the assumed level. Typically, project risk management contains separate processes or steps. A simple management process includes the following phases: 1. risk identification; 2. risk analysis; and 3. risk response.

Uncertainty management is typically a rather similar process and similar steps and methods as the ones used in risk management can be used also for uncertainty management (Kolltveit, Karlsen and Grønhaug, 2004). However, tools created for risk management are often inadequate and useless alone in uncertainty management (Cleden, 2012; Harvett, 2013). Furthermore, the process of uncertainty management should contain risk and opportunity management, and identifying and managing the sources of uncertainty in a broad sense (Ward and Chapman, 2003; Atkinson, Crawford and Ward, 2006). Even if uncertainty is well managed in a project, it can never be eliminated completely (Cleden, 2012). Some level of uncertainty remains unfulfilled in the project during its life-span (Cleden, 2012; Lund *et al.*, 2016).

The process of uncertainty management can be derived from project risk management by modifying the process and shifting the emphasis. This might contain the following approaches:

- revising terminology such as from risk management into uncertainty management (Ramgopal, 2003);
- putting more emphasis on the origins of uncertainties (Ward and Chapman, 2003);
- emphasising some aspects of project-related uncertainty outside of the project context (Ramgopal, 2003);
- advancing the process, since uncertainties can be identified with less information than risks (Ramgopal, 2003);
- reflective learning and sensemaking;
- enabling flexibility (Perminova, Gustafsson and Wikström, 2008);
- classifying uncertainties into various types on the basis of the potential effects and estimating which types are the most important (De Meyer, Loch and Pich, 2002), and;
- forming good relationships with all the project participants (Ali and Zakaria, 2012).

In addition, uncertainty can be managed by adopting knowledge strategies to advance discovering the sources of uncertainty; by using anticipation strategies to gain a more holistic view of uncertainty; and by utilising resilience or learning strategies (Cleden, 2012).

Even though multiple tools and methods have been created for managing risks and uncertainty, they are not broadly used. For example, according to Cooper et al. (2019), in municipalities, risks are often managed informally based on the extensive experience and knowledge of municipal workers and leaders.

2.6 Decision-Making under Uncertainty

The literature provides multiple theories and models of decision-making. These theories are often divided into two basic models: a rational model and a bounded-rational model. Typically, the rational model breaks down decision-making into six stages as follows:

1. Identifying the problem
2. Generating alternative solutions
3. Evaluating the alternatives
4. Choosing an alternative
5. Implementing the decision
6. Evaluating decision effectiveness

The rational model assumes decision-makers to know their alternatives, outcomes, and decision criteria, and to be able to make optimal decisions. While the rational model presumes a decision-maker as completely rational and systematic, the bounded-rational model emphasises incompleteness, as decisions are made with limited time, information, and resources—under uncertainty. The bounded-rational model implies decision-makers never to be able to find all possible alternatives and never to be able to evaluate the alternatives completely (Simon, 1979). This high uncertainty is a key characteristic significantly affecting decision-making in refurbishment projects. The world itself, including nature, and social and cultural constructions, is not uncertain (Lindblom, 2006). In contrast, uncertainty is a social construction created and maintained by a decision-maker due to the limited knowledge of the world around the decision-maker (Duncan, 1972).

The majority of decisions in a real-world situation are made in circumstances in which goals, constraints or possible actions are not well-known precisely (Bellman and Zadeh, 1970). However, a decision-maker tends to evaluate the future prospects as well as the consequences and probabilities of the alternative decisions based on the available information (Lindblom, 2006). Thus, the quality and quantity of the information has a significant role on the uncertainty the decision-maker experiences when making the decision (Lindblom, 2006). However, due to the limited

information and knowledge, as well as uncertainty related to the future, the decision-maker cannot evaluate all future prospects, including probabilities and their consequences (Davidson, 1991). This causes uncertainty in the decision-maker about the validity and consequences of his or her decision, and typically delays the decision-making process (Shelley, 1991).

Even though multiple theories have been generated to describe decision-makers' actions, different people approach decision-making in different ways (Galotti *et al.*, 2006), since a decision-maker's cognitive style significantly influences the individual's decision process (Mason and Mitroff, 1973; Mitroff and Kilmann, 1975; Henderson and Nutt, 1980; Scott and Bruce, 1995). The main differences among decision-makers are the amount of information used when making a decision, and the number of alternatives identified when reaching a decision (Driver, Brousseau and Hunsaker, 1998). These differences in human behaviour are explained by Simon (1956), who presented the theory of seeking satisfactory solutions rather than optimal ones. Additionally, Schwartz (2002) redeveloped the theory and proposed that some decision-makers attempt to find the best solutions while others tend to find a solution that is satisfactory or good enough in the given standards. According to Driver *et al.* (1998), a satisfier uses only enough information to get one or more good enough solution, whereas a maximiser tends to collect all relevant information before making the decision. In addition, some decision-makers try to avoid the decision-making process entirely (Scott and Bruce, 1995; Galotti *et al.*, 2006), and some tend to implement the decisions immediately (Scott and Bruce, 1995).

Often, decisions contain multiple separate decisions, such as those determining whether to renovate an existing building or build a new one, and if renovating the building, what the extent of the renovation will be (Wilkinson, Remøy and Langston, 2014). Hence, decisions are limited by prior decisions (Cyert and March, 1963), and decision-making can be considered as a process that involves multiple choices (Lunenburg, 2010). All decisions are not equally important, as decisions differ in terms of their scope, consequences, risks and benefits (Natarajan and Duran, 2012).

In organisations, decisions are, typically, made in groups. Multiple scholars state that decisions made by groups often lead to better outcomes compared to decisions by individuals (Cooper and Kagel, 2005; Kugler, Kausel and Kocher, 2012; Tindale and Winget, 2019). For example, groups are better at reaching correct solutions to problems (Laughlin, 1980); providing more accurate forecasts (Kerr and Tindale, 2011); and generating more ideas (Paulus and Nijstad, 2003). However, multiple

features affect the ability and success of a group's decision-making. Generally, the potential of the group can be best utilised when the group members share all information (Brodbeck *et al.*, 2007); are open to diverse opinions (Homan *et al.*, 2007); have diverse perspectives (Davis-Stober *et al.*, 2014); are highly motivated to make accurate decisions for the group (De Dreu, Nijstad and Van Knippenberg, 2008); and the group contains wiser members (Budescu and Chen, 2015).

2.7 The Municipal Environment

The municipal environment significantly affects the implementation of a building project compared to projects in the private sector. This chapter addresses the special characteristics of municipal building stocks and municipal building refurbishment projects as well as presents the municipal organisation structure and decision-making process in Finland.

In 2020, there are 310 municipalities in Finland (Kuntaliitto - The Association of Finnish Local and Regional Authorities, 2020). The average number of inhabitants in a Finnish municipality is over 17,000, but half of the municipalities are rather small with less than 6,000 residents (Kuntaliitto - The Association of Finnish Local and Regional Authorities, 2020). The numbers are similar in other Nordic countries as well as in Great Britain, Belgium, and northern Germany, whereas many countries in eastern Europe, and France and Switzerland represent the opposite pole with a high number of small municipalities with less than 2,000 inhabitants (Westman and Hiltunen, 2012). The number of municipalities in Finland has progressively decreased due to the consolidation of municipalities. This has led to a situation in which multiple municipality-owned buildings have become useless in their original purpose of use since overlapping municipal operations have been integrated. Furthermore, in rural areas, municipal buildings have also become vacant because of urbanisation.

2.7.1 The Municipal Building Stock

In many countries, municipalities own a substantial amount of building stock, including schools, day nurseries, hospitals, nursing homes, residential buildings, and offices. In Finland, the municipal building stock covers about 35 million sq m, which is over 7 per cent of the country's entire building stock (Korhonen *et al.*, 2018). A

large share, over 25 per cent in terms of area, of municipality-owned buildings are schools (Korhonen *et al.*, 2018). Also, health care buildings and residential buildings comprise remarkable shares of municipal buildings, both over 10 per cent in terms of area (Korhonen *et al.*, 2018). Generally, the municipal building stock is rather old. The height of construction was in the late 1970s and the early 1980s but, overall, during the period from 1965 into the early 1990s, municipalities built about 65 per cent of their current building stock (Korhonen *et al.*, 2018).

Currently, a major share of the municipal building stock in Finland is in urgent need of refurbishment. In many municipalities, repairs are postponed, and the maintenance of the buildings has been inadequate (Kero, 2011). Therefore, a repair backlog has progressively increased. At present, the repair backlog of school buildings and health care buildings is estimated to be over 1 billion euros in each of these building sectors (Korhonen *et al.*, 2018). In these estimates, the target level of building condition is defined as 75 per cent of the condition of a new building, and the repair backlog is referred to as the particular amount of money that is required to improve the condition of the building onto that target level (Korhonen *et al.*, 2018).

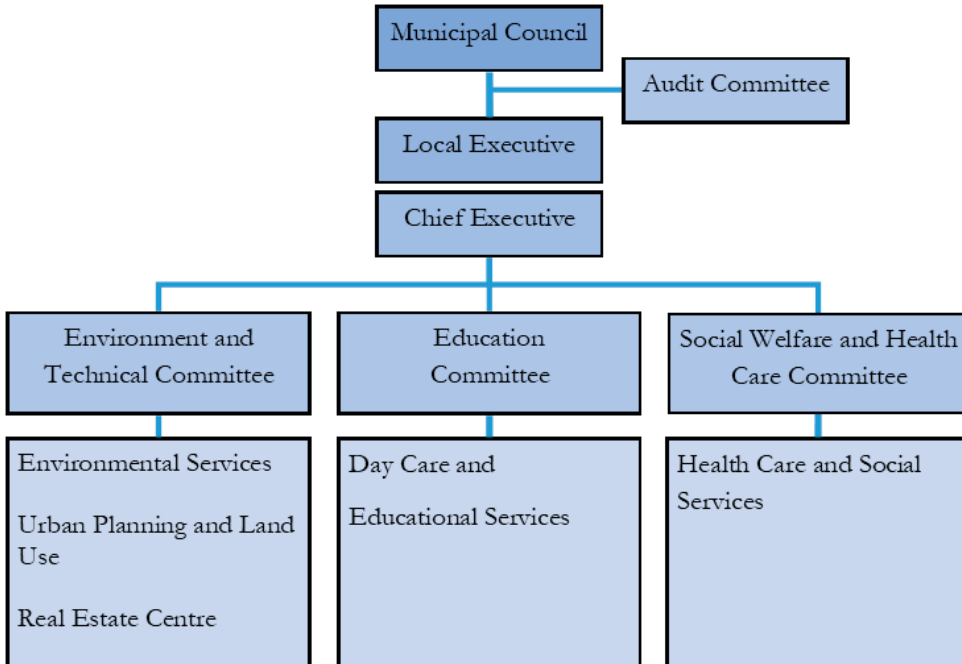
2.7.2 Municipal Organisation Structure in Finland

In Finland, the municipalities have a wide range of functions and responsibilities. The municipalities arrange and finance about two thirds of the basic public services for the residents, including health care, education, and social welfare, whereas the remaining one third is arranged by the central government. Municipal decision-making is governed by the Local Government Act and the Administrative Procedure Act.

The local authority system in Finland entails both political and professional management. Even though municipal administrations are organised relatively freely, each municipality must have a municipal council, a local executive, and an auditing committee for auditing municipal administration and finance. The municipal council is elected for four years in direct proportional elections by the residents. Typically, the municipal council sets up decision-making bodies, e.g. committees, for operating different areas of responsibility, such as building and environment management or education. (CEMR, 2016; Kuntaliitto - The Association of Finnish Local and Regional Authorities, 2020). An example of a typical municipal organisation

structure in Finland is presented in Figure 3. (Kuntaliitto - The Association of Finnish Local and Regional Authorities, 2020)

Figure 3. Example of a municipal organisation structure in Finland



In Finnish municipalities, the most senior position is chief executive, but also the mayor model has been adopted in a few cities. The chief executive is a local government officer and not a member of the municipal council, whereas the mayor is chosen from among local councillors. The municipal council has general decision-making power in the municipality, and it should express the will of the residents. It is responsible for municipal activities and finances. It is also responsible for determining the municipality’s long-term objectives and goals. The role of the local executive is more practical than that of the municipal council, as it prepares and implements the decisions the municipal council has made. The local executive is also responsible for the municipality’s administration and financial management as well as supervising the legality of the decisions. The members of the local executive are selected by the municipal council. The committees, set to operate under the local executive, supervise and control the activities in their designed areas of responsibility. Typically, the committees also manage the planning, development, and monitoring

of operations, finances, and organisations. (Kuntaliitto - The Association of Finnish Local and Regional Authorities, 2020)

2.7.3 Management of the Municipal Building Stock

Recently, it has been recognized that municipalities face multiple challenges in the management of public property, including difficulties in the execution of renovations, a lack of funding for maintenance and refurbishment, unsatisfied users of buildings, and challenges in decision-making processes concerning public facilities (Lewis *et al.*, 2000; Haugen, 2003; Yi and Komatsu, 2010; Kero, 2011; Vermiglio, 2011; Valen and Olsson, 2012; Barber, 2015; Baadjies, 2018; Hopland and Kvamsdal, 2019). As a result, a large share of the public building stock is in poor condition and needs refurbishment (Lewis *et al.*, 2000; Lawrence, 2003; Bello and Loftness, 2010; Valen and Olsson, 2012; Hopland, 2014; Filardo, 2016; RIL, 2019). In addition, the changed needs and requirements for buildings, such as new educational requirements in schools, increase the need for refurbishment. Typically, municipalities are unable to implement the actions fast enough, and refurbishment backlogs increase (Valen and Olsson, 2012; Støre-Valen, Kathrine Larssen and Bjørberg, 2014; Korhonen *et al.*, 2018). Hence, in order to keep building condition and facilities at the desired level, the buildings would need more repairs than are carried out. Partially, these above-mentioned challenges may originate from the difficulties many municipalities have in building a competent organisation for managing public property in an efficient way (Valen and Olsson, 2012). In addition, Valen and Olsson (2012) have proposed that lack of funding may decrease the property value and functionality of municipal buildings.

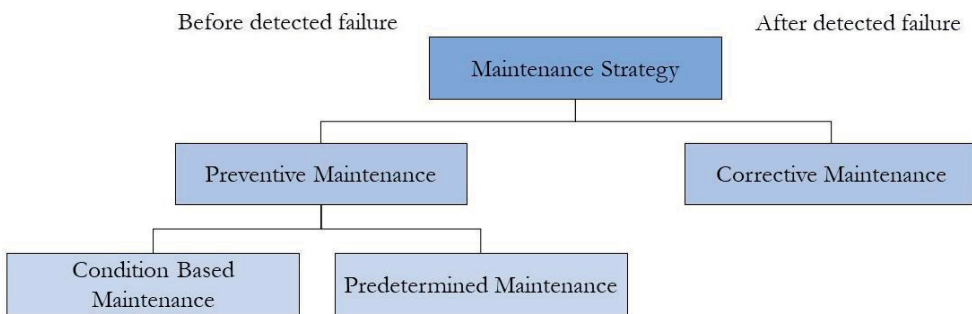
According to Valen and Olsson (2012), in good municipal property management, the decisions for municipal refurbishment actions are based on a long-term plan and a strategy of political objectives. Hence, good municipal property management is indicated to have the following characteristics (Valen and Olsson, 2012):

- a long-term plan; partial or complete;
- a good overview of maintenance needs;
- a clear strategy on how to develop the building portfolio according to changes in user demands; and

- know-how to do value driven maintenance successfully.

Many times, a building refurbishment is a result of poor maintenance. Therefore, the maintenance strategy that municipalities have chosen and follow has a remarkable effect on the number and types of refurbishments that are needed. Maintenance strategies have been classified in a number of different ways. One classic categorisation is to subdivide the strategies into two main strategies: preventive maintenance and corrective maintenance, as presented in Figure 4.

Figure 4. Different types of maintenance strategies. Adapted from (British Standards Institution, 2010)



Preventive maintenance refers to situations where actions take place without the occurrence of any specific fault. Condition based maintenance is preventive maintenance where an object is inspected on a regular basis, and serviced or replaced when a certain condition is detected, whereas, time-based maintenance is a policy where maintenance tasks are carried out at regular intervals regardless of the actual condition of the object (Muyingo, 2009). In contrast, corrective maintenance follows a policy where maintenance is carried out after fault recognition (British Standards Institution, 2010).

Typically, the strategy is chosen based on the allocation of maintenance resources (Lee and Scott, 2009). As these resources are often inadequate to meet the maintenance requirements (Shen, 1997; Tse, 2002; Yi and Komatsu, 2010; Valen and Olsson, 2012), maintenance personnel cannot use preventive maintenance strategies; instead they need to focus on fixing failures afterwards (Tse, 2002; Muyingo, 2009; Ogungbile and Oke, 2015). Thus, the maintenance personnel needs to balance between maintenance resources and facility costs when defining the maintenance standard (Lee and Scott, 2009). Valen and Olsson (2012) suggest that the

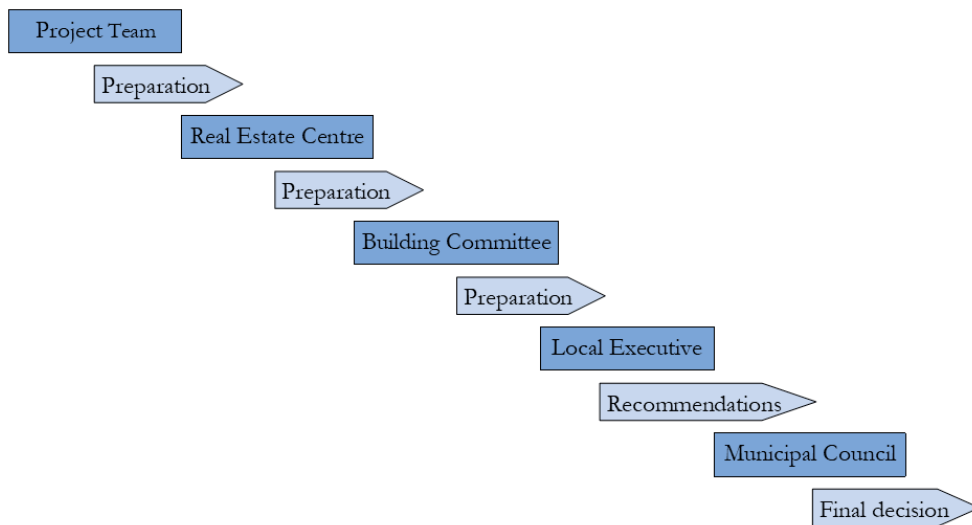
consequences of the lack of maintenance should be highlighted to politicians. In addition, they establish a balance between reactive and preventive maintenance in order to minimise acute repairs (Valen and Olsson, 2012).

As the management of the municipal building stock is challenging, high competence and skills are required. Alexander (1992) argues that excellent technical skills are no longer sufficient in facility management, but instead, co-operation between professionals and educational establishments is essential in order to meet the needs in the constantly changing environment.

2.7.4 Decision-Making Process in Municipal Building Projects

In Finland, key decisions of building projects are made at the various municipal hierarchy levels. The decision-making hierarchy and the examining tasks of each level are presented in Figure 5. The overall process and steps are rather similar in every municipality even though the used terms and formations vary between the municipalities.

Figure 5. The decision-making process of municipal building projects



Typically, a building project is initiated in the department responsible for the municipal building stock, e.g. a real estate centre. A project team, operating under the real estate centre, is assembled to prepare the project and decisions. Often, the

strategy and policy that the project team follows when preparing projects has been approved by the municipal council. The preparation proceeds in the real estate centre, the employees of which are typically also municipal authorities with competence and skills to work with building projects. The real estate centre presents the project to the building committee, which develops the initial decisions and presents the suggestions and alterations to the local executive. Minor decisions concerning building projects can also be made in the building committee without further processing at higher municipal levels. As the decisions and suggestions have already been initiated at the administration levels, e.g. the project team and the real estate centre, the local executive, typically, just makes the preliminary decisions for the municipal council. The final decisions are made by the municipal council. The prepared items can also be referred back to preparation by the municipal council to gather more information. (Kuntaliitto - The Association of Finnish Local and Regional Authorities, 2020)

Most of the practical work in the projects are made by the project teams, and also by the real estate centre. The workers of these bodies have the competence and skills to carry out building projects and to prepare the decisions. As the building committee, the local executive and the municipal council are bodies of elected officials, they may not have a broad understanding of building projects, including technical details, regulations, and practises. Even though the decisions or alternatives are initiated and prepared by experts of construction, the final decisions made by the municipal council, may be impacted by the council members' own interests, attitudes, personal experiences, or social and emotional states.

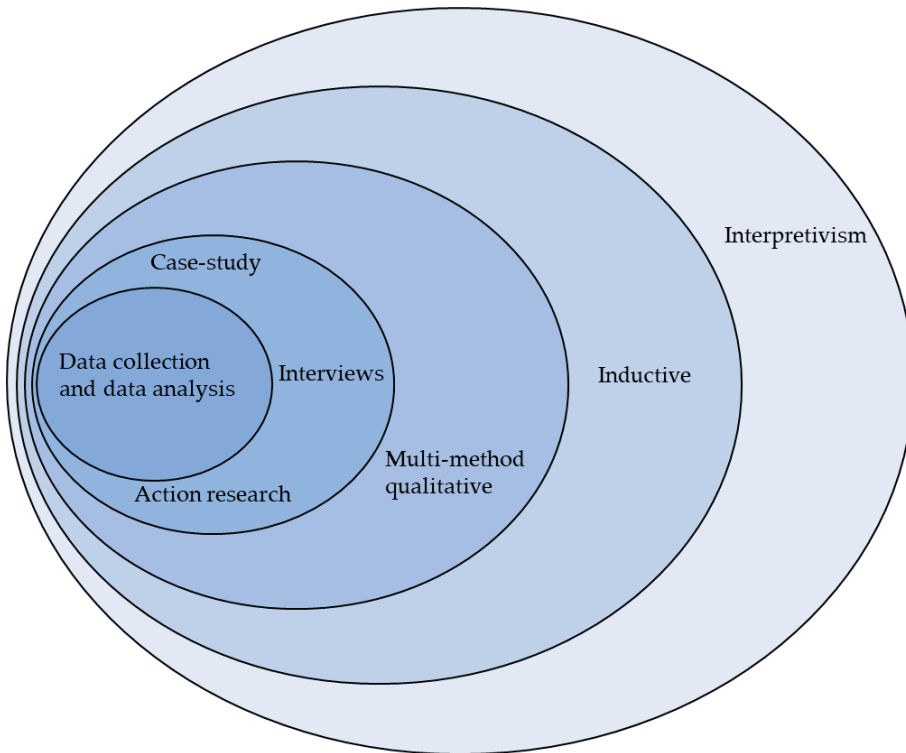
3 METHODOLOGY

During a research process, each researcher makes a number of assumptions, including assumptions about the nature of reality, known as ontological assumptions; assumptions about human knowledge, referred to as epistemological assumptions; and assumptions of how the researcher's own values influence the research process, known as axiological assumptions (Burrell and Morgan, 1979). These assumptions and the researcher's own beliefs shape the researcher's understanding of the research questions and the methods to use in the research study, and also affects the researcher's interpretation of the findings (Crotty, 1998). A consistent and well-thought-out set of these assumptions and beliefs constitutes a research philosophy (Saunders, Lewis and Thornhill, 2009b).

This study is based on interpretivist philosophy, which aims to develop a deeper understanding and interpretations of social worlds and contexts (Schwandt, 1994; Saunders, Lewis and Thornhill, 2009b). It emphasises the individual's role as an actor in the social world rather than focusing on the way they are acted upon (O'Reilly, 2014). Furthermore it holds a hermeneutic understanding, which includes understanding the other's point of view from their perspective, in the context of their social phenomena (O'Reilly, 2014). In addition, interpretivism considers the researcher's own role in interpretations, as interpretations are shaped by the researcher's own experiences and background (Ponterotto, 2005; Creswell, 2007; Collis and Hussey, 2013). Interpretivism is employed in this dissertation to explore the project stakeholders' actions and practises in municipal building refurbishment projects. In addition, it is adopted to understand their roles and intentions in the context of a municipal organisation.

To fulfil the research questions of this study, an inductive approach, using qualitative methods, was adopted. The research philosophy of this study, broken down into more detailed approaches, techniques and procedures, is presented in Figure 6.

Figure 6. The philosophical approaches followed in this study. Adapted from the 'research onion' by Saunders et al. (2009b)



This study uses triangulation to enhance in-depth understanding in the study and to provide more perspectives on the studied phenomena. Triangulation refers to the strategy of using multiple approaches for measuring the same object. Four common forms of triangulation are data triangulation, method triangulation, researcher triangulation, and theory triangulation (Duffy, 1987; Denzin, 2017). In this study, data triangulation was adopted, as multiple sources of data were used. In addition, researcher triangulation was used, since three investigators were employed in observations, the action research, and analysing the phenomena in order to gain multiple perspectives on the studied theme. By using triangulation, the risk of false interpretations and erroneous conclusions was reduced. In addition, the use of triangulation also increases the validity of the results (Hirsjärvi, Remes and Sajavaara, 2007).

As the study aims to develop a deeper understanding of the management of municipal building refurbishment projects, qualitative methods were considered the most appropriate methods for addressing the research topic. The exploratory nature

of qualitative research helps to obtain a very deep understanding of the studied processes, as the authors are able to get close to the objects (Creswell, 2007; Klenke, 2016). Moreover, qualitative methods aim at understanding the context and settings in which the participants of a study operate (Creswell, 2007). The qualitative methods of this study were used as follows: a case study – publications 1 and 3, action research – publication 2, and interviews – publication 4. The aim of this presented approach to conducting the research was to provide a holistic view of the management of municipal building refurbishment projects.

3.1 Case Study

A case study, typically, allows the exploration and understanding of complex issues (Zainal, 2007), and investigates a contemporary phenomenon or problem within a real-life context (Scholz and Tietje, 2002; Yin, 2003; Baxter, Susan Jack and Jack, 2008). It is typically adopted to gain a thorough understanding of the phenomenon of interest (Darke, Shanks and Broadbent, 1998; Ellinger, Watkins and Marsick, 2005). In addition, case studies are typically the most appropriate methods for answering 'how' questions (Merriam, 1998), and relevant when aiming to understand a process in a real-life context (Ellinger, Watkins and Marsick, 2005). In this research, the case study approach was, first, used to discover how a municipality has tried to manage a school building with noted building-related symptoms in the users. In this study, the documents, including investigation and repair reports, and questionnaires, from a period between 2003 and 2018 comprised the main data. First, this qualitative data were organised by using content analysis. All the implemented refurbishment actions and the surveys were listed. In addition, participatory observation in project planning meetings of the refurbishment project and site visits were used in order to understand the practical challenges more accurately. Secondly, a case study was selected to address the sources of uncertainty in a municipal building refurbishment project, concerning the same school that was studied previously. In this study, the data was collected by participatory observation; site visits; reviewing the documents, including reports from surveys and questionnaires as well as building documentation; and informal discussions. The participatory observation was executed in the project planning meetings of the refurbishment project, in which the researcher and the co-authors of the publications were taking notes. The meetings were usually attended by a representative of the building developing department, condition assessment consultants, the head teacher and the deputy head teacher, and sometimes also the

chief of the maintenance department, a representative of the school committee, kitchen and cleaning experts, the chief of early childhood education and the researcher with the co-authors of the publications. In the final stages of the project planning phase, one or two designers also participated in the meetings. The first project planning meeting was organised in February 2018 and the last one that the authors attended was in March 2019. The original project planning schedule was delayed; thus, the authors were not involved in the project planning in its final stages. The authors actively attended a total of 21 meetings. In these meetings the project participants sought to identify the uncertainty concerning the buildings and the entire project. The condition assessment consultants focused in particular on uncertainty related to technical issues, and the users on uncertainty associated with functionality. The uncertainties were freely pointed out in the project planning meetings. The gathered data were analysed by using thematic and causal analyses and classification. The case study approaches were chosen because of the complicated nature and the real-life context of the studied issues. In addition, they were considered to be the most appropriate methods, as the researchers aimed to gain an in-depth and a holistic understanding of these studied topics.

The case study concerned a school campus with a day nursery located in Vantaa, Southern Finland. The campus consists of three buildings: the so-called white building, built in 1997; the brick building, built in 1955; and the pavilion, built in 2001. In total, there were almost 800 pupils and kids using the campus. The white building, containing 4,620 sq m of heated floor area, has had a number of problems, including water leakages, from a very early stage. In addition, the staff and pupils had complained of symptoms and an unpleasant smell in the building for several years. The brick building has undergone small-scale renovations multiple times but, currently, it is in need of major renovation actions. The building has primarily natural ventilation, which limits the number of pupils in the rooms. The total heated area of the brick building was 4,261 square metres. The pavilion, with a total heated floor area of 611 sq m, was built as a temporary building in 2001, and its efficient space utilisation was rather poor. At the time of the research, especially pupils with special needs studied in the pavilion. The building was strongly being considered for demolition in the foreseeable future. Due to the need to substantially increase the space for kids and pupils on campus; the structures and systems of the buildings ageing and being damaged; and the complaints of building-related symptoms, project planning was initiated in March 2018 to generate a proposition for refurbishment actions to the city council.

3.2 Action Research

Action research is a research approach that describes and explains the studied issue. It also provides both the researcher and the people in the studied organisation with a deep understanding of the studied phenomena and practises and the processes in the organisation (Kemmis, McTaggart and Nixon, 2013). It is generally considered to have been identified first by Lewin (1946) in the 1940s. Lewin (1947) described the method as ‘a comparative research on the conditions and effects of various forms of social action and research leading to social action’. He illustrated the process of action research as a cycle of steps including planning a change, putting the plan into action, observing what happened, and re-formulating the plan (Lewin, 1946). However, many authors have argued that those steps poorly describe the action research process, and therefore, the action research process is nowadays more often described with the ‘self-reflective spiral’ that includes more reflection compared to Lewin’s steps (Kemmis, McTaggart and Nixon, 2013).

Action research provides a relationship, where the researcher becomes involved in the studied organisation, and the practitioners of the organisation get benefits from the research (Greenwood, Whyte and Harkavy, 1993; Eden and Huxham, 1996). In addition, the entire organisation or community might gain advantage from the research outputs (McIntyre, 2007). Participatory action research emphasises participation, co-learning, and organisational transformation (Greenwood, Whyte and Harkavy, 1993). It is also case-oriented, as it attempts to learn lessons from specific cases (Greenwood, Whyte and Harkavy, 1993). Due to the above-mentioned characteristics, participatory action research was selected as the research method to study the decision-making process of a municipal building refurbishment project. The action research study concerned the project planning of the school campus refurbishment project presented in the previous—case study—section. During the study, the researchers attended a total of 21 project planning meetings between March 2018 and April 2019. Besides observing, the researchers asked questions and made suggestions in these meetings. Hence, the majority of the data was gathered by taking notes in the meetings, but also memos and other documents were used. The researchers focused and noted down, especially, the topics concerned in the meetings, the decisions made, and the progress of the project. The gathered data was analysed in an iterative process using a thematic analysis guided by grounded theory. The main principle of grounded theory is to generate theory on the base of the collected data (Charmaz and Belgrave, 2007). Finally, the findings of the analyses were interpreted.

3.3 Interview

Interviews are used for gathering rich and in-depth information about the experiences of individuals (DiCicco-Bloom and Crabtree, 2006). Since the lack of proper initial data has been detected to cause uncertainty in building refurbishment projects, interviews were adopted for addressing the use of laser scanning as a method for decreasing uncertainty in these projects. Hence, the challenges of and barriers to laser scanning implementation in building refurbishment projects were established by qualitative theme interviews. Even though laser scanning has been presented as an efficient tool for gathering accurate as-built data of an existing building prior to refurbishment, in literature, the use of laser scanning is still rather rare in building refurbishment projects in Finland. Qualitative interviews were selected as the method to study this phenomenon as they provide a better understanding of situations; are appropriate for describing the processes; and help the researcher to understand how events are interpreted (Weiss, 1995). In addition, when previous research on the topic is limited, as in this study, this method allows the researcher to collect data flexibly and ask follow-up questions, if needed, during the interview (Hirsjärvi, Remes and Sajavaara, 2007). In this study, a semi-structured interview method, which focuses on certain themes, was used, since it allows the researcher to deepen the conversation on certain subjects under the main themes (Hirsjärvi and Hurme, 2008). In addition, the open nature of questions may bring out new ideas and concepts (Hand, 2003). However, each interview has a certain basic structure (Hirsjärvi and Hurme, 2008), which provides clarity and allows the researcher to focus on the researched issues (Miles, M.B & Huberman, 1994).

Appropriate interviewees were identified by searching through related publications and projects in which laser scanning had been used, contacting pioneering organisations in the use of laser scanning in refurbishment projects, and contacting participants of and organisations involved in laser scanning training organised in Finland between 2016 and 2017. To get a wider perspective on the studied themes, the respondents represented various companies and organisations, and also their job titles and work assignments varied. Nine persons with experience of laser scanning in building refurbishment projects were interviewed between autumn 2017 and early winter 2018. The titles and responsibilities of the interviewees are presented in Table 2.

Table 2. The interviewees' titles and responsibilities

Title	Job description
architect	director of building information modelling team
architect	responsible for construction contracting
architect	specialised in building refurbishment
architect	project director
architect	point cloud expert
managing director	consulting and coordination of building information modelling
archaeologist	responsible for the management of digital documentation of buildings
modelling engineer, land surveyor	director of laser scanning team
manager	manager of maintenance of parish buildings

The interviewees represented both the public and the private sector, and, also among the projects they had gathered their laser scanning experience in, there were both public and private ones. The three principal themes of the interviews were: the spatial data of building refurbishment projects; the measuring process of building refurbishment projects; and the use of laser scanning in refurbishment projects. The questions used for the interviews are displayed in Appendix 1. The duration of the interviews varied between 45 and 100 minutes. The gathered data were analysed thematically by adopting grounded theory.

4 SUMMARIES OF THE PUBLICATIONS

4.1 Publication 1

This study examined how the municipal authorities and the practitioners have tried to manage building-related symptoms in a school, and addressed how the campus buildings had been repaired and maintained during a period of 15 years. The case study approach was used as the research method since the aim of the study was to gather a deeper understanding of the implemented actions, including repairs and surveys, and the reasons for the attempts having being unsuccessful. Hence, it also addressed the renovation and maintenance history of the building. The researchers reviewed and analysed the documents of these actions from the period between 2003 and 2018. In addition, the researchers attended the project planning meetings of the school campus refurbishment to attain a broader knowledge of practises.

The findings show that municipalities have a tendency to respond to faults and occupants' symptoms actively by procuring multiple investigations and repair actions in schools. However, the responses have often been ineffective. The main reasons for the failure of the attempts to manage building-related symptoms can be summarized as follows:

- lack of competence in procuring condition assessments and interpreting the results of the surveys;
- ineffective repair actions and maintenance, including delayed and failed actions, and partial and small-scale repairs;
- characteristics of the building, such as at-risk structures;
- organisational challenges: overlapping work between the maintenance department and the developer department and ignorance of the work the departments have done, and;
- communicational and political challenges, including public pressure for swift actions.

The case school building has complex design solutions and several errors have been made during construction. Furthermore, the building has suffered from vandalism. These above-mentioned features, partially, affected the development of health problems of the occupants. As a conclusion, the authors suggest proper and systematic maintenance; quick response to hazards; timely repairs; and monitoring the symptoms as tools to better manage building-related symptoms in a municipal building. In addition, these aforementioned propositions might be considered to be appropriate practices for property management also at a general level.

4.2 Publication 2

The aim of this research is to better understand the decision-making process in the project planning phase of a municipal building refurbishment project. The project planning phase is a vital stage of a refurbishment project since key decisions considering project targets, including the size, characteristics, schedule and budget of the project, are typically made then. As refurbishment projects often fail to achieve their targets, the potential reasons for the failures were examined by addressing the decision-making and the actions taken in this phase.

Participatory action research was adopted as the research method of this study since this approach affords the researchers to come closest to the studied process and obtain a very deep understanding of the process. As the researchers work closely together with the studied organisation, the risk of misunderstandings is reduced. In this study, three researchers attended the project planning meetings actively by asking questions and making suggestions besides observing. A total of 21 meetings were attended.

The study addressed how the project stakeholders made decisions in the project planning phase of a municipal school campus refurbishment. The project was initiated by the municipal Building Unit, which operates under the command of the Real Estate Centre. A multidisciplinary approach was used for decision-making, since the group of participants in the meetings was composed of representatives of the education department and the maintenance team, the condition assessment consultants, the designers as well as the users, including the head teacher and the deputy head teacher, alongside with the project manager and the authors.

The target of the case project planning phase was to create a solution to organize facilities for a day nursery, a school and a kitchen on the existing campus. Since building-related symptoms had been noted particularly in one of the buildings on the campus, the other aim of the project was to eliminate the symptoms. However, the results of this study show that the decision-making in this phase was mainly focused on organizing the facilities, including the location of the extension, and technical aspects, instead of establishing alternatives for organizing the facilities on a broader scale. The discussions in the meetings probably focused on resolving the space requirements because it was much easier to find the alternative solutions for the facilities, especially by building an extension, than solving the problem of building-related symptoms.

Even though the project planning proceeded quite informally, the decision-making process contained the phases of identifying the target and the current problems; gathering information; generating alternatives; and evaluating the alternatives. However, the alternatives were not evaluated on the basis of preformed criteria and the matters displayed were not weighted. The decision-making processes was rather complex, since the stakeholders had different interests and priorities. Also, during the phase, multiple uncertainties were identified, but these were not considered broadly.

On the basis of the findings of this study, the authors suggested that the decision-making could be improved by determining evaluation criteria in advance for project targets and needs, as well as considering the sources of uncertainty more closely.

4.3 Publication 3

As uncertainty is recognised to significantly affect decision-making and, thus, the progress of a municipal building refurbishment project, the sources of uncertainty were selected to be studied more closely in this study. Hence, the third publication examined the sources of uncertainty in a municipal building refurbishment project, in the early project phase. Furthermore, the study established, how the identified sources were treated during this early phase. These issues were addressed by a case study of the project planning of a publicly owned school in Finland.

The study identified multiple sources of uncertainties in the case project, and these sources were divided into three categories as follows:

1. uncertainty from the project, including sources of uncertainty concerning the existing buildings and the campus, the project targets, schedule and costs;
2. uncertainty from the organisation, including separately operating units, and the project stakeholders' competence;
3. uncertainty from the operational environment, including the municipal policy, estimates, needs and decision-making process.

The sources of uncertainty concerning the project mainly originated from the characteristics of the existing buildings. Project uncertainty was also related to the special needs and requirements of the project. In addition, uncertainty was related to the design.

The uncertainty arising from the organisation was mainly connected to the project stakeholders as well as the organisational structure. Separate municipal units were partly operating overlapping activities, which caused uncertainty as communication between the units was deficient and the boundaries of the operating areas of the units were unclear. Thus, decisions concerning the same issues were made in several units. In addition, the separate units had different kinds of interests in the project. The interests were unclearly prioritised or evaluated in the meetings. This may lead to irrational decisions, since minor issues may gain a disproportionately large importance in the project whereas key issues can be overlooked.

Multiple significant sources of uncertainty originated from the municipal environment. The indecision at a higher municipal level hindered the decision-making processes at the project level as the project team advanced the plans with deficient information and had to make assumptions. In addition, the project team had to consider multiple alternatives during the phase as the key decisions and limits had not been concluded at the higher organisational level.

In the case project, no systematic risk or uncertainty management method was used during the early project phase. However, some sources of uncertainty were identified, but most of these sources were not evaluated, which might affect the validity of the decisions. Uncertainty was reduced by gathering more information, e.g., by implementing a condition survey and structural openings. Hence, some of

the uncertainties were transformed into risks. Mostly, the uncertainties the project team focused on were arising from the project, whereas external uncertainty and uncertainty originating from the municipal operational environment were mainly ignored. In addition, the uncertainties were treated only as threats for successful project implementation instead of possibilities.

On the basis of the results of the case study, it was suggested that the municipal decision-making process concerning building refurbishment should be modified. First, the major lines concerning the project should be determined at the high municipal level, e.g. the key decisions should be made in the municipal council. Secondly, the specific targets and requirements of the project should be described, and the required competence established by the organisation. If a higher level of competence is needed, experts should be hired. In addition, alternative solutions for satisfying the project targets should be investigated. Then, the details of the targets and needs should be established by the project team. Moreover, the project team should investigate the implementation of the alternatives more precisely. Furthermore, the alternatives should be evaluated at the organisational level. The final decision of implementation, concluded at the higher municipal level, e.g. in the municipal council, should be completed on the basis of the evaluation and the suggestions made by the organisation level and the project team.

4.4 Publication 4

Defects and omissions in measurement data and as-built data have been proven to increase uncertainty and lead to adverse outcomes in building refurbishment projects. It has been suggested that the use of advanced technology, such as laser scanning, could enhance the quality of this initial data and decrease the uncertainty concerning this data. Although the use of laser scanning has become more common in building projects, its use is still rather limited in building refurbishment. Therefore, this fourth publication established the current barriers to laser scanning in building refurbishment in Finland.

Theme interviews in a semi-structured manner were used as the research method since the aim of the research was to address practitioners' experiences of laser scanning in building refurbishment projects. Nine persons with experience in laser scanning in such projects were interviewed.

The study showed that the main barriers to laser scanning implementation are associated with clients' lack of competence in procuring LS services. This includes challenges in technical determination, which may lead to the procurement of inappropriate data for design work. Furthermore, the barriers to using laser scanning were also linked to the limitations of the laser scanning technique in building refurbishment. In addition, the rather varied quality of purchased inventory models, as well as laborious processes, were indicated to reduce interest in the technique. As the process from a point cloud into an inventory model is laborious, time-consuming and error-prone, the laser scanning technique was perceived as being a rather unsuitable tool for projects with minor refurbishment work. Hence, the study indicated that a larger extent of refurbishment actions is connected to greater benefits from the technique. Moreover, as the drawings of buildings built since the late 1990s are, typically, relatively appropriate and accurate, it was considered that an inventory model is less time-consuming and laborious to produce by using the drawings instead of a point cloud. Hence, the benefits of the technique are fewer when refurbishing buildings built in the past 20 years compared to the benefits gained in the refurbishments of older buildings. The study also showed, that understanding of LS is still rather limited and insufficient among stakeholders of building refurbishment projects, which potentially reduces the utilisation of the technique in these projects.

The results of this research indicated that modification of the project preparation process is needed, as the designer's involvement during the early phase of a building refurbishment project appears to be vital. By involving the designer in project preparation, the designer could assess the requirements concerning the as-built data of the existing building. In addition, the designer could contribute to the technical determination of the laser scanning, including describing the scope, content, levels of details, delivery formats, and accuracy of the data acquisition. Furthermore, the designer could co-operate with an inventory modeller already at the beginning of the modelling process in order to achieve a model that can best be utilised in the design. Also, by implementing laser scanning at a very early phase of the project, the designer could use the data already in the design development, which may reduce overlapping work in later design phases. The designer's involvement in the project preparation process could reduce the requirements concerning the client's competence to purchase as-built data.

The interviewees' competence in utilising laser scanning in building refurbishment projects varied significantly, as well as their understanding of the

benefits and possibilities of the technique. This indicated that understanding of the benefits and limitations of the technique in building refurbishments might still be rather deficient. This limited understanding may become a barrier to implementing LS in building refurbishments. In particular, if clients and building owners are not aware of the potential of LS, they are not willing to pay for these services. Thus, increased understanding of this technique is needed, especially at the beginning of projects. Broader knowledge of LS could increase the utilisation of the technique, and the method could be used in more useful ways.

The full potential of laser scanning has not yet been utilised in building refurbishment projects in Finland. However, as the modelling technique and devices still evolve, more automation is adopted, and the popularity of BIM implementation in existing buildings, perhaps, increases and results in a particular importance of accurate spatial data, the use of laser scanning, also, may gain popularity in building refurbishment over the coming years.

5 DISCUSSION

In this section, first, the results of this dissertation are discussed by answering the research questions. Secondly, the study is critically evaluated in terms of reliability and validity. Thirdly, the utilisation and restrictions of this study are discussed.

5.1 Answering the Research Questions

RQ 1: What challenges do municipalities have when refurbishing and managing municipality-owned buildings?

The results of this study indicate that a notable reason for challenges in the management of a municipal refurbishment project is uncertainty concerning political alignments and decisions. High responsibilities, including preparing projects and propositions, are shifted onto municipal authorities. However, the information required in project planning, including project targets, budget and issues related to the arrangement of municipal operations and services in future, is greatly limited and uncertain due to the instability of political outlines and short-sighted policymaking. This hinders project planning and compels municipal authorities to head towards short-termed solutions. Similarly, Borge and Hopland (2012, 2017) established the political challenges but linked them with the poor condition of municipal buildings due to the lack of allocations for maintenance. The results of this study imply that clearer political outlines and strategies concerning municipal services and operations can potentially improve the management of municipal buildings more effectively in the long term. Borge and Hopland's (2012, 2017) and Hopland and Kvamsdal's (2018) findings of the relationship between weak political leadership and poor condition of municipal buildings can be considered to support these suggestions. Moreover, Schulte and Ecke (2006) stated that politicians' involvement in decision-making slow down the processes and manoeuvres.

The results of the empirical study showed that municipal authorities may have an inadequate overview of the condition and repair needs of their buildings. Hence, the repairs are carried out after observed damage, and the actions, often, concern only

the damaged structures or materials. Typically, damage is not observed immediately after it appears. It may increase in scale and spread to other structures before it is noticed, resulting in the need for large-scale and expensive repair actions or refurbishment. In addition to the delay in the detection, the case study showed that also the repair actions are delayed. This often further increases the required scale of these actions. The delays in major actions and poor maintenance were often caused by limited budget allocation, which coincides with the findings of Haugen (2014), Borge and Hopland (2017), and Hopland and Kvamsdal (2018). The results of the case study indicate that, due to the inadequate budget, municipal workers need to prioritise between refurbishment and maintenance actions. These findings correspond to previous discoveries (Shen, Lo and Wang, 1998; Kero, 2011; Chong *et al.*, 2019).

Since the municipal strategies concerning providing municipal operations and services were not well-defined and stable in the case study of this dissertation, the planning of refurbishment with a long-term perspective was difficult. In addition, as public pressure and political issues had a bearing on the decisions and allocations, the refurbishment decisions could not be made in an economically priced way. These results support the previous findings (Alexander and McShane, 2006; Li and Wang, 2008; Hanis, Trigunarsyah and Susilawati, 2010) that politicians' various interests towards projects significantly affect project outcomes or project implementation. For example, a budget allocation to new construction instead of refurbishment and maintenance might ensue from politicians' aim of improving their chances of re-election. Furthermore, past studies (Veiga and Veiga, 2007; Drazen and Eslava, 2010) have shown that the strategy of expenditures changes during an election period, and just before the elections, since more municipal funds are then spent on matters that are visible to voters.

Furthermore, the results of the case study indicate that the short-sighted actions municipalities often implement may be rather ineffective and costly in the long term. In the case study, funds had been allocated largely to maintenance instead of refurbishment projects. This finding concerning allocation differs from the previous studies by Haugen (2014) and Hopland and Kvamsdal (2019), which emphasise a lack of municipal appropriations for maintenance instead of refurbishment. The findings of this case study imply that in order to provide functional and healthy municipal facilities for residents, it might be beneficial to adopt a long-term perspective when planning and implementing refurbishments and maintenance. This long-term perspective should be allowed, also, in decisions about the allocations for

the municipal building stock. Parallel to what Valen and Olsson (2012) have indicated, the long-term perspective can be considered to include creating flexible technical solutions for changes in the future; paying attention to the functionality and usability of facilities; proper maintenance of the buildings; and good quality of design and construction. Moreover, since the results of the case study indicate that the municipals' decisions of refurbishment actions are often based on investment costs instead of life cycle costs, the potential savings for the municipal economy through lower expenditures in maintenance and renovations might be disregarded. Therefore, the study suggests that this lapse might be avoided by shifting the financial focus from investment costs to life cycle costs.

The scale of a refurbishment is, often, largely based on information of the condition of a building. Thus, municipalities, typically, tend to establish the condition and repair needs of their buildings by purchasing investigations. However, the lack of competence in purchasing condition assessments and interpreting the results of these surveys was considered a notable challenge among the municipal workers, in this study. The purchased investigations had been rather superficial, the survey scope defective, and the suggestions for further investigations had been ignored. These findings concerning the lack of skills agrees with the findings of Marttila et al. (2015). In addition, the case study showed that the repair actions did not follow the recommendations of condition surveys, which is consistent with the findings of a study carried out by Marttila et al. (2017). If proper information about the condition of the building and recommendations of experts are not used when planning and implementing the refurbishment, there is a high risk that the actions do not fulfil the repair requirements, and the repair backlog of the municipal building stock accumulates further. Therefore, this study suggests that municipal workers require more education and knowledge of the condition assessments, including a higher level of skills to purchase and interpret the investigations.

The results of the case study provide evidence of municipal authorities' serious challenges in project management. In the case study, the municipal authorities prepared a project schedule but it was not followed, and the project was significantly delayed from its the temporal targets. This was partly caused by the increased condition investigation needs but also by the lack of schedule and target times of the investigations. In addition to time, also costs are, typically, a substantial part of project management. However, the project costs and life-cycle costs were hardly considered or estimated in the case project. The municipal authorities had estimated the rough cost concerning the alternatives for refurbishment, new buildings and

demolition in the very beginning of the project, along with a feasibility analysis. However, in the project planning phase the life-cycle and project cost of the different alternatives were not evaluated. The cost estimation was completed only for one solution, after it had already been selected to be promoted. A cost estimation of different solutions during the project planning phase could enable savings in costs as the characteristics of each solution could be compared also in their economic aspects.

Many municipalities in Finland have a department responsible for maintenance and minor repairs and another department responsible for major refurbishments. The case study shows that clear areas and boundaries of responsibilities of these two departments are difficult to define. Moreover, these two departments are not fully aware of the actions the another department has taken. Hence, this research indicates that good communication between the departments is vital for clarifying the departments' tasks and operating ranges. Furthermore, more effort should be devoted to communication and information flow between the departments due to the high turnover of municipal workers, which, also, seems to cause information loss. This improvement in the flow of information could bring financial savings for municipalities, since the departments could combine minor repair actions into a major refurbishment, plan actions in more long-sighted way, and avoid overlapping work such as purchasing similar condition surveys.

The results of the case study support the previous findings of municipalities' major challenges when trying to manage and refurbish buildings with users' complaints of building-related symptoms. The results of the case study demonstrate that eliminating these symptoms is difficult, and the implemented refurbishments have failed to achieve the desired outcomes multiple times, which is consonant with previous studies (Ebbehøj *et al.*, 2002; Rudblad *et al.*, 2002; Meklin *et al.*, 2005; Haverinen-Shaughnessy *et al.*, 2008; Bailey *et al.*, 2011; Iossifova *et al.*, 2011). The case study revealed that complaints of building-related symptoms may cause high public pressure for swift actions at both the administrative municipal organisational levels and the operative levels. This may partially explain the hasty actions with unsatisfying outcomes that the municipalities in this case study, and generally, have recently implemented. As Haverinen-Shaughnessy *et al.* (2008) state, the elimination of the symptoms requires proper investigations since the origins of the symptoms need to be found out first. Hence, the eliminating process, including investigations; planning the repair actions; and implementing the actions, cannot be done in a very short period of time with hurried planning.

Often, building-related symptoms are, in this study and more broadly in literature, linked with structures damaged by moisture and mould (Savilahti *et al.*, 2000; Meklin *et al.*, 2002; Handal *et al.*, 2004; Patovirta, 2005; Lignell *et al.*, 2007; Sahakian, Park and Cox-Ganser, 2008; Haverinen-Shaughnessy, 2012). As mentioned above, municipalities have serious challenges in managing the condition of their buildings. Therefore, this study proposes that a long-term strategy concerning maintenance and refurbishment actions of the municipal building stock, systematic follow-up of the condition of the buildings, as well as actions implemented more quickly after a hazard might benefit also the management of the process of eliminating symptoms. Moreover, it could decrease the structural damaging causing the symptoms. In addition, municipal workers' competence and skills to carry out the refurbishment of a building with noted health symptoms needs to be improved, and also more allocations are required for these projects.

RQ 2: How are decisions made in a municipal building refurbishment project in the early project phase?

This study indicates that the project stakeholders' various and conflicting interests towards the project outcomes greatly affect the decision-making and the target-setting of refurbishment projects. At the project level, stakeholders of municipal building refurbishment projects, representing various municipal departments, have different views and interest concerning project targets. The results gathered by the action research show that as project targets are not always clear and commonly determined, the stakeholders may utilise the opportunity to influence the direction of the project and impose the needs of their own or the department they represent. In addition, the results imply that as the needs and requirements the stakeholders present are not prioritised at the project level, it is challenging to distinguish the key targets and needs from secondary targets. This may lead to inconvenient project outcomes and short-sighted decisions. Thus, this study proposes that common perceptions of project targets and priorities as well as evaluation criteria created in advance could greatly simplify the decision-making process of a refurbishment project and bring benefits in the long run. In addition, since it is generally hard to create a solution that is optimal for every stakeholder, members of the project team need to reach compromises in order to achieve the key project targets.

It is possible to meet the municipal facility needs and requirements through several different solutions. As a new finding, the results of the case study implied that it might be beneficial to keep these alternative solutions open in the early phase

of the refurbishment project. If the project team adheres to one solution in the beginning of the project, this choice might define the data and information to be collected in the later phases. Hence, the project is, as if, advanced towards the chosen solution. As a consequence, it is later hard to find or justify alternative solutions, as all the data has been collected to support one solution.

Typically, decision-making is rather complicated in a municipal building refurbishment project as the decisions are made under high uncertainty. The municipal environment can be considered as a dynamic environment since the factors that need to be taken into consideration in the decision-making are continually changing. In a dynamic environment, it is difficult to have the relevant information available for the decision-making situation, and the decision-makers experience a high level of uncertainty in the decision-making situation (Duncan, 1972). This study implies that these changing factors, including political outlines and resources; limited information and data concerning the existing building, project targets and needs; stakeholders' various interests; and limited time and budget hinder and delay the decision-making processes. In addition, the high turnover of municipal workers, causing information and tacit knowledge loss, appear to complicate the decision-making. As all the decisions are not properly documented, the same issues are discussed and decided on several times. Typically, a project contains multiple separate decisions. However, as the action research revealed, sometimes the key decisions are not distinctly discerned from secondary decisions, and the decisions are not made in a consistent order. Hence, the main project targets may be obscured, and resources, including time and money, might be invested in minor targets.

Decision-making is basically choosing between alternatives. However, only some of the alternatives deliver high value outcomes. This study implies that when generating alternatives for reaching the municipal facility needs, it might be beneficial to set the alternatives on a broad scale by taking the entire building stock into account instead of concentrating only on one existing building. However, this larger scale approach requires a comprehensive understanding of the facilities and the use of the present municipality-owned buildings. By concentrating on an existing building and a plot, alternative solutions are probably easier to generate, but many good solutions might be disregarded. It might be possible to fulfil the project targets more efficiently, for example, by utilising the rooms of some other municipal buildings, or by renting rooms, instead of renovating or building an extension. This open-minded approach might be beneficial, as according to Guillemette et al. (2014) the openness of spirit leads to increased effectiveness in the decision process. However, the results

gathered by the action research approach appear to show that ambiguity concerning strategies and outlines of municipal operations directs the municipal authorities' focus on individual buildings instead of the entire building stock, as it is challenging to generate and evaluate alternatives on a large scale with that defective information. Additionally, it is much easier for the municipal authorities to try to manage the uncertainty concerning an individual building compared to the uncertainty concerning the entire municipal building stock, as individual buildings contain less parameters. Hence, this study indicates that clearly defined municipal strategies and outlines concerning municipal operations as well as long-term plans could facilitate the generation and evaluation of alternatives on a large scale.

In addition to the generation of alternatives, proper decision-making requires evaluation of these alternatives. Cleden (2012) proposes defining the evaluation criteria in advance, since the determination clarifies the project targets. However, the results of the case study, surprisingly, showed that sometimes the criteria are not pre-determined or even used in municipal building refurbishment projects. This practice potentially hinders reaching effective and knowledge-based decisions concerning a municipal refurbishment. As the decisions concerning municipal refurbishments need to be made with very limited time, budget and resources, the results of this study imply that it might be worthwhile to deliberately follow Simon's satisfactory theory (Simon, 1955, 1956), e.g. to seek satisfactory or good enough solutions instead of perfect ones. By using evaluation criteria in decision making, the best alternative, supporting the project targets, is found and can be further developed. However, the project team must compare the relationship between the potentially achieved benefits of the further development and the volume of resources used in the process of upgrading. It is not worthwhile to use a lot of time and finances to gain only minor benefits in a project. Similarly, the project team could weigh up the cost of containing uncertainty related to the best solution and the potential hazards likely to be caused to the project. Hence, it may be beneficial to use more costly uncertainty strategies in projects with a low capacity for uncertainty.

Based on the results of this research, project planning in haste and project implementation with dispatch can be considered typical characteristics of municipal refurbishment projects. Hence, the planning focuses on swift refurbishment solutions instead of solutions that might be the most optimal in the long run but require more time for planning. For example, it is not usually possible to make alterations to the town plan due to tight project schedules. By examining the future needs and requirements concerning the municipal operations and changes in user

demands earlier and in a longer term, alternative solutions could be studied on a more broad scale. These suggestions support Valen and Olsson's (2012) discourse of good property management.

Often, small-scale and temporary refurbishment actions are prioritised before a replacement or a major refurbishment. This may be due to the almost constant use of municipal buildings, and the high cost of the use of temporary buildings and rooms. For example, the refurbishment actions of school buildings are often arranged in a short period of time, usually, during holiday periods. However, these minor refurbishment might be problematic when aiming to repair a building with noted health symptoms, as Meklin (2002; 2005) reported partial actions to cause ineffective outcomes. In addition, delaying major refurbishments may increase the scale of the damage and spread it to other structures. Hence, more consideration of a long-term strategy is needed also in decision-making.

RQ 3: Where does uncertainty in the early phase of municipal building refurbishment projects originate from and how can it be identified and reduced?

The results of this study suggest that the uncertainty of a municipal building refurbishment project originates from three key sources. These sources contain, firstly, the project, including the sources of uncertainty concerning the existing buildings, the project targets, schedule, and costs. Secondly, they comprise the organisation, including separately operating units, and the project stakeholders' competence. Thirdly, the sources include the operational environment, including municipal policy, estimates, needs and the decision-making process.

Agreeing with past research, lack of initial data, classified under project uncertainty, was recognised to cause uncertainty in building refurbishment projects, in this research. To be precise, consistent with previous findings (Arain, 2005; Ali, 2010; Zolkafli *et al.*, 2012; Mokariantabari *et al.*, 2019), lack of information regarding building condition was identified to cause uncertainty in these projects. Besides lack of proper information on building condition and improper site surveys, the results of the interviews establish that also incorrect and insufficient as-built data may increase uncertainty as well as impede the project by causing errors in design and implementation. These results are consonant with previous findings (Arain, 2005; Ali and Au-Yong, 2013; Oloke, 2017; Yacob *et al.*, 2017; Ekanayake, Sandanayake and Ramachandra, 2018). Furthermore, consistent with the suggestions of Le *et al.* (2018, 2017) and based on the results of the interviews, it can be indicated that using

technology, such as a laser scanner and a BIM, in the field could benefit refurbishment projects, as accurate information could be used in the decision-making and design process. This accurate information could reduce the project complexity and uncertainty already in the beginning of the project. The interviews indicated that the full potential of laser scanning has not been utilised due to the lack of competence to procure laser scanning services; limitations of the laser scanning technique; and challenges in utilising the captured data in design work. Furthermore, the laborious modelling process may reduce interest in the technique. As these barriers are mainly related to the technical challenges, the popularity and extent of laser scanning in refurbishment projects may increase in the future as the modelling technique still evolves and more automation is adopted.

In the case study, the organisation was also indicated to cause uncertainty. The results of the study show that clear limits concerning the units' responsibilities are difficult to determine. Thus, the units are unaware of the implemented or planned actions and the condition of the municipal buildings. Ward and Chapman (2003) present rather parallel findings as they report the multiplicity of people and business units to cause uncertainty in a project. They also emphasise uncertainty arising from ambiguity related to the perceptions and specification of responsibilities, which is parallel to the results of this study. In addition, the results of this study indicate that this organisational uncertainty can be potentially reduced by improving communication between the units, as the information flow and communication between the units were noted to be rather deficient. Aside from the separate units in the organisation, uncertainty related to the organisation was also emerging from workers' lack of skills and capacity in the case study. Consistent with the study of Ali and Au-Yong (2013), poor leadership was also recognised to cause uncertainty in this study.

As a new finding, this study presents the municipal operational environment as a key source causing uncertainty in a municipal building refurbishment project, although, some features encompassing this theme have also been recognised to cause uncertainty in previous studies. For example, Ramgopal (2003) and Ward and Chapman (2003) have reported bases of estimates to cause project uncertainty, as well as linked unclear objectives and priorities with uncertainty. The results of this study highlight the uncertainty caused by unstable political outlines and strategies; incoherent decision-making; and unclear targets set at higher authority levels.

The case study provides discussions, site visits, brainstorming, past experiences and reviews from similar projects as the methods for identifying uncertainty. The case study, also, indicates that the uncertainty is not sought to be managed to a large extent in a municipal refurbishment project. This was predicted, as Kähkönen (2008) has claimed that practitioners are often unfamiliar with uncertainty management, and according to Green (2001), Ramgopal (2003), and Ward and Chapman (2003), the management scope is, commonly, in the risks instead of uncertainty. Even though uncertainties were partially identified in the case study, these sources were not further established and, moreover, were only slightly taken into account in planning.

As mentioned above, this study presents challenges in the decision-making process as a source causing uncertainty. This uncertainty, as well as several other uncertainties, can potentially be reduced by gathering more information and data, including investigations, estimations, and reviews of requirements and needs. This more proper information can be reached by using technical tools, scrutinising existing data more carefully, conducting condition assessments in more detail, implementing site visits and hiring experts to produce analyses and share their experiences and knowledge. Through this expanded information, it could be easier to generate and evaluate realisable alternatives, and decisions based on proper information available are easier to justify.

5.2 Evaluation of the Research

The quality of research is typically evaluated in terms of reliability and validity (Saunders, Lewis and Thornhill, 2009a; Leung, 2015). Reliability concerns replication and consistency (Saunders, Lewis and Thornhill, 2009a). Validity refers to the appropriateness of the methodologies, tools, processes, and data used in the study (Leung, 2015). Often, validity is divided into internal validity, which refers to the casual relationships between variables and results (Gibbert, Ruigrok and Wicki, 2008), and external validity, which deals with generalisation (Saunders, Lewis and Thornhill, 2009a).

This study used data and research triangulation to enhance in-depth understanding of the phenomena and to provide more perspectives on the studied themes. This reduced the risk of false interpretations and erroneous conclusions and increased the validity of this study. Moreover, the validity of this study was improved by using participant collaboration as the results and conclusions were discussed with

the participants of the studied municipal refurbishment project. Publications 1–3 concerned the same case. This uniqueness of the case can be seen as a weakness of the study, but also as a strength since it enables carrying out more in-depth and diverse analysis of the studied case.

The quality of the external validity of research often refers to the extent to which the findings of a study can be generalised to other relevant contexts (Saunders, Lewis and Thornhill, 2009a). However, in qualitative research, this point of view is also criticised due to the unique and context-dependent nature qualitative research typically has (Yilmaz, 2013). The results of this dissertation cannot be generalised due to the nature of the case and the action research methods adopted in this study, as the empirical study focused on the management practices of only one municipal organisation and one campus. Even though the literature review shows that many municipalities face similar challenges related to the management of municipal building assets and refurbishment projects, the present study does not provide direct evidence that the reasons for the challenges and management practises in other municipalities and other types of municipal buildings would be similar as those presented here. However, these results that correspond with previous findings support and highlight the extent of these detected municipal challenges and provide potential causes for these difficulties. Furthermore, as many registered challenges and sources of uncertainty are connected to the organisation and the municipal environment, these features must depend on actions and practises of municipal authorities on a broader scale. Thus, these findings must also reflect the actions in refurbishment projects of other types of municipal buildings.

Also, it must be noted that the cultural differences between the studied contexts in this dissertation and other contexts could also affect the generalisability of the findings. In addition, due to the relatively small number of interviewees, the results of publication four cannot be used to make generalisations either. Instead, the results of this dissertation aim to extend the understanding of the themes encompassing the various aspects of the management of a municipal building refurbishment project and to address the organisation's and individuals' experiences.

Reliability of research is often linked with transferability and replication (Gibbert, Ruigrok and Wicki, 2008). To strengthen the reliability of this study, the research design, methods, context, findings and interpretations are described in detail in each publication of this dissertation. Hence, the researcher provides the opportunity to judge the transferability of this study and allows other researchers to repeat the study

if so desired. The empirical study focused on the actions, practices and decision-making of only the personnel of the Real Estate Centre and the project team of the studied case project, whereas the actions and decision-making of the higher authority levels were not established more closely in this research. Instead, the information about the actions of the higher municipal levels is based on the reviewed documents and the comments of the stakeholders of the case project. Thus, the full reliability of this information cannot be proved and verified.

This dissertation used qualitative methods to gain a better understanding of the complex reality of the management of a municipal refurbishment project, especially focusing on refurbishment of schools and day nurseries. Furthermore, the results of each appended research publication filled a relevant gap in the knowledge of the studied phenomena. As the study provides valid and reliable information of managing a municipal building refurbishment project, the research target of extending the knowledge of municipal building refurbishment was achieved. Given the above, the contribution of this doctoral thesis can be considered scientifically valid.

5.3 Utilisation and Restrictions of the Research

This dissertation contributes to the knowledge of the management of municipal building refurbishment projects. Multiple challenges in the current practises of managing these projects were identified. In addition, tools and methods for both avoiding these challenges and improving the management process were presented in this study. The key suggestions concerning practical improvements that could be adopted in municipal building refurbishment projects are summarised as follows:

- A great amount of effort, including the use of technical tools, should be devoted to the acquisition of accurate initial data.
- Alternative solutions of implementation should be kept open in the early project phase instead of making the choice first and then collecting data.
- A long-term perspective should be employed when generating refurbishment alternatives.
- The alternative solutions of project implementation should be evaluated based on criteria specified in advance.

- The attendance in project meetings of stakeholders representing different user groups as well as various departments and project parties is beneficial for project implementation.

Also, several features and practices that could be adopted to improve the management of municipal building refurbishment projects in a more broad and long-term perspective were identified. The main principles of these findings are listed as follows: Key decisions and policies should be made on the upper level of the administrative hierarchy before project planning of a single project.

- Well-defined limitations, political outlines, project targets and requirements facilitate the process of project planning and decision-making.
- More skills and capacity in purchasing and interpreting condition assessments are needed for municipal workers.
- More training for municipal workers or the use of external experts is needed to establish the scale and contents of refurbishment.
- More effort should be devoted to documentation of hazards, repair actions, systematic maintenance, and surveys.

The results of this study may be useful and interesting not only in academia but also to a broad audience of municipal authorities and workers, policy makers and stakeholders of municipal refurbishment projects. The adoption of the suggestions to improve management practices may enable municipalities to use public finances in a more cost-effective way and to help conserve cultural history. In addition, the improved courses of action might have a positive effect on residents' health and well-being.

Besides the possible values this dissertation offers for practitioners, the key limitations of this study must be pointed out. This study is limited to concern the early phases of a refurbishment project. Thus, the management practises during the design and refurbishment implementation phases were not investigated. Moreover, as this study focused on management practises of refurbishment of schools and day nurseries, much cannot be concluded regarding the refurbishment management of other municipality-owned buildings, including hospitals, offices, and municipal residential buildings. These other building types have very dissimilar technical characteristics from school buildings, and also the building users and project stakeholders vary greatly.

6 CONCLUSION

The aim of this doctoral dissertation was to extend understanding of the management of a municipal building refurbishment project in its early phases. To achieve the target, research questions were formed to steer the study. The questions were addressed in the journal articles, which were validated through a scientific blind peer-review.

The first research question was ‘What challenges do municipalities have when refurbishing and managing municipality-owned buildings?’. This question was addressed broadly in the first publication, in which the challenges and actions concerning the municipal building stock were studied in the environment of a school campus. In this case study, the documents of actions, from a period of 15 years, were reviewed and analysed. In addition, the challenges and actions in a municipal refurbishment project were addressed by adopting participatory observation in the project meetings of a school refurbishment. The challenges were also identified in literature, and to some extent also recognised in publications two, three, and four.

The case study indicated that the demanding technical characteristics of municipal buildings, including at-risk structures, complex design solutions, and construction defects, complicate refurbishment and management of municipal buildings. In addition, the findings of the case study imply that repair actions of municipal buildings are often implemented with a delay, unsuccessfully, on a small scale, or only partially due to the lack of allocation for refurbishment. Moreover, the standard of maintenance and cleaning was indicated to be poor because of the demanding characteristics of the buildings. Furthermore, municipal buildings were observed to suffer from vandalism.

The case study also showed municipalities’ serious organisational challenges, such as overlapping work between the maintenance department and the developer department and ignorance of the work the departments have done. These challenges are mainly caused by a breakdown in communication between the departments and a poor level of documentation. Furthermore, the results of the case study support the earlier findings that municipal organisations suffer from a lack of competence in

purchasing condition assessments and interpreting the results of the surveys. Typically, the content of the surveys is too limited, as are the survey methods and number of samplings. In addition, the case study revealed the municipalities' lack of competence in carrying out repairs. Furthermore, uncertainty concerning political alignments was detected to complicate the management and refurbishment of municipal buildings. Municipalities were also registered to have communicational and political challenges, especially concerning public pressure for swift actions.

The second research question, 'How are decisions made in a municipal building refurbishment project in the early project phase?', was addressed in the second publication, in which the decision-making was examined by completing an action research study concerning the planning of a municipal building refurbishment project. As the municipal organisation is hierarchic, the decision-making process is multi-layered and proceeds rather inconsistently. Irrespective of this complexity, the decision-making process in the case study encompassed the early key phases of the rational decision-making model: identifying the target and the current problems; generating alternatives; and evaluating the alternatives. As the project contained a high level of uncertainty, also the sources of uncertainty were identified. However, these sources were not evaluated, and neither were evaluation criteria used when comparing the alternatives. In this project, multiple stakeholders were involved in the decision-making. Because of stakeholders' various interests and the lack of evaluation criteria, the decision-making processes progressed slowly.

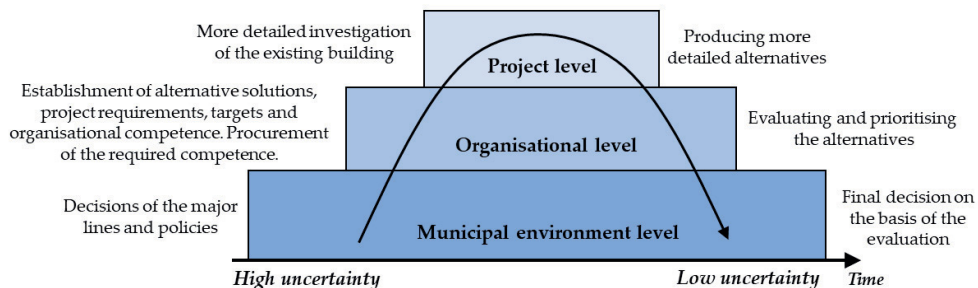
The third and fourth publications sought to answer the research question 'Where does uncertainty in the early phase of municipal building refurbishment projects originate from and how can it be identified and reduced?'. The origins of uncertainty were addressed by a case study as well as through a broad literature review. Three main categories, in which the origins of uncertainty in the early project phase were identified, as follows:

- uncertainty from the project, including the sources of uncertainty concerning the existing buildings, the project targets, schedule and costs;
- uncertainty from the organisation, including separately operating units, and the project stakeholders' competence, and;
- uncertainty from the operational environment, including municipal policy, estimates, needs and the decision-making process.

Commonly, a high amount of uncertainty is associated with an existing building due to insufficient as-built data. In addition to an extensive condition assessment, this uncertainty might be decreased, as presented in publication four, by using technical tools, such as laser scanning, for acquiring proper as-built data. However, due to the lack of competence to procure proper laser scanning services and the current limitations of the laser scanning technique in building refurbishment the full potential of this technique has not been utilised. Furthermore, the challenges in utilising the data in design work and the laborious modelling processes may also have reduced interest in the technique. However, since the modelling technique is still evolving, and more automation is adopted, the popularity of these technical tools in building refurbishment might increase in the future. The detailed and accurate data, gathered by laser scanning, could reduce the uncertainty related to design work and, also, provide a solid foundation for decision-making. The interviews indicate that greater benefits of this technique are connected to a larger extent of refurbishment actions. However, due to appropriate and accurate drawings of buildings built since the late 1990s, the benefits of the technique are fewer when refurbishing buildings built in the past 20 years compared to the benefits gained in the refurbishments of older buildings.

Besides using technical tools for decreasing uncertainty concerning initial data, methods to decrease the uncertainty in a municipal refurbishment project were addressed more broadly. As a result, a model for decreasing uncertainty in a municipal refurbishment project, in the early project phase, was developed. This model, presented in Figure 7, emphasises clear definitions of the concluded tasks in each municipal organisation layer. The tasks and decisions concluded on each level are based on the information gathered and the decisions made in an earlier step. Hence, this cumulative and shared information facilitates the practitioners' work on each level and decreases the uncertainty concerning information and project targets and limitations. In this model, the project is systematically evolved in each step towards the final decision.

Figure 7. A proposal for the process of decreasing uncertainty in the early phase of a municipal building refurbishment project



Novel knowledge produced by this dissertation comes from a variety of aspects in the management of municipal refurbishment projects. This research field is very limitedly addressed in literature, and the previous studies have not taken a holistic approach to examining this matter. Instead, they have concentrated on rather narrow topics within this field, such as the condition of the municipal building stock; maintenance management of municipal buildings; and refurbishment management in general. Therefore, the added value from this research is the diversified approach to the management of municipal refurbishments. Hence, the theme was addressed by taking into account aspects concerning the municipal organisation, its actions, and the environment; current challenges in the management; decision-making; and uncertainty. Through the discussion of these themes, this dissertation sought to provide an overview of certain aspects concerning the management of municipal refurbishment projects.

6.1 Suggestions for Future Research

This study adopted qualitative research methods, and the key results were based on the practices and procedures of one Finnish municipality. However, each municipality has its own characteristics and specific challenges. Therefore, a broader perspective on the management of municipal refurbishment projects is needed to obtain results that can be utilised more generally. The case study implemented in this dissertation could be repeated in a larger number of municipalities in order to achieve a wider overview of the current management procedures and to better understand the challenges in different circumstances. In particular, it might be profitable to address the management practices in municipalities with various population sizes. Also, it must be noted that the practices and municipal organisation structures vary

significantly from country to country. Hence, widening the range of the study to cover experiences in other countries might also be an interesting topic for future research.

Even though the literature review shows that many municipalities face similar challenges related to the management of municipal building assets and refurbishment projects, the present study does not provide direct evidence that the reasons for the challenges and management practises in other municipalities and other types of municipal buildings would be similar as those presented here. However, these results that correspond with previous findings support and highlight the extent of these detected municipal challenges and provide potential causes for these difficulties. Furthermore, as many registered challenges and sources of uncertainty are connected to the organisation and the municipal environment, these features must depend on actions and practises of municipal authorities on a broader scale. Thus, these findings must also reflect the actions in refurbishment projects of other types of municipal buildings. Benchmarking the suggestions generated in this study, in practice in a municipal building refurbishment project and organisation, might be useful. Hence, the validity of the adaptations in the procedure of a municipal refurbishment project could be evaluated more appropriately. In addition, the suggestions could still be redeveloped and more improvements generated.

While this study highlighted several challenges and difficulties municipalities have when managing building refurbishment projects, it could be beneficial to also address good practices in the field. Studying the characteristics, procedures, and factors of municipal refurbishment projects that have reached their outcome, budget, and time targets might reveal new features of this phenomenon. In addition, experiences of successful actions in eliminating building-related symptoms might be useful, too. Furthermore, it would be interesting to address the question of whether different types of organisations face similar challenges with municipalities and examine what types of tools and practises these organisations use in managing their buildings. The approach to examine these successful actions more broadly could be useful especially in generating new practices and in the development of current procedures.

This thesis focused on the management of the refurbishment of school buildings and day nurseries. These buildings have rather different characteristics compared to other municipal buildings, such as hospitals or municipal residential buildings. Due to these differences, it might be interesting to examine practices, processes, and

stakeholders of refurbishment projects of different building types. This wider perspective could potentially also reveal new aspects and practices to adopt in the refurbishment management of different types of municipal buildings.

In future, the management of municipal building projects will become even more important for municipalities, since the quantity of refurbishment projects will probably increase due to the ageing of the municipal building stock, but also more challenging, since buildings are more complex with advanced technology and have already undergone several refurbishment actions. In addition, municipalities are required to respond to the targets concerning energy efficiency and sustainability set by the European Union and Finnish legislation. Hence, more extent research into this phenomenon is urgently needed to improve current management practises.

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APPENDIX

Appendix 1. Theme Interview Questions

Questions for designers and architects

Themes

1. Measurement data of a building refurbishment project
2. Measurement process of a building refurbishment project
3. The use of laser scanning in building refurbishment projects

Background questions

- What is your job description?
- What kind of experiences you have of laser scanning? How many projects have you been involved in, in which laser scanning has been used? How is laser scanning used in your organisation?

Questions

- 1.1 What methods and tools are used for collecting as-built data of an existing building?
- 1.2 What challenges and problems are connected to the initial data or as-built data of building refurbishment projects?

- 2.1 In which phases of the project is the as-built data of an existing building collected?
- 2.2 What measures are taken, and which methods or techniques are used for that?
- 2.3 What tasks are related to the process of measurement or the further process of the as-built data in the phases of a) a feasibility analysis; b) project planning?
- 2.3 How is the measurement technique chosen? Are multiple various methods used and if so, why?
- 2.4 What type of laser scanning data is procured? What issues need to be considered when procuring laser scanning?
- 2.5 Who determines the plan, including accuracy, for laser scanning? What level of accuracy is appropriate in different kinds of projects?
- 2.6 Who does the further processing of laser scanning data?
- 2.3 How is the laser scanning data used in design work? In which format would the designer like to get the data?
- 2.4 Are the laser scanning data or the further processed model utilised during the construction phase?
- 2.5 In which format is the laser scanning data delivered to the building owner?
- 2.6 Is it possible to utilise the laser scanning data after the refurbishment?
- 3.1 In which phase of the project is the decision to use laser scanning made? Who makes the decision?
- 3.2 Why is laser scanning used in certain projects? Why it is not used in some projects?
- 3.3 In which project phases is laser scanning operated?
- 3.4 To what extent is laser scanning typically used in buildings? What are the typical buildings or projects where laser scanning is used? In which types of projects or buildings is laser scanning adopted, in particular?
- 3.5 What kind of data is purchased?

- 3.6 How much time does it take to operate laser scanning and to further process the data?
- 3.7 How many persons are needed to implement laser scanning and to further process the data? Who does the further processing of the data?
- 3.8 Which stakeholders are involved in projects where laser scanning is used? What tasks do these stakeholders have?
- 3.9 Who utilises the laser scanning data and in which way?
- 3.10 Are laser scanning or the laser scanning data used for other purposes than collecting as-built data?
- 3.11 How much do laser scanning and further processing of data cost?
- 3.12 Do you think that the benefits of laser scanning are greater than the costs?
- 3.13 Do you know any projects where deficient measurement data has caused problems? What effects has deficient or defective initial data caused?
- 3.14 Does laser scanning have any effect on the number of defects in designs?
- 3.15 Are there many operators who provide laser scanning or further processing of laser scanning data? What is the quality of those products?
- 3.16 Which types of challenges and possibilities does laser scanning provide?

Questions for modeller

Themes

1. The measurement process of a building refurbishment project
2. The use of laser scanning in building refurbishment projects

Questions

- 1.1 What challenges or problems are connected with the initial data or as-built data of a building refurbishment project?
- 1.2 What items and features are measured in building refurbishment projects?

- 2.1 In which phases of building refurbishment projects is laser scanning implemented?
- 2.2 What kind of models or data is procured from you?
- 2.3 What details are determined when making the procurement? What items should be determined?
- 2.4 How much does laser scanning cost? How much does the further processing of the laser scanning data cost?
- 2.5 How much time does it take to implement the laser scanning and the further data processing?
- 2.6 How many persons are involved in the laser scanning operation and in the further data processing?
- 2.7 What stakeholders are involved in the laser scanning of building refurbishments, and what tasks, related to the laser scanning, do they have?
- 2.8 Which types of projects does laser scanning suit well? Which types of projects does it not suit?
- 2.9 What challenges are faced in the process and in the use of inventory models?
- 2.10 What kind of initial data is needed for implementing an inventory model?
- 2.11 What challenges and opportunities are connected with laser scanning?

PUBLICATIONS

Publication I

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PUBLICATION

I

Municipal challenges in managing a building with noted health symptoms

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Municipal challenges in managing a building with noted health symptoms

Municipal challenges

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Abstract

Purpose – This study aims to present property management challenges that municipalities have encountered regarding a public building with noted building-related symptoms. The study goes on to provide reasons for the failure of attempts to manage the symptoms and discusses the current challenges concerning the process.

Design/methodology/approach – A participatory case study was used as the research methodology to identify the current challenges concerning a municipal approach to managing the building-related symptoms in a case-study building. The researchers scrutinised the history of the health symptom management process and attended the project planning meetings focused on the investigation of the condition of the building.

Findings – Multiple challenges concerning maintenance and omitted or postponed repair actions, as well as vagueness in the management process were found. In addition to this, it was noted that the complexity of the initial design of the building and vandalism have resulted in challenges for the maintenance and moisture performance of the building structures. According to the study, more orderliness and a more systematic process is needed when managing a municipal property.

Practical implications – The identified property management challenges may be of practical value for the facility managers and the property owners, especially when managing the building-related symptoms and a damaged building.

Originality/value – This study highlights the importance of having an in-depth understanding of condition assessments as well as proper maintenance and timely repairs for the successful management of the building-related symptoms in a municipal building. This is a pilot project in a larger project of management of building refurbishment.

Keywords School, Condition assessment, Management, Health effects, Building-related symptoms, Moisture damage, Mould, Case study

Paper type Case study

Introduction

In many countries, municipalities own a substantial amount of building stock, including public buildings, schools and day nurseries. In all respect, management of extensive building stock is challenging, as in recent years, serious and widespread problems concerning municipal properties have arisen. In several countries, building-related symptoms, indoor air problems, mould and water leaks are considered common problems in public buildings such as schools and day nurseries (Borràs-Santos *et al.*, 2013; Cai *et al.*,



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2011; Dangman *et al.*, 2005; Ebbehøj *et al.*, 2005; Jurelionis and Seduikyte, 2008; Kielb *et al.*, 2015; Meyer *et al.*, 2004; Park *et al.*, 2004; Saijo *et al.*, 2010; Savilahti, 2009; Taskinen *et al.*, 1997; Zhang *et al.*, 2013, 2011).

A substantial amount of a municipal building stock is damaged, and refurbishment is typically delayed, with only minor renovations carried out to repair damage observed. As a result, the damage increases in scale and may spread to other structures, resulting in a need for large-scale and expensive replacement or refurbishment work later. In addition to this, the refurbishment process is challenging and identification of building-related symptoms, pinpointing of the sources and management of the damage elimination process require wide-ranging expertise.

The building-related health problems may be divided in two classes: building-related illnesses and sick building syndrome. Building-related illnesses are health effects, which have well-defined link between environmental agent such as chemicals, gases, volatile organic compounds (VOCs), fibres and bacteria (Seltzer, 1994; Tong, 1991). The sick building syndrome is a complex problem with variety of factors resulting in a typical set of symptoms, including eye irritation, blocked, stuffy or runny nose, dry throat, headache, lethargy and dry skin (Tong, 1991). Those symptoms have linked to reduced effect on performance and sick leaves (Niemelä *et al.*, 2006; Tong, 1991). This study focus on the managing of the symptoms related to sick building syndrome.

This study examines the building-related symptom management practices in a municipality-run school with a day nursery. The municipalities have taken action to find and minimise sources of the symptoms multiple times, but the results have not been satisfactory. Thus, this case study will identify the current challenges faced in relation to the process and aims to establish the reasons for the failure.

Challenges in managing building-related symptoms in a school and day nursery environment

In Finland, municipal building stock covers about 35 million sq. m, which is over 7 per cent of the country's entire building stock. Most of those buildings require refurbishment because the majority of the stock was built before the early 1990s, and health complaints are relatively common, especially in school buildings (Korhonen *et al.*, 2018). Overall, the prevalence of building-related symptoms in municipal buildings has increased in recent years, and the condition of the buildings is deteriorating (Korhonen *et al.*, 2018).

Usually, the health symptoms in a school environment are related to structures damaged by moisture and mould (Annala *et al.*, 2017; Handal *et al.*, 2004; Haverinen-Shaughnessy, 2012; Koivisto *et al.*, 2002; Lignell *et al.*, 2007; Meklin *et al.*, 2005; Patovirta, 2005; Patovirta *et al.*, 2004; Sahakian *et al.*, 2008; Savilahti *et al.*, 2000; Taskinen *et al.*, 1997). The damage may be caused by several factors, including water leaks, the moisture load from outdoors, failures in structures and a technical ageing of materials (Koivisto *et al.*, 2002; Meklin *et al.*, 2002; Täubel and Leppänen, 2017). However, other factors, such as dust mites (Kielb *et al.*, 2015), volatile organic compounds (Åhman *et al.*, 2000; Norbäck *et al.*, 1990) and a lack of ventilation (Simoni *et al.*, 2010) are also strongly associated with the health symptoms. Typically, Finnish municipalities organise facility management by taking integrated responsibility for administration, operation and maintenance of the public building stock and the executive financial decisions are usually made by the municipal council.

Method and material

A participatory case study approach was adopted to identify the current challenges related to the municipal management practices of the building-related symptoms in a municipality-run school and a day nursery. The data used for the analysis was based on documents

including reports from investigations, surveys and questionnaires as well as building documentation. In addition to this, the authors of this article attended project meetings with municipal authors and condition assessment consultants, as the municipal authors were purchasing a new condition assessment.

The municipalities undertook measures eliminate the symptoms in the case study building for several years, but the results had been unsatisfactory. In 2018, the municipalities started project planning for refurbishment and an extension of the case study building, as the number of pupils in the school and children in the day nursery will increase in coming years. At the beginning of the project planning phase, in April and May 2018, the municipalities purchased a condition assessment, and the investigations were carried out during summer and autumn 2018. From March to November 2018, 14 project meetings were held, focused on the content and results of the new condition assessment, the content and results of the investigations carried out and the repair actions implemented. The authors of this article actively attended the project planning meetings, with the number of participants at the meetings ranging from 6 to 18. The participants of the meetings are listed in Table I.

The nature of the case study gave the authors an opportunity to study the organisation in practice and build understanding of the phenomenon and the process.

This research is part of the “Management of Complex Building Refurbishment” project, which aims to develop tools and practices for improving the management of complex building refurbishment projects. The project team selected the case study school as a pilot project.

Case study building

The case study building is a primary school with a day nursery located in a metropolitan area of Southern Finland. The two-storey building was built in 1997, and the total floor area is 5,223 m². Currently, approximately 400 children attend in the primary school and just over 40 children attend the day nursery. In addition to this, 50 faculty and 14 staff members work in the building. Furthermore, a secondary school building and a building for pupils with special needs are located on the same campus, but all the pupils use each of the buildings. In total, almost 800 pupils attend one of the facilities on the campus.

The building has a pier foundation with ground-supported footing units and concrete plinth panels. The frame is plastered brickwork and combined with sheet iron caisson. The load-bearing external walls are concrete elements with mineral wool insulation installed during the construction phase. A flat roof covers a number of different levels and has

Stakeholder	Participant
Authors of this article	Three university researchers
Condition assessment consultants	Five condition assessment consultant the building developing department purchased in May 2018
Municipal authors	Representatives of the building developing department The chief of the maintenance department The representative of a renovation contractor The representative of a school committee Kitchen expert Cleaning expert
Users	The chief of early childhood education The head teacher and the deputy head teacher

Table I.
The participants of
the meetings

hollow-core concrete slabs as its load-bearing structure. The roof was repaired during 2015-2017. The building has a mechanical supply and exhaust ventilation (Plate 1).

Health symptoms

The staff has complained for several years about an unpleasant smell and health symptoms when using the building. Usually, a person who suffer from such symptoms contacts an occupational health centre, where the staff then inspect the symptoms and gives a diagnosis. In addition to this, some wider health questionnaires have also been conducted. In a health questionnaire survey implemented in spring 2017, 41 per cent of the staff reported health symptoms, such as repeated and persistent respiratory disorders, eye irritation, headache, allergic symptoms, coughs and fatigue. The staff pointed out that the pupils also suffer from symptoms. In a health questionnaire survey implemented between November 2018 and January 2019, directed at all users of the building, over 60 per cent of the respondents reported having symptoms when using the building.

Results

The surveys implemented

The municipality authors have sought the reason for the building-related symptoms for several years by purchasing multiple investigations. The reports considering the condition of the building are presented in Table II.

The reports were scrutinised and the analysis shows that the investigations covered all the structural parts of the building as well as a yard, the ventilation ducts and installations and a sewer system. Several techniques and methods were used for surveying work: structural openings were made in the external and partition walls, the roof, the false ceiling and the floors. Surface moisture from the floors and the walls and the air pressure of the rooms were measured several times and a tracer gas was used to study a local air leakage. Additionally, temperature, relative humidity and carbon dioxide levels in the classrooms were measured for several weeks. Volatile organic compound were also detected, and samples from the air and various materials were taken and analysed. Twice mould was detected using a trained dog.

The results of the reports presented multiple factors that might have affected the development of the building-related symptoms. The sources and findings presented are collected and categorised in Table III.

The majority of the investigations led to suggestions for repair and maintenance actions, such as regulation of the ventilation, repair of a skylight window, sealing repairs and an



Plate 1.
Aerial view of the
building (feasibility
analysis)

Date	Type of the survey
August 2003	Inspection of kitchen by environmental centre
June 2008	Microbial survey of eight rooms
September 2008	Health-related inspection of working conditions
January 2009	Moisture survey in rooms complaints have been received about
February 2009	Condition survey of a ventilation system
September 2009	Inspection by labour protection district
March 2011	Indoor environmental survey in one class room
March 2011	Survey of water leakage from the roof
June 2011	Mould survey using trained dog
August 2011	Indoor environmental survey in three class rooms
October 2011	Quality assurance of sealing work
February 2012	Indoor environmental survey of the kitchen
June 2013	Survey of water leakage from the roof
March 2014	Indoor environmental survey
July 2014	Survey of water leakage
July 2014	Survey of water leakage
August 2014	Survey of water leakage
September 2015	VOC survey
September 2015	Microbial survey of indoor air
May 2016	Indoor air environmental and moisture performance survey
January 2017	Inspection by environmental centre
April 2017	Condition survey of pipes
May 2017	Indoor air environmental and moisture performance survey
August 2017 (26.7.2017)	Leakage test of sewers
October 2017	Building condition evaluation and long-term plan
February 2018	Ventilation assessment, research memo
February 2018	Renovation action plan
February 2018	Indoor environmental condition survey, research memo
October 2018	Microbial survey
October 2018	Condition survey

Table II.
The reports of
investigations,
inspections and
renovations between
2003 and 2019

upgraded standard of cleaning, as well as more additional investigations, including a greater amount of microbe samples.

In the initial years, microbial surveys of material samples were relative random; therefore, the comprehensive overview of the microbial situation of the structures was insufficient. In the most recent microbial studies, in summer 2019, samples were collected from several locations. High concentrations of fungi genera, which are often associated with mould, were found in several locations in the partition walls, external walls and insulation of a skylight base, especially in the area where the users have complained about the symptoms. Therefore, it can be concluded that the microbes found in the partition walls are one of the main reasons for the symptoms. The damaged materials were concentrated in the area where several water leakages have occurred. Some materials in an area that was covered with water in 2014 were replaced after the water leakage. However, it seems that the water ended up in a wider area that previously assumed, or that not all the moisture-damaged materials were replaced.

In several reports, vandalism to the roof was detected, and it was suggested that further such actions should be prevented. During a roof repair, it was suggested that a plywood board be installed on the wall of a store area to prevent access; however, that has not had the desired effect.

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Table III.
Findings of the
surveys

Structure/feature	Findings
<i>Microbes</i>	High concentrations of different bacteria, fungi and microbes have been detected in several air and material samples
<i>Roof and skylights</i>	Water leakages occurred several times from roof and skylights Failures in structures due to vandalism Construction errors
<i>Walls</i>	Indication of water damage and microbes in partition walls External walls not studied on a large scale Construction errors in external walls
<i>Windows</i>	Recurring water leakages from windows in two classrooms
<i>Floor</i>	High relative humidity in several areas of the base floor Unpleasant smell from the base floor Material emissions from glue on the concrete floor
<i>Sewers</i>	Smell from sewers Corrosion in some sewers Accumulation of debris and dents in rainwater drains
<i>Ventilation and air pressure</i>	Air flow in many rooms lower than planned High negative, 25-30 Pa, air pressure in some rooms compared to outdoors Blocked ventilating pipes
<i>Indoor environment</i>	Carbon dioxide levels in classrooms were reported to be generally at a normal level Temperatures in classrooms generally at a normal level Relative humidity has been occasionally slightly below normal level, relative humidity 20-30%, resulting in a feeling of dry air
<i>Yard</i>	Pooled water close to the building Plants growing close to the building Minor slanting of the yard away from the building No underdrain system
<i>Other</i>	Dust, poor standard of cleaning Cracks in joints of several structures, leaking structures

Repair actions

Over the years, several repair and replacements actions have been implemented in the building. However, not all the actions have been documented or reported systematically, and thus, a complete overview of the repairs carried out is lacking. The chief of maintenance and the existing reports substantiate that the following repair actions are executed:

- The roof was completely renovated during the summers 2015-2017. The original roof structure was stripped back to the concrete slabs, and the new structure was built on the top of the cleaned slabs. Some levels of the roof were lifted to the same level as the other parts of the roof.
- Multiple small-scale repairs after water leakages between 2006 and 2014.
- Drying of some of the rooms after a water leak and replacement of some of the materials in 2011.
- A bottle was removed from a sewer in summer 2017, and the functionality of the sewer system was examined using a smoke test. No leakages were observed.

Between May 2018 and February 2019, multiple rooms were repaired extensively with the aim of decreasing the prevalence of the symptoms. The repair actions included sealing the rooms to make them airtight, putting an epoxy membrane coating on a concrete floor and replacement of a floor coating. The actions were based on a repair suggestion given in a condition assessment implemented in 2017 and early 2018. In addition to this, some actions

were taken on the basis of the most recent condition assessment carried out in summer 2018. During the demolition work in June 2018, mould was spotted across a wide area of the partition wall between a corridor and a classroom; in addition to this, staining from prior water damage was observed on the partition wall behind cupboards in another classroom.

The purchase of the condition assessment

In April and May 2018, the municipalities purchased a condition assessment. Two separate consultant companies were selected to carry out the surveys: one of the companies was commissioned to survey the technical building services and carry out microbe explorations and the other was commissioned to investigate the structural physics of the building and to make structural openings. The content of the surveys, the progress and the findings were discussed in the project meetings between May and November 2018. The municipalities also purchased some additional surveys as suggested by the consultants. However, some of the additional investigations the consultants suggested, including the additional microbial sampling of the external walls, were not purchased, even though the parties were unanimous as to the need for the investigation in the project meetings.

In addition, as there were refurbishment actions in progress during summer and autumn 2018, the content of those actions was also discussed in the meetings. Different perspectives on the renovation actions and the elimination of the symptoms emerged in the meetings. The chief of maintenance stated that the purpose of those renovation actions was to respond quickly to the symptoms exhibited by users. Whereas the condition assessment consultants, on the other hand, drew attention to the elimination of the sources of the symptoms and the long-term perspective. For this reason, they did not consider the sealing of the external wall to be the most appropriate renovation method, as the potential microbes in the external wall had not been investigated and their presence established.

The persons in the meetings had also different impressions of the prevalence of the symptoms and of the success of the renovations carried out in previous years. According to the building development department, users have had symptoms for several years, but the chef of maintenance stated that the symptoms significantly decreased occasionally over the years. Different impressions were also presented regarding the functionality of the repaired roof and the ventilation equipment. The building development department pointed out that the sources of the symptoms had not been determined, whereas the maintenance department claimed that the sources were stated in the condition assessments carried out in 2017 and early 2018. The diversity of views indicates that different persons have interpreted the results of the condition assessments in different ways.

Discussion

The investigations purchased show that municipalities have tended to respond to failures and observations actively. However, because the failures have been repeated and the symptoms have persisted, the responses have been relatively ineffective. The study found several challenges in the management process for building-related symptoms, as well as multiple factors that have caused the indoor air problems and complicated the management of the building. The findings can be summarised as follows:

- (1) failures:
 - breakdowns of the devices and the structures.
- (2) characteristics of the building:
 - at-risk structures.
- (3) procurement of the investigations:

- limited content of the study: structures, rooms; and
- limited survey methods and amount of samplings:
- (4) lack of competence in the evaluation of the investigations
 - lack of procurement of additional surveys; and
 - lack of implementation of the suggested repair actions.
- (5) repair actions:
 - delayed actions;
 - only partial actions;
 - small-scale and temporary repairs instead of replacement; and
 - failed actions.
- (6) poor standard of cleaning.
- (7) poor standard of maintenance:
 - difficulties in maintenance because of building characteristics.
- (8) lack of documentation.
- (9) vandalism.
- (10) lack of communication between the users, the maintenance department and the building developer.

Attempts were made to manage the building-related symptoms in the case study school for several years, and accordingly, multiple studies and repair actions were implemented. The explanation given in the investigations showed that the sources of the symptoms were usually studied on a small scale and the investigations were limited to only some rooms. In addition to this, the investigation techniques were limited, for example only few or no material samples were gathered from the structures, with most of the samples were gathered from air and dust from the floor. The findings of these deficient and limited condition assessments are in accordance with previous findings (Marttila *et al.*, 2015). Additionally, some of the investigations presented requirements for further research, for example, it was suggested more material samples from the partition wall structures be gathered, but those needs were not systematically responded to. Therefore, the content of the investigations remained limited. Perhaps, a more extensive study and varied techniques would have produced more reliable results and indicated more potential sources of the symptoms earlier on.

The interpretation of the investigation results and content may have been limited or the previous investigations may not have been processed well or trusted, as multiple studies overlapped and presented similar results. In addition, the repair actions suggested in the condition assessments were often implemented only partially and after a delay. Therefore, even though some of the noted failures were repaired, the damage might have expanded in some structures, and therefore, the symptoms did not decrease markedly. Furthermore, Marttila *et al.* (2017) stated that condition assessment observations are not always considered in the execution of a renovation.

Some actions might have been postponed because of a lack of funding or because of awareness that larger building refurbishment projects were being planned for the future. Other studies have also reported that a lack of funding for refurbishment and maintenance impaired the condition of the municipal property (Kero, 2011; Korhonen *et al.*, 2018; Lewis *et al.*, 2000).

Both the maintenance department and the building development department purchased condition surveys. This explains the overlapping of the content of the surveys but also

indicates a breakdown in communications between the departments. The challenges in communications and information flow may have partly originated from a high turnover of municipal workers: during the project planning phase of the case study school, the project manager changed twice.

Many of the investigations claimed that there was no need for further research even if the reason for the health symptoms had not been established. In addition to this, condition assessment observations were somewhat inconsistent with each other. For example, some assessments stated that a new, replaced roof worked correctly and had no faults, whilst another one discovered several defects in the structure and functionality of the roof. Because the level of the condition assessments varies greatly, the municipalities require comprehensive understanding when it comes to purchasing the investigations, and they also need competence in interpreting and evaluating the investigation results.

Many of the investigations highlighted deficiencies in maintenance and cleaning. The standard of the cleaning level was noted as being relatively poor in several condition assessment reports, for example, microbes growing in toilets and high amount of dust and dirt on the floors were detected. It was suggested that it be improved, as some reports indicated that a poor level of cleaning might be one reason for the health symptoms. However, it can be assumed that there has not been any improvement as this is mentioned in five reports. Perhaps, the cleaners were not notified for the required level of cleaning, the cleaning is done indifferently or the result of the work is not briefed or supervised. In other study, a poor level of cleaning was linked to building-related symptoms in schools (Wälinder *et al.*, 1999). Additionally, defects in a ventilation system have been ongoing for a long time because failures in the system, complications with operating times and a recommendation for more accurate maintenance of the devices were pointed out in several condition assessments reports. The faults with the ventilation system caused a pressure difference in the rooms, and that might have brought microbes from the structures into the indoor air. In addition, the records concerning air regulation and servicing of the machines were vague and incomplete. Therefore, it has been challenging to establish which actions have been implemented and what effect they have had. The results of the reports imply that a lack of a proper maintenance played a role in the damage the school has incurred, and other authors have reported similar results in different buildings (Chelelgo *et al.*, 2001; Kero, 2011; Lavy and Bilbo, 2009).

The repair actions carried out over the years were not systematically documented, and the documentation that did exist was not kept safe. Therefore, carrying out a systematic follow-up examining the success of the repairs in eliminating health symptoms has been challenging. According to one head of maintenance, occasionally, the symptoms almost disappeared. However, because the documentation of the repair actions has been sub-par, and the symptoms have not been systematically followed-up on, it is challenging to establish afterwards which of the actions have been successful.

The challenges faced at the school have been complex and varied and have covered multiple failures in several structures and systems. For example, the water leakages originated from the roof, the skylights, around the windows and the rainwater drain under the floor. The standard of construction work has been relatively poor, because the condition assessments found several errors as a result of the work, and the initial structural solution of the building is complicated. The roof initially had several levels, and the envelope of the building is structurally complex and includes multiple recesses and corners. The complexity has caused problems for maintenance because walking on and access to the roof, for example, are challenging. In addition, some unfavourable modifications were implemented during the construction phase. For example, there is no underdrain system under the

building, even though one was designed, and the building is built on a soil with high capillarity in relation to the design plan.

As the building is complex and failures have been detected in multiple structures, elimination of the symptoms is challenging. To eliminate the symptoms and prevent the new ones occurring, a comprehensive and systematic management of the building is required. Proper and systematic maintenance, quick response to hazards, timely repairs and follow-up of the symptoms seem to be important, which supports the findings of Kero (2011). In addition, a comprehensive investigation of a building after a hazard or symptoms arises appears to be necessary, and the repairs suggested should be carried out without delay after a failure such as a water leakage, to curtail the damage.

Consistently with past research, water leaks were one of the major reason for moisture damage in the school (Gravesen *et al.*, 1999). A blockage in the rainwater drains and the drainage pipes caused moisture damage, which is consistent with the study carried out by Leivo and Rantala (2005). In addition, the roof outlets were relatively small, and the maintenance was not implemented in a particularly careful or timely manner. Therefore, the outlets were blocked up, resulting in water leaks. Overall, water leaks have proven to be a very common reason for mould exposure (Crook and Burton, 2010; Haverinen-Shaughnessy, 2012; Nduka *et al.*, 2018; WHO, 2009; Yang *et al.*, 1997). A significant finding of this study was that vandalism caused the water leaks and moisture damage, which other authors have not strongly associated with the building-related symptoms.

Even though this study was limited to one public building in Finland, the authors believe that municipalities across multiple countries, whose mission is to improve the management process of a damaged building or building-related symptoms, may find the findings of this study useful. The municipal challenges reported in this study are not limited to this case as other studies present similar problems, such as challenges with maintenance and an urgent need for repairs (Hopland, 2014; Kero, 2011; Lavy and Bilbo, 2009; Lewis *et al.*, 2000; Smith and Stewart, 2007), inadequate information about the building condition (Kero, 2011; Lavy and Bilbo, 2009), a lack of competence in purchasing and interpreting the condition assessments (Kero, 2011; Marttila *et al.*, 2016) and similar technical challenges in school buildings (Lewis *et al.*, 2000).

Conclusions

This study highlights the importance of proper maintenance, as well as an in-depth understanding of condition assessments in the management of building-related symptoms. The research aimed to identify property management challenges that municipalities have encountered regarding a public building with noted building-related symptoms. The study revealed multiple reasons for the failure of municipal attempts to manage the building-related symptoms in the building occupied by the public school and day nursery. The main findings can be summarised as follows:

- technical challenges and failures: ignorance of the sources of the building-related symptoms;
- organisational challenges: overlapping work between the maintenance department and the developer department and ignorance of the work the departments have done;
- lack of competence in purchasing the condition assessments and interpreting the results of the surveys; and
- communicational and political challenges: public pressure for swift actions.

In addition to this, the research discovered that a lack of proper maintenance, as well as omission of repair actions, impacted the extent of the symptoms. Additionally, vandalism, the complex design solutions and defects in building work have had a partial effect on the development of the problems.

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PUBLICATION II

Decision-making when organising facilities for a school: a participatory action research approach

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Decision-making when organising facilities for a school: a participatory action research approach

Organising facilities for a school

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Abstract

Purpose – Public authorities are required to organise new facilities to respond to changed user demands in terms of a public-owned school. The number of pupils attending the case study school will increase in the following years, as will the number of children attending a day nursery located on the present campus. In addition, the users of the campus have complained of building-related symptoms. This study aims to understand the municipal decision-making process in organising the school's facilities, in particular, the factors used for decreasing uncertainty around a project.

Design/methodology/approach – This study is a case study undertaken through an action research approach. The researchers participated in the project planning meetings concerning the future activities to take place in the building.

Findings – Over a 13-month period, multiple stakeholders participated in the project planning meetings providing a deeper understanding of the space demands posed, current challenges and opportunities offered by the existing building. In addition, the alternative solutions generated were evaluated. The problem identification and information gathering periods lasted over nine months, which was far longer than predicted. Thus, generating alternative solutions and evaluation of the solutions also delayed. As the entire process was delayed substantially, the final decision on organising the facilities was not made during this research.

Practical implications – This research may be of practical value for a property owner and a project team for decision-making concerning changed facility demands.

Originality/value – This paper provides information about how public authorities are making decisions on facility organisation during conditions of uncertainty.

Keywords Public decision-making, Uncertainty management, Project planning, School facilities, Building-related symptoms, Facility organisation

Paper type Case study

Introduction

Public authorities all over the world must constantly make decisions on actions concerning public building stock. Currently, a large amount of a public building stock, such as school buildings, is in poor condition and needs refurbishment (Bello and Loftness, 2010; Filardo, 2016; Hopland, 2014; Lawrence, 2003; Lewis *et al.*, 2000). In addition, a multitude of building users are complaining of building-related symptoms when using the public buildings



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(Åhman *et al.*, 2000; Borràs-Santos *et al.*, 2013; Patovirta *et al.*, 2004). Public decision-making concerning organisation of a facility is typically complex and needs proper information on future needs and the condition of the existing buildings, as well as careful identification of risks and uncertainties of each alternative, before the final decision is made.

In decision-making concerning a damaged building, the condition of the building plays a major role in the decision from a financial perspective, as well as in terms of the future use of the building, including space demands (Marttila *et al.*, 2016) and environmental and social factors. Often, it is necessary to make a decision concerning future functions of the building in conditions where some uncertainty still prevails (Farsäter and Olander, 2019). Typically, an overall impression of the condition of a building must be sought as the initial data is often incomplete. In addition, users' needs and demands may be unclear and change during a project.

The need to create space for an increasing number of pupils and kids, the changed demands in terms of amount of food preparation and the modified needs of a school were the factors that initiated this participatory action research. Action research is an approach that aims to both take action and generate knowledge of that action. In the process the researchers are not solving the problems for the others but with the others (Ottosson, 2003). The idea behind action research originates from Lewin (1946). As the researchers are involved in the organisation studied, they can use unspoken and unfurnished information and resolve the practical challenges of the organisation. Whereas, when using traditional research methods, researchers are standing outside the studied social system, may not see every aspects of the system and the data is often reconstructed (Ottosson, 2003). This study is proposed as a framework for demonstrating how decisions on municipal facility organisation are made in conditions of uncertainty.

Organisation of school facilities

Working with an existing building entails several uncertainties, including technical, financial, functional and project management challenges, as well as health-related factors. When making a decision concerning a building with reported building-related symptoms, management of uncertainty is important for avoiding and overcoming indoor air problems and health symptoms. Refurbishment of a building about which health complaints have been made is complex to manage and to complete successfully, and a project typically involves a high level of uncertainty (Ebbehøj *et al.*, 2002; Haverinen-Shaughnessy *et al.*, 2008; Kero, 2011). Therefore, a comprehensive understanding of the condition of an existing building, indoor air science, the moisture performance of structures, the total performance of a building envelope and sustainable renovation actions is needed to produce a healthy environment for users.

In Finland, decisions concerning school facilities are made by local councils, and the proposals for organising those facilities are typically prepared by municipal workers. Often, the decisions include multiple separate decisions, such as those determining whether to renovate an existing school or build a new school, and if renovating the building, what the extent of renovation will be (Wilkinson *et al.*, 2014). Farsäter and Olander (2019) reported that functionality and accessibility as well as architectural and cultural values were the main themes in the decision-making of the early stages of a school renovation study, instead technical status, energy use and indoor environment in the buildings were discussed to a limited extent. In general, municipalities face a number of challenges in managing public property, encompassing executing renovations, a lack of funding for maintenance, renovation works and replacement of facilities, unsatisfied building users and making

decisions concerning public facilities, as several authors have reported (Baadjies, 2018; Barber, 2015; Haugen, 2014; Kero, 2011; Lewis *et al.*, 2000; Vermiglio, 2011).

Decision-making in conditions of uncertainty

The decision-making process typically involves the following themes:

- generating available options;
- evaluating the options; and
- selection of an action.

The decision-maker rarely has all the information available and a limitless amount of time to make the best decision. Thus, the decisions are made in conditions of uncertainty. Uncertainty may be defined as “a lack of certainty”, and may be related to cost, duration, information required or quality (Ward and Chapman, 2003). It can be classified according to the issues the decision-maker is uncertain about, including outcomes, situation and alternatives, and according to the sources of the uncertainty, including incomplete information, inadequate understanding and undifferentiated alternatives (Lipshitz and Strauss, 1997). Uncertainty can be reduced using several procedures, including collecting additional information to be processed before decision-making (Galbraith, 1974), deferring decisions until the required information is available (Hirst and Schweitzer, 1990), eliminating sources of uncertainty (Allaire and Firsirotu, 1989) and improving predictability through shortening time-horizons (Cyert and March, 1963).

Research method and material

This case study was carried out as action research by participating in information gathering and discussions at the project meetings as well as following the decision-making process. Thus, the authors could come to the closest of the studied process and were able to obtain the very deep understanding of the process. In addition, the risk of misunderstandings was reduced as researchers worked closely together with the studied organisation on a daily basis in the project. The authors gained data all the time during the process and could use unfurnished data, unspoken information and impressions in a qualitative way.

The researchers started the study in spring 2018, at the beginning of the project planning phase, and the study lasted 13 months. The researchers attended actively a total of 21 project planning meetings, observing as well as making suggestions and asking questions. The meeting dates and a summary of the issues discussed during the meetings are presented in Table 1. At the beginning of the project planning phase, the meetings were usually attended by university researchers, a representative of the building developing department, condition assessment consultants, a head teacher and a deputy head teacher, and sometimes also a chief of a maintenance department, a representative of a school committee, kitchen and cleaning experts and the chief of early childhood education. In the final stages of the phase, one or two designers hired by the municipality also participated in the meetings. The number of participants in the meetings ranged from 6 to 18.

Characteristics of the case study buildings

The case study concerns a school campus that consists of three buildings: the so called white building, the brick building and the pavilion, located in the Vantaa metropolitan area, Southern Finland. All the pupils use each of the buildings and in total there are almost 800 pupils using the campus (Figure 1).

Table 1.
Project planning
meetings and the
main topics
discussed

Date	Main topics
27.3.2018	Launch of project planning and presentation of the stakeholders
6.4.2018	Structural issues, condition of systems and devices and layout of the facilities
10.4.2018	Visit to the campus
10.4.2018	Facilities and functionality, usage of the site and an extension to the day nursery
4.5.2018	Requirements associated with ventilation and adequacy of the initial data
16.5.2018	The need for a condition assessment
21.5.2018	The procurement of a condition assessment
8.6.2018	The content of the condition assessment and the repair actions executed during the summer
28.6.2018	Progress of the condition assessment and the repair actions
9.8.2018	The condition assessment task and repair actions executed during the summer
6.9.2018	The results of the condition assessment
10.9.2018	Procurement model
11.9.2018	Project planning
5.10.2018	Presentation of the results of the condition assessment
3.12.2018	The results of the condition assessment and effects of the results on project planning
3.1.2019	Visit to the buildings, review of the results of the condition assessment and general notices
16.1.2019	Commencement of the designing work
31.1.2019	The matters required related to the design
28.2.2019	Presentation of the design layouts
14.3.2019	Review and evaluation of the design layouts
28.3.2019	Review and evaluation of the design layouts



Figure 1.
The case-campus is
light-coloured and the
numbered buildings
are (1) the white
building, (2) the brick
building and (3) the
pavilion

Source: Copyright @Vantaan kaupunkimittaus 2020

The white building is currently a primary school with a day nursery. This two-storey building with a total heated floor area of 4,620 m² was built in 1997. Currently, the building has places for approximately 400 children in a primary school and places for 42 children in a day nursery. In addition, 50 faculty and 14 staff members work in the building. The building features a kitchen and a dining room, conventional classrooms and some classrooms equipped for more demanding activities, such as rooms for timber and metal work. In

addition, the pupils also use lobbies when studying. The staff have complained for several years about symptoms and an unpleasant smell in the white building. In a survey concluded in 2017, 41% of the staff reported experiencing symptoms, such as repeated and persistent respiratory disorders, eye irritation, headaches, allergic symptoms, coughs and fatigue, when using the building. In addition, a significant number of pupils have also suffered from various symptoms, such as nasal congestion, rashes and other skin symptoms.

The three-storey brick-framed building “the brick house” was built in 1955. Currently, the school’s capacity is about 300 pupils, and the total heated floor area is 4,261 m². Most classrooms are conventional rooms with natural ventilation. Some rooms have been refurbished to be special classrooms, such as home economics and physics. Local exhaust ventilation is built into those rooms because of more demanding condition requirements. However, these ventilation systems disturb the natural ventilation and, thus, the special classrooms are not suitable for the brick house.

The timber-framed pavilion, with the total heated floor area of 611 m², was built as a temporary building in 2001 and it is being strongly considered for demolition in the foreseeable future.

History of the buildings

The white building has had a number of problems from a very early stage. There have been several water leakages and the users have complained of building-related symptoms for many years. Multiple repair actions have been carried out in the building because of the failures, and the roof has been replaced. During summer and autumn 2018 and winter 2019, several measures were carried out in the building, including addition of an epoxy membrane coating on the concrete floor; replacement of the floor coating and sealing rooms to be air tight.

The brick building still has many of its original systems, components and structures. However, it has undergone small-scale renovations multiple times, for example, some of the windows have been replaced. There is natural ventilation in most of the classrooms, and the rooms are perceived as stuffy, while the temperature during winter is too cold and during summer is too hot. The condition of the buildings as well as the executed condition assessments and refurbishment actions executed are presented more widely in a previous study (Uotila *et al.*, 2019).

Action research process

The first project planning meetings focused on describing the initial situation of the school and the day care centre, as well as elaborating with a feasibility analysis and a project target. In addition, the users’ views and experiences were explored in depth. There is a need for a day nursery with 192 places, and the number of pupils on the campus will rise by 150 pupils in the coming years. In the surroundings, there are no usable plots for a new day nursery building, according to the municipal authority. In addition, the serving capacity in terms of lunches will be increased on the campus as the school also provides lunches to other pupils in the area, and the numbers of pupils in nearby schools will increase as well.

Some problems and requirements of the facilities were defined in the feasibility study, but the targets and current challenges were still elaborated on in these meetings. In particular, the users of the school presented challenges they currently face in the buildings. The main targets and current problems presented at the meetings can be summarised as follows:

Targets:

- Organising facilities for 192 children in a day care centre.
- Organising facilities for 950 pupils on the campus.
- Organising facilities to make 1,800 lunches per day.
- Providing disabled access into all the classrooms.
- Ensuring the learning spaces are compliant with the new curriculum.

Challenges:

- The spaces are not large enough for an increased number of pupils and day care attendees.
- The kitchen is too small to increase the service capacity.
- Complaints have been made of building-related symptoms in the white building.
- Several failures in the white building have occurred over the years, such as water leakages.
- The problematic route for service traffic through the yard is problematic.
- The yard is fairly small for the number of pupils and children at the day care centre.
- The present classrooms are fairly inefficient in terms of space usage.

Currently, the space usage of the brick building and the pavilion is fairly inefficient. For example, the target space demand for a secondary pupil is 8.5 m² and the current space per pupil is 13.17 m². On the other hand, the rooms of the white building are used more efficiently and, for example, corridors are also used during the lessons.

The day nursery definitely requires a larger space, but the school also has needs related to the characteristics of the rooms. The present dining room is noisy and impractical, the room for woodwork needs modernising and more safe spaces, and the gym should be more multipurpose. In addition, the classrooms should generally be more adaptable to be more appropriate for a new curriculum.

Gathering information

During the spring and early summer 2018, all the existing materials related to the building condition, including 30 reports covering condition assessments, surveys, hazards, audits and repair measures carried out, were collated and scrutinised by the authors. In addition, the authors made a map of the investigations: each survey was pinpointed on a plan and the results were presented briefly. The aim of the map was to help those involved visualise the surveys of the building implemented and to sum up the results of those studies. The scrutiny highlighted that the white building has been subject to a broad range of investigations, but some omissions in the data on the condition of the building were found. The brick building has also been studied a lot, but the investigations were somewhat outdated and generally more limited. To establish more precisely the condition of the buildings and the needs for future repair measures, the municipal authors hired condition assessment consultants to survey the buildings. The surveys were carried out between May and October 2018. The condition assessment consultants also attended the majority of the project planning meetings until the end of the study.

The most recent survey and the earlier surveys reported multiple failures and hazards in the white building, as well as the building's renovation needs. The surveys reported the following failures and observations, among others: water leakages from the roof and the

skylight windows, blocked sewers during heavy rainfall causing water to flood the floor, moisture damaged partition walls because of splashing of water near the taps, microbes in the insulation of the partition walls, poor ventilation and a poor standard of cleaning. Therefore, multiple structures are in need of renovation measures but the building is also in a need of more careful maintenance. The brick building also has multiple needs for renovation. In particular, the base floor of the basement is in need of replacement and multiple other structures have been damaged over time.

Identifying the uncertainty in relation to the case buildings

During summer and autumn 2018, the project participants tended to identify the uncertainty concerning the buildings and the entire project. The condition assessment consultants focused in particular on uncertainty related to technical issues, and the users on uncertainty associated with functionality. The uncertainties were freely pointed out in the project planning meetings. The authors documented the following challenges and uncertainties identified concerning the white building:

- (1) The uncertainties concerning the most recent repair actions:
 - *Sealing work in the classrooms:* The condition of the external walls was unknown, it is possible that some of the external walls that underwent sealing contain microbes, and gradually these microbes will spread into the indoor air.
 - *Epoxy-membraned floor:* The moisture performance of the structure will change, and the epoxy membrane prevents moisture rising up from the concrete floor. Therefore, some of the moisture content of the concrete floor may rise. The areas under the partition walls were not epoxy membraned, and there is a risk of moisture rising by capillarity into the partition walls and leading to moisture damage.
- (2) Construction failures.
- (3) Failures in the roof.
- (4) *Challenges with maintenance of the roof:* The access hatch is at almost the same level as the roof and during winter, snow sometimes drifts against the hatch and prevents access to the roof. The drifting snow may also let water into the structures of the external walls from the joint in the access hatch.
- (5) *Vandalism:* Trespassing on the roof is quite common, and people on the roof have damaged the structures, which has probably contributed to water leaks. If access to the roof cannot be prevented, there is a high risk that acts of vandalism will continue to occur and also cause water leaks in the future.
- (6) *Technical uncertainty related to the floor surface:* The floor surface is almost at the same level as the surrounding ground-level in several locations.
- (7) *Microbes in structures of the white building:* High levels of microbes and spore cases were found in several structures and multiple locations.
- (8) The learning environment is noisy.
- (9) The yard is unsafe for children and pupils.
- (10) There are not enough car parks.

The uncertainty concerning the most recent repair actions can be responded to by revealing the success of the renovation. The success and the consequences can be tracked in multiple ways: changes to the moisture performance of the structures can be tracked by continuously

monitored sensor data, and air-tightness can be monitored by smoke tracer testing. However, of greatest importance is monitoring the symptoms exhibited by the users.

The uncertainty concerning the brick building was discussed more briefly. However, the following uncertainties were identified:

- microbes and other impurities in the basement;
- unpleasant conditions during lessons; and
- accessibility problems.

As it was assumed that the pavilion is to be demolished, the uncertainties considering that building were not discussed.

Generating alternative solutions and evaluating the alternatives

In December 2018, the municipal administration hired consultants to design solutions for organising facilities. As it was assumed that the brick building was not having a notable negative effect on the health of users, the starting point of the design was to keep the frame of the building relatively unchanged and create an extension into the white building. In February 2019, the designers presented three alternative procedures for responding to the new space demands.

Evaluation. The project planning participants gave feedback on the alternatives presented during the project planning meeting. The authors created an evaluation of the design alternatives presented in the meetings, and summary of the alternatives and the evaluation is presented in Table 2.

As all three alternatives have many disadvantages and challenges, the project team decided that the designers would create a new alternative, in which the feedback given would be taken into account.

Alternative four. In the middle of March, the designers presented a new design, where an extension, connected to the existing building with a walkway, would provide a new kitchen, a dining room and day care facilities. Again, the project team commented on and evaluated the design at the project planning meeting on 13 March 2019.

The alternative four (A4) has many advantages compared to the previous designs, but it also has significant downsides. The children and accompanying parents arriving to the day care centre need to enter the building from the inner courtyard as this is where the playground for the children is, and they will leave their shoes near those entrance doors. The walking distance from any nearby car park or bus stop to the entrance from the inner yard is relative far. Therefore, accompanying the children takes a long time; this also means that some nearby car parks will be occupied for a longer time, which may cause traffic congestion.

The A4 features an entrance from the inner yard and from outside into the walkway between the extension and the existing building. The authors and condition assessment consultants established that previous experiences have shown that an external wall, which would be inside the building following the extension, has caused indoor air problems several times. The risk can be minimised by planning the extension to be separated from the original building and connecting it to the building, for example, with a separate walkway. This solution has advantages as it simplifies the access to some rooms significantly, but also complicates the idea of a school where users do not have to put shoes on to move from one area to another. In any case, the safest solution is to build the new extension entirely separated from the existing building, as this means any potential air impurities cannot be transferred into the extension. However, the majority of the municipal employees wished to

Characteristic	Alternative 1	Alternative 2	Alternative 3
Facilities the new extension comprises	Facilities for a day care centre	Facilities for fine art, handcrafts, home economics and natural sciences	New kitchen facilities, a dining hall and facilities for natural science and home economics
Area of extension (Gross floor area, m ²)	1,812 + ventilation engine room	2,284	2,233
Technical level of the extension	*	**	***
Cost	*	**	***
Advantages	Functionality of the day nursery facilities Minor renovation needs in the existing classrooms The yard of the day nursery is quieter than the current yard as it is further away from the road, and particle emissions levels are lower	Functionality of the natural sciences, home economics, handcraft and fine art facilities Possibility of building demanding facilities in a way that offers better moisture performance than currently	Practical and safe service transport Functionality of the natural sciences and home economics classrooms Possibility of building demanding facilities in way that offers better moisture performance than currently
Downsides	Delivery of the lunches to the day nursery The service vehicles often drive through the yard, where the pupils spend time Another kitchen and dining room in the extension	Particle emissions and noise in the yard of the day nursery Loud noise from the dining hall being conveyed into the facilities of the day care centre The service vehicles often drive through the yard, where the pupils spend time Five units of day care instead of the required six units. The five units would cover the area of six units, but requires increasing the number of children in every unit	Delivery of lunches to the day nursery Particle emissions and noise in the yard of the day nursery Five units of day care instead of the required six units
Risks		High financial losses if the refurbishment to eliminate the symptoms does not produce successful results as when the kitchen is refurbished, the room layout will be significantly modified and new staff facilities built	Financial losses if the refurbishment to eliminate the symptoms does not produce successful results, as the room layout will be significantly modified and new staff facilities built

Table 2.
Evaluation of
alternatives 1, 2
and 3

persist with the idea of connecting the new spaces to the existing building. This would allow the users to move between the extension and the present building quicker and without putting their shoes on. The walkway option presented was felt to be inconvenient as there is no space for a cloakroom for outdoor clothes.

Alternative five. On the basis of the feedback, the designers created alternative five (A5), which was commented on at the meeting held on 28 March 2019. The extension proposed in A5 provides a new kitchen and a dining room as well as day care facilities. The rooms in the existing building remain generally unmodified. The extension is connected to the existing building but the risk of the indoor air problems caused by external walls occurring inside the new building is minimised by demolishing the external wall between the extension and the existing building. At the meeting, in particular a passage through an entrance hall into the dining hall was perceived as unpractical as the children walk barefoot. In addition, the entrance into the day care was criticised.

Choice of solution

At the end of March, when the action research ended, new significant information concerning the conditions and symptoms of the users of the brick building was received. Thus, more solutions continued to be generated after March, and the final decision on organising facilities was not concluded during this research.

Discussion

Over a 13-month period, the project participants aimed to create a solution to organise facilities for a day care centre, a school and a kitchen. The decision-making did not strictly follow any scheme as the process proceeded quite informally. However, from the process, the following phases can be observed: identifying the problem and the target; gathering information; generating alternative solutions; and evaluation of alternatives.

The uncertainty of the decision-making could be reduced by means of a proper investigation of the existing building, identifying the uncertainties and evaluating the alternatives generated. As multiple participants attended the project planning meetings, the demands of the users, the project targets, the condition of the existing buildings and the refurbishment needs were properly established. Consequently, the problems and the targets were properly identified, and a significant amount of information was gathered. However, the collected information, the problems and the targets were not succinctly documented and similarly understood among the project participants, which complicated the decision-making process.

Figure 2 shows the stakeholders involved in the decision-making process, and their relationships with one another. The Real Estate Centre is responsible for the development and acquisition of municipal properties and spaces, and the Real Estate Centre's Building Unit is responsible for renovation investment projects. The local council approves their proposals.

Decision-making process of the alternative designs

The designers created the alternative designs on the basis of the information they received. Then, the design solutions generated were evaluated and commented on freely during the project planning meetings, and multiple advantages and downsides of the design alternatives were pointed out. However, during the evaluation process, the matters displayed were not weighed. Therefore, some good solutions might have had rejected because of a relatively small impediment. By attaching weight to the matters displayed, the evaluation could have been made more realistic. In addition, this phase was prolonged as a design solution that would have satisfied all the demands was not found. Typically, the decisions must be made under limited time, budget and data (Farsäter and Olander, 2019); therefore, the decision-making is mostly reaching a compromise instead of aiming for a perfect solution. In the case study, the compromises were difficult to find as stakeholders'

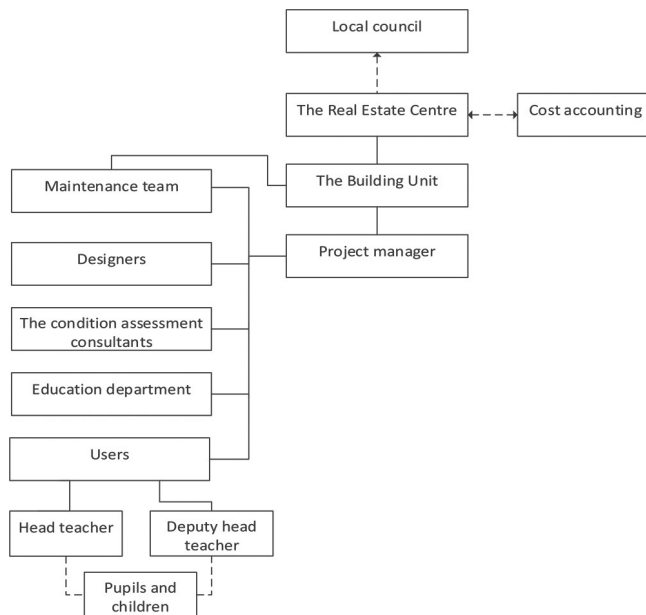


Figure 2.
Decision-makers organising the school facilities

priorities varied significantly, and common perceptions of the priorities were not created. Hence, the evaluation criteria created in advance could have simplified the decision-making and accelerated this phase. In addition, some limits, such as project budget, were unclear.

Identified uncertainties and challenges of the project

The project participants identified multiple uncertainties concerning the project, as well as encountering several factors that complicated and delayed the decision-making. A significant challenge was positioning the day care facilities, school facilities and facilities for a kitchen also providing meals to other schools and day care centres, on the present campus. As the site is relatively small, not all of the facility demands and requirements could be met to a high level. In addition, some risks identified could not be responded to because of site limitations. For example, logistics regarding the food preparation are impossible to organise without detriment to passage to the campus or activities in the yard. Furthermore, current land-use planning created limitations that could not be overcome within the schedule of this project planning phase. Therefore, more adaptable or far-reaching land-use planning could facilitate preferable outcomes.

The municipal maintenance team attempted to eliminate building-related symptoms caused by the white building by repairing some structures between summer 2018 and February 2019. However, the success of the actions could not be ensured during the project planning phase as the refurbishment was implemented so recently. Therefore, a risk of a continuance of the building-related symptoms of the users of the school remained. In the project planning meetings, most of the municipalities tended to ignore the scenario of continuance of the building-related symptoms, and underlined their need to be able to trust that the refurbishment actions implemented would be successful. The refurbishment was mainly based on condition research carried out in 2017 and early 2018. However, the condition research implemented during the project planning phase found even more

seriously damaged structures and microbes than the previous research, as well as reporting on several high-risk structures and executions. In addition, the condition assessment consultants pointed out that the condition of some structures, including external walls, was still unknown. Therefore, the risk of continuance of the building-related symptoms is still relatively high, even after implementing the most recent refurbishment.

The project schedule was delayed, which is fairly common in municipal building projects (Bourn, 2001). The information-gathering phase lasted approximately eight months, which was far longer than predicted. The condition assessment proceeded relatively slowly because the municipalities did not enter into a contract with the condition assessment consultants. Furthermore, the additional surveys were extended as the studies suggested were not officially ordered even though they were agreed on verbally with the municipalities and the condition assessment consultants. In addition, the refurbishment actions in the progress over summer impeded the survey. The project manager changed twice during the project planning phase, which might have delayed the project, as it took time for the new project manager to absorb all the information generated. In addition, tacit knowledge might have disappeared during the reshuffle.

The main discussions during the meetings concerned the location of the extension rather than the different options for organising facilities on a broader scale. However, potential outcomes and future condition possibilities that Wilkinson *et al.* (2014), for example, have presented, had been considered before the project planning phase. Technical aspects such as the condition of the building were discussed at great length contrary to school renovation study of Farsäter and Olander (2019). However, the costs of the alternatives were not discussed to any great extent. A forecast of the total costs was left until later in the process, at which point, a cost accountant will estimate the costs of the chosen alternative. This complicates the comparison of the alternatives and decision-making as the decision must be made on the basis of insufficient data.

There were two different types of needs to resolve in the project: the need to create more space for day-care attendees and pupils, and the need to eliminate building-related symptoms. However, the decision-making was focusing largely on resolving the space requirements. Generally, decision-making is a process of selecting an option from a set of alternatives. The project participants did not manage to find alternatives to resolve the problem of building-related symptoms, but alternatives for space requirements were easier to find. This was probably the reason the project participants dismissed the topic of building-related symptoms in decision-making and concentrated only on solving the space requirements.

Conclusions

Public authorities all over the world are tackling modified needs for public facilities. In addition, a large proportion of the public building stock is damaged and in need of refurbishment. Therefore, the public authorities are constantly under pressure to make decisions concerning facility organisation. The decision-making is typically complex and each project has own characteristics, therefore, the public authorities cannot use the same plan for each project without adaptation.

This study presented the action research of a project planning process concerning a decision on organising facilities for a school and a day care centre. The decision-making process entailed the phases of identifying the target and the current problems; generating alternatives; and evaluating the alternatives. The project needed more accuracy concerning some sources of uncertainty, as one of the school buildings was significantly damaged. Therefore, the uncertainties were also identified in several phases of the project. In addition,

establishing evaluation criteria for alternative designs in advance could have simplified the decision-making process.

This study is based on one case campus; however, other projects have similar characteristics to this research. The findings may provide insights that could be useful in the other public projects, and may increase project stakeholders' knowledge of decision-making in terms of organising facilities, and offer practical value for owners of a damaged building.

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Article

Uncertainty in the Early Phase of a Municipal Building Refurbishment Project—A Case Study in Finland

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Abstract: Municipal building refurbishment projects are carried out under conditions of high uncertainty and complexity, which often result in unsatisfying outcomes. In this research, a case study approach is used to provide a holistic presentation of the sources of uncertainties in the early phase of a municipal school refurbishment project in Finland. The study also explores how these sources are treated in the case project. It is considered that the uncertainty in the case study originated from three key sources: from the project due to the characteristics of existing buildings; from the organization due to the separately operating municipal units; from the municipal environment due to the municipal policy, and decision-making process. This study shows that more emphasis should be laid on the sources of uncertainty in the early phases of a municipal building refurbishment project for reaching proper decisions. In addition, the study presents suggestions for improving the municipal process.

Keywords: uncertainty; risk; refurbishment; renovation; early project phase; municipal property; case study

1. Introduction

Challenges in the management of building refurbishment projects have been identified in several countries. Unsatisfying project outcomes, and budget and schedule overruns are common problems, especially in many municipal building refurbishment projects [1,2]. Typically, these negative outcomes are associated with the project complexity [3,4], whereas complexity is strongly related to uncertainty [1,3–6]. Commonly, building refurbishment projects are carried out to fulfill new technical, physical or technological requirements [7]. Recently, an increasing number of renovation scenarios, typically characterised by high levels of complexity and uncertainty, have also been carried out because of a grown importance of the energy efficiency of existing buildings [8,9].

Building refurbishment projects include more uncertainties than new building projects because of the circumstances and limitations that the existing building imposes, as well as due to the social, technological and legislative aspects. The project costs and duration of time are more inaccurate due to the uncertainties associated with the existing building. Furthermore, a lack of “as built” data and defective drawings cause design changes and impromptu decisions on site. The projects also have a number of stakeholders and contracts between the parties, and the conditions and environments vary in every refurbishment project. Additionally, the nature of a public environment and political issues cause uncertainties and difficulties for a public construction project, including differing interests among the various public sector parties, as well as a hurried start and poor preparation of projects as the project needs to be implemented before the next elections [10–12].

Building refurbishment risks and sources of uncertainties are confronted in each phase of a project, from the project planning phase to the end of the project [13]. The Finnish standards [14] for a building project, including refurbishment projects, are roughly divided into eight stages: feasibility analysis; project planning; schematic design; design development; detailed design; construction; commissioning; guarantee period. This study focuses on examining the sources of uncertainty that need to be identified and analysed before setting project targets. These targets, such as the specific scope, budget, quality and schedule of the project, are set in a project planning phase. The phase is a critical stage in project management, since the most significant decisions are made in the project planning phase. Uncertainties that have not been identified and prepared for can then cause serious consequences at later phases, such as failures in realisation and project delays, accidents or health hazards or massive financial losses. As presented above, uncertainty has a high impact on project outcomes and success. These outcomes are eminently substantial in projects characterised by a high complexity, such as municipal building refurbishment projects. However, the uncertainties are not typically considered at a broad level in construction projects [15,16]. To address these aforementioned problems, this study presents an analysis of the sources of uncertainties identified in the early phase of a refurbishment project of a publicly owned school. As the risks are project-specific and depend on the project targets, uncertainties come from more general sources and arise from ignorance. This study also demonstrates how some of these sources of uncertainty are transferred into risks as more information and knowledge are gathered. The identification of uncertainties and transferring these sources into risks, as well as processing these sources, avail a project team to determine a more informed decision regarding the alternative approaches of providing a healthy and functional campus. Furthermore, the authors suggest improvements to the early phase of municipal refurbishment projects.

Multiple descriptions are provided to describe the term “refurbishment”, and the meaning of the term has become blurred to an extent [17]. In this study, refurbishment encompasses the series of work parcels, including the renovations, alterations, modernizations, demolitions and extensions carried out on the case campus. That description is rather similar to the definitions Ali and Rahmat, Quah, and Egbu et al. [18–21] have provided. In addition, the term “renovation scenario” is used in this study to describe the combination of “renovation approaches”, such as the replacement of a natural ventilation system and building envelope implementation. This terminology follows Kamari et al. [7].

2. Uncertainty and Risk

In the literature, the terms risk and uncertainty are defined and linked with each other in multiple ways. A large group of scholars define uncertainty as risk or risk as uncertainty [22,23], but more often these are classified into two different concepts. The practical difference between these concepts is that the outcomes of the risks are known, while the outcomes of uncertainty are unknown [24]. Relationships among uncertainty, risks and outcomes are presented in Figure 1.

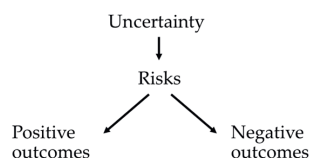


Figure 1. Relationships among uncertainty, risks and outcomes. Adapted from [25].

The ISO standard 31,000 on risk management defines risk as “the effect of uncertainty on objectives” [26]. Risk is also considered to be an uncertain event or the presence of a potential or actual threat or an opportunity that has a negative or positive impact on the project’s success [27]. Often, risk is attributed to uncertainty [25,28]. In turn, uncertainty is referred to in the ISO standard as “the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequences or likelihood” [26]. Aven [29] has defined it in a simpler way: “uncertainty means

that we do not know if a specific event occurs or not, and what the consequences of the activity will be". Uncertainty is often also defined as the difference between the amounts of information required to perform the task and the amount of information already possessed by the organisation [30]. In the construction project field, uncertainty is also referred to as a "lack of certainty" or "lack of knowledge" considering the current and future information and circumstances [16,27]. It is also defined to as "ambiguity" with regard to the project participants, lack of data and lack of knowledge, as well as ignorance of the issues that should be known when dealing with the project, and ignorance of the level of knowledge [16]. The former US Secretary of Defense, Donald Rumsfeld, famously categorised the understanding in three levels: known-knowns, known-unknowns and unknown-unknowns [31]. This categorisation is a simplified version of the Johari window, which presents, in addition to these three levels, a fourth level, "unknown-knows". The Johari window was created to help people understand their relationship with themselves and others [32], but it can also be used for explaining the level of uncertainty. These four levels can be divided and explained as follows:

- Known-knowns: things we know that we know.
- Known-unknowns: things we know we do not know.
- Unknown-knowns: things we do not know we know.
- Unknown-unknowns: things that we do not even know that we do not know.

Project risk management tends to detect the unknown-knowns and decrease uncertainty so that all the risks can be transferred into known-knowns [33]. As risks are usually considered as events, uncertainty tends to be examined in a broader perspective and based on more general sources. In project management, uncertainty is traditionally seen as causing only negative effects. Thus, the tendency is to eliminate it as far as possible. However, especially in more recent studies, uncertainty is also viewed from positive perspective by emphasising its opportunities and possibilities [27,34,35]. Risks are generally considered as having both negative and positive effects. However, risk management also typically focuses on the potential threats for successful project implementation instead of opportunities [35,36].

The level of uncertainty can be determined by defining knowledge about the likelihoods and outcomes [37]. The more the knowledge is lacking, i.e., the indeterminacy, the deeper the uncertainty becomes [38], whereas uncertainty is low in a situation where the likelihoods and outcomes are roughly known [39].

Uncertainties may be divided into two categories: aleatory uncertainties, also known as variability, and stochastic and epistemic uncertainties, also known as ambiguity [39–41]. Aleatory uncertainty results from the variability and represents the randomness in natural systems, thus it cannot be eliminated [40]. However, it can be quantified by using the classical frequentist methods [41] or by an expert opinion [40]. Epistemic uncertainties come from a lack of knowledge about phenomena [41]. It can be reduced by more research [38] and quantified by expert opinions, but it cannot be measured [40]. Typically, uncertainty management requires a combination of the measures of both the aleatory and epistemic uncertainties [41], and the most common way to measure it is through probability [29].

Based on the origin, sources may be divided into external and internal uncertainty. These largely correspond to epistemic and aleatory uncertainties, as external uncertainty is defined as a lack of information that may affect the project performance related to external factors, whereas internal uncertainty is related to a project's internal factors [42]. Typically, external uncertainties are more challenging to manage since these sources can seldom be changed. Instead, the project team can influence the sources of internal uncertainty by making decisions [42].

3. Uncertainty Management in Construction Projects

In building refurbishment projects, the sources of uncertainty are unique in every project, and thus more challenging to identify and manage. However, multiple common sources exist in these projects, as presented in Table 1.

Table 1. The sources of uncertainty of building refurbishment projects.

Source of Uncertainty of Building Refurbishment Project	Authors
Unforeseen site conditions, lack of drawings, lack of design information	[43–51]
A tight budget, a lack of funds	[21,44–46,48,52,53]
A lack of predictability of costs	[53]
A tight schedule	[44–46,48,49,53]
A lack of availability of materials	[21,50,52]
Occupants in the building during the refurbishment work	[21,49]
A lack of availability of working space on site	[21,49]
A lack of involvement of key participants in a project and poor communication among project participants	[3,45,47,48,54]
A lack of precise definition of what is required	[45–47]

As current risk management processes are generally well-known and used in projects, practitioners are relatively unfamiliar with uncertainty management [55]. However, uncertainty management is essential since risk management practices and tools alone are inadequate and useless, especially in complex projects with a high level of uncertainty [16,56]. The aim of the project risk management is to improve a project's performance by decreasing the probability and impact of negative events and increasing the probability and impact of positive events [56,57]. In addition, risks tend to be reduced or maintain the assumed level. The aforementioned targets can, also, be set for the uncertainty management.

Typically, project risk management is divided into separate processes, phases or steps. A simple risk management process includes the following key phases:

1. Risk identification;
2. Risk analysis;
3. Risk response.

However, often more steps or processes—such as risk assessment; risk estimation; risk mitigation; risk monitoring—are involved in the process [13,27,36,55,57–59]. As a process, uncertainty management is partly similar to project risk management, and the similar methods and steps used in traditional risk management can be used for uncertainty management [42]. However, the process of uncertainty management should involve risk and opportunity management as well as identifying and managing the sources of uncertainty in a broad sense [16,60]. In contrast to risk management, in uncertainty management the tendency is to understand where and why uncertainty is important and unimportant in the project context [16].

A typical project risk management process can be modified into project uncertainty management by modifying the process and shifting the emphasis. This approach might include, e.g., revising terminology, such as from risk management into uncertainty management [56]; putting more emphasis on the origins of uncertainties [16]; emphasising some aspects of project-related uncertainty outside of the project context [56]; advancing the process, since uncertainties can be identified with less information than risks [56]; reflective learning and sensemaking, enabling flexibility [61]; classifying uncertainties into various types on the basis of the potential effects and estimating which types are the most important [62].

From an economical viewpoint, the uncertainty can be evaluated by making a tradeoff between the cost of mitigating the uncertainty and that of the damage likely to be caused to the project [63]. Thus, the limits of the zone of an affordable uncertainty protection can be set [63]. However, it must be noted that not all uncertainty can be addressed via analytical approaches, and some uncertainty will always remain in a project [63]. Systematic risk management has been shown to have a positive effect on a construction project's success. Several authors [64,65] have found a strong relationship between the implemented risk management efforts in a project and the level of the project's success. According to Smith et al. [13], each building refurbishment project should be divided into a number of

separate phases, and each phase should contain risk assessment and risk management. Thus, the risk management leads to a continuous process that spans the entire project [13]. Regular risk assessment and management is important because the risks of a building refurbishment project differ, and new risks arise at every phase. Additionally, the nature of managing the risks changes during the project. In the early phases of the project, the range of the possible options is very broad, but in later phases the range of the risks narrows [13]. This corresponds with uncertainty, as during the project uncertainty gradually shrinks since more knowledge is obtained [66].

Despite the multiple efficient tools and models that can be used in risk and uncertainty management, as well as the encouraging results of project management methods, various problems concerning risk and uncertainty management in practice are identified. Many project managers consider the tools to be difficult to use in complex projects and the quality of their use to be poor [67]. Additionally, the effectiveness of the tools is perceived as quite low, which reduces the interest towards risk management [67]. In addition, Ehsan et al. [68] posit that most of the risks are perceived subjectively and are related to contacts or construction processes; thus it is better to deal with them on the basis of previous experience. Despite the wide variety of risk management tools, the project managers use only some of them [67], and the studies of Mansfield [69] and Ehsan et al. [68] reveal that most of the practices do not use any formalised risk identification method. Several authors [15,16,56] have criticised the project risk management process as having an excessively limited focus as the norm and paying too little attention to uncertainty. According to Ward and Chapman (2003) and [56], the focus is often on threats which may result in a lack of attention to many areas of uncertainty, such as the variability arising from a lack of knowledge. Paté-Cornell [41] states that a full analysis of uncertainties is a complex and costly procedure to exercise. Cleden (2012) concurs, and states that “the goal is containment of uncertainty, not elimination”.

4. Methods and Materials

As this study aims to identify the sources of uncertainty and examine the treatment of these sources in the early phase of a refurbishment project of a publicly owned building, a participatory case study was chosen as the research method. This approach is used to gain greater insights into the studied issue or community [70]. Besides, the participatory research method allows researchers to obtain new knowledge, and the studied community often benefits from the research process [71,72]. In this research, the approach was employed to develop a comprehensive understanding of the studied project. In qualitative research and participant observation, the influence of researchers and the chosen sources of information play an important role in the results. The authors participated in the project planning meetings where the potential actions of a publicly owned school were considered. The research data collection method was through participant observation in the project meetings. In addition, the authors scrutinised the documents and minutes concerning the project and conducted site visits. The first project planning meeting was organised in February 2018 and the last one that the authors attended was in March 2019. The original project planning schedule was delayed; thus, the authors were not involved in the project planning in its final stages. The authors actively attended a total of 21 meetings, and observed, made suggestions and asked questions through the process. The number of participants at the meetings ranged from 6 to 18. The participants of the meetings are listed in Table 2.

This research is part of the “Management of Complex Building Refurbishment” project, which aims to develop tools and practices to improve the management of complex building refurbishment projects. The project team selected the case study school as the pilot project. Details concerning the condition and investigation of the buildings, as well as the decision-making process and alternative solutions, are presented in earlier publications [73,74].

Table 2. The participants of the meetings.

Project Stakeholder	Participant
Authors of this article	Three university researchers
Municipal employees	Representatives of the Real Estate Centre The chief of the maintenance department The representative of a renovation contractor The representative of a school committee Kitchen expert Cleaning expert The chief of early childhood education
Condition assessment consultants	Five condition assessment consultant the project leader purchased
Users	The head teacher and the deputy head teacher

Case Study

The case study concerns a school campus composed of three buildings: a white building built in 1997; a brick building built in 1955; a pavilion built in 2001. In addition, a day nursery was operating in the white building. The campus, presented in Figure 2, is located in Southern Finland, in the city of Vantaa.



Figure 2. The school campus is composed of a (1) white building; (2) brick building and (3) pavilion.

The number of children and pupils in the surrounding area of the campus increased. Therefore, there was a need for additional places for over 160 children in the day nursery, and approximately 150 pupils. In addition, lunches were prepared on the campus and also served in the surrounding schools. The number of pupils also increased in said schools, resulting in an increased requirement for lunches. Therefore, major kitchen modifications were required in the campus.

The pupils and the staff of the white building have suffered from various building-related symptoms. The municipal employees have tended to solve the problems by commissioning multiple investigations. However, any clear source causing the symptoms had not been identified. The white building had also sustained multiple hazards, including several water leaks from the roof. These hazards tended to be repaired. However, any larger-sized renovation scenarios had not been made in the building.

Since the technical systems, some materials and structures of the brick building had come to the end of their useful life, the building was in need of major renovation approaches. The natural ventilation in the building was considered challenging since the number of pupils in the classrooms is nowadays greater than was designed. Additionally, during summer, the temperature in the classrooms was considered too high, while during winter it was too low.

The alternative solutions for organising the facilities were examined in the feasibility analysis. On the grounds of the analysis, the city council had decided that the project planning would be advanced on the basis of a solution that contained renovation scenarios of the white building and the brick building: an extension and alteration considering the kitchen, and the demolition of the pavilion. However, other alternatives were not ruled out.

5. The Sources of Uncertainty in the Case Project

Multiple sources of uncertainty were identified in the meetings, by scrutinizing the minutes and documents concerning the campus, and by observation in the meetings. These sources are divided into three main areas: uncertainty from the project, including the characteristics of the existing buildings and campus; uncertainty from the organisation; uncertainty from the operational environment. As the uncertainties were discussed in the meetings, respectively, these are presented in this chapter in the previously mentioned order. The project team also processed and tended to create methods for responding to some of the uncertainties and risks in the meetings. However, the approach was casual and informal as the project team did not have a risk management plan for the project, nor did they handle risk and uncertainty management in a structured way.

5.1. The Process of Identification and Treatment of Uncertainties

The process of identification and treatment of the sources of uncertainties, in the project meetings, is presented in Figure 3. The participants in the meetings did not generate the sources of uncertainty deliberately, instead, the sources arose from discussions. The process started by examining the sources of uncertainties considering the existing buildings, such as the building condition and indoor air problems. The meetings were particularly focused on these sources. In addition, uncertainties concerning the project needs and requirements, measurement data, and design were discussed in the meetings. In the early planning phase, the project team also showed a higher level of competence and acquired more knowledge after hiring consultants. As the project planning phase progressed, the team noted several sources of uncertainties arising from the municipal environment. However, these uncertainties could not be reacted to.

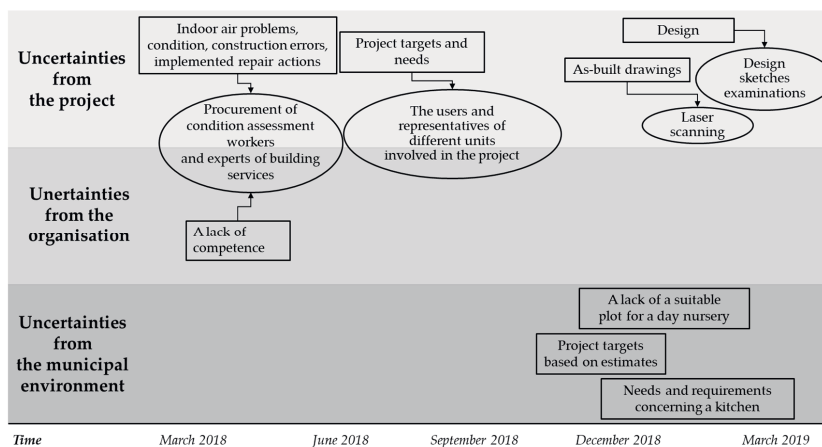


Figure 3. The identification and treatment of the sources of uncertainty considered in the project meetings.

5.2. Uncertainty from the Project

In the beginning of the project planning phase, there was a high level of uncertainty concerning the circumstances of the existing buildings due to a lack of initial data and lack of knowledge of the initial state. During the project planning phase, the project team focused most on these sources of uncertainty. The municipal employees were neither conscious of the repair needs nor of the origins of the building-related symptoms, even though they had sought the reasons for the symptoms for several years by commissioning multiple investigations. In addition, they did not know how the buildings had been studied and repaired over the years. Besides the uncertainty concerning the existing buildings, project uncertainty was also arising from the design, project targets and costs.

This uncertainty, related to the existing buildings and campus, tended to decrease and transfer into risks by gathering more information. First, the authors tended to create an overall view of the condition of the buildings and the identified potential sources of the building-related symptoms by scrutinising all the reports concerning the condition of the buildings. Even though the results of the reports presented multiple potential factors that have affected the development of the building-related symptoms, the scrutiny also found some omissions and a lack of knowledge considering the condition of the buildings. To respond to this shortage, the municipal employees commissioned consultants to survey the buildings more accurately and extensively during the summer and autumn of 2018. The consultants' findings provided a more accurate overall picture of the condition of the buildings, as well as an increased knowledge of the location of the microbes and faults.

Several sources of uncertainty were decreased or transferred into risks after more information was gathered and processed. For example, there was a high uncertainty concerning the condition of the structure of the white building due to the complaints of the building-related symptoms, water leakages and noted construction errors. The scrutiny revealed missing drainages under the white building and high values of relative humidity measured from the slab-on-ground floor. Additionally, the composition and quality of the soil under the white building was unknown in the beginning of the project. This brought out a risk of a capillary suction from the underlying ground into the structures. The uncertainty concerning the ground floor was reduced by examining the composition of the capillary break drainage layer from the test pits on the side of the building, by cuts on the ground floor and by measuring the moisture from the concrete slab. These actions exposed a soil with a high capillary rise, which may cause capillary suction from the underlying ground. The wet soil may cause water to rise up to the base floor, causing it to stay constantly wet. The exceptionally high values of relative humidity were measured in several places of the slab-on-ground floor. Thus, there is a risk that the moisture load would lead to moisture damage in structures such as partition walls. The scrutiny of the investigations also revealed damaged materials in multiple places in the white building that were outside the locations of recorded damage. The project team aimed to reduce the uncertainty concerning the damaged materials and microbes by investigating the structures. The condition survey investigators implemented structural openings and took samples from the materials. Thus, the potential damaged areas tended to be located. Several damaged materials were found; however, the samples were not taken in such a large scale that all the damaged structures could have been found with certainty. In addition, it must be noted that a completely reliable comprehension of the location of damaged materials is only possible by investigating all the structures and materials of the building, which, in practice, is impossible. Thus, all the uncertainties could not be eliminated.

The project team tended to respond to some of the identified project risks. For example, an unpleasant smell and high values of relative humidity in some of the structures were noted in the basement of the brick building. A former condition assessment investigator suspected that the structures contained harmful microbes. Due to the potential health hazard, pupils and staff were banned from using the rooms in the basement. Since the renovation of the structures of the basement is relatively challenging and expensive to implement, the project team discussed the reduction of the risks related to the microbes instead of risk elimination. The project team discovered some methods for reducing the risks, such as not placing the rooms for educational use in the basement; locating

the bottom floor of the new elevator on the first floor instead of the basement; installing a ventilation machine, separated from other ventilation, in the basement.

When implementing a building refurbishment, accurate measurement data are important for producing a proper detailed design. The project team did not have confidence in the accuracy of the measurement data of the existing buildings as they comprised old drawings and some pictures in .dwg format. Therefore, laser scanning covering the white building and the brick building was conducted in order to gather more accurate and detailed measurement data. Thus, a risk related to the errors in measurements, such as faults in design, tended to be reduced.

The uncertainty was also related to the feasible repair actions of the brick building, since there was a need to increase the number of pupils in the rooms, which creates a requirement to increase the ventilation rate. A change from natural ventilation into the other systems may cause changes, e.g., in air pressure, which may present difficulties, such as microbes spreading into the indoor air. The project team decreased this uncertainty by commissioning ventilation experts to compile a draft of potential ventilation alternatives. The experts presented four potential solutions, involving threats, opportunities and the number of pupils that the solution enables, for organising the ventilation procedure. The decision of the implemented ventilation was deferred to the later project phase.

A high level of uncertainty was related to the project targets, even the preliminary project objects, set in a feasibility analysis. These targets are closely connected to the project but are presented more specifically in Section 5.3, as the primary reasons for uncertainty are considered to arise from the operational environment instead of from the project.

The uncertainty also concerned the design task implemented in the project planning phase. In this phase, the preliminary design focused on the outlines of the facilities and the extension. The uncertainty concerning that task tended to decrease and transfer into risks by sharing information between project stakeholders. The risks concerning the design faults tended to be reduced and responded to by purchasing several design sketches and evaluating these informally in the meetings. Thus, some design errors, such as mistakes regarding the number of required rooms for the day nursery, were noticed early on and corrected. In addition, the attention paid to the project requirements and the targets of the design could be followed up, leading to the right direction in terms of project management.

The investment costs of the alternative solutions regarding demolitions, extensions and a new building were roughly estimated in the feasibility study. However, the costs concerning the alternative solutions of refurbishment actions and an extension were not evaluated in the project planning phase. Thus, the project team neither knew the cost difference between the alternative solutions nor the rough estimate of the costs of the potential actions. The standard procedure in the municipality is to calculate the costs after the final design is completed. Therefore, there was high uncertainty with regard to the potential project costs. Even if the cost was calculated later, reducing the costs would have been challenging since the design solutions were already decided.

The sources of uncertainty concerning the project, as well as the potential outcomes, are summarised in Table 3.

Table 3. The sources and the potential outcomes of the uncertainty concerning the project.

Key Source of Uncertainty	Contributing Factors	Potential Outcomes
The existing buildings	Unknown repair needs Lack of as-built data Ignorance of the implemented repairs Lack of knowledge of how the buildings are studied Ignorance of the results of investigations Unknown origin of the building-related symptoms	Inappropriate scope of the work, failed actions, construction errors, cost overrun, prolonged duration of the project, unhealthy and unsafe facilities, decreased quality of the work
Project targets	Ignorance of the project targets	Unsatisfying outcomes, financial losses
Design	Ignorance of the requirements and the design targets Ignorance of the scope of work	Unsuitable facilities for the purposes, additional costs, delayed schedule
Costs	Ignorance of the budget Ignorance of the costs of different actions	Unnecessary expenses, poor use of the municipal finances, stillborn project

5.3. Uncertainties Related to the Organisation

Some sources of uncertainty were identified in the organisation's structure. The municipality has a number of separate units administering different municipal activities. These units operate rather independently and have their own responsibilities. The Real Estate Centre is responsible for purchasing and developing the municipal facilities and real property with the city's customer departments: the City Planning Unit, and Financial Planning. The Maintenance Unit is responsible for the maintenance and minor repairs of the municipal facilities and real property. The case project was initiated by the Real Estate Unit.

In the early project planning phase, the project team found out that multiple repair actions would be implemented in the white building during the summer and autumn of 2018. The Maintenance Unit commissioned several actions, such as sealing the gaps between the floor and wall, to decrease the users' building-related symptoms. However, the implemented repair actions somewhat conflicted with the actions the condition assessment workers had proposed in the project planning phase. This may have resulted from the divergent time spans regarding the two units. The Maintenance Unit tended to respond to users' complaints quickly and within the limits of their administrative district. Therefore, the unit paid for the actions to be taken, which were estimated to last about five years. In contrast, the project team took a much more long-term view when examining the campus and thus required the appraisal of refurbishment actions with a long-term perspective. Since these two units operate separately, the project leadership becomes more complex. The project team cannot conclude advisable long-term decisions as some project limitations have already been created in other municipal units. In addition, the information flow between the units was deficient. This increases the project uncertainty, as not all the existing information and knowledge considering the project was available to the project team.

The final major refurbishment decisions were concluded in the city council one project at a time. However, the municipal employees prepared the proposals for the council. Thus, they have a remarkable role in the decision-making process. In the project meetings, the project stakeholders tended to ensure the implementation of the needs and requirements of the spheres of authority they represented. Thus, it was challenging to find the order of priority of the project targets as well as the compromises. This increased the uncertainty towards the validity of the chosen solutions.

The sources of uncertainty concerning the organization, as well as the potential outcomes, are summarised in Table 4.

Table 4. The sources and the potential outcomes of the uncertainty concerning the organisation.

Key Source of Uncertainty	Contributing Factors	Potential Outcomes
Separately operating units in the municipal organisation	Lack of common project targets	Inappropriate facilities, poor solutions, challenges in project leadership, financial losses, cost overrun
	Lack of prioritising of the requirements	
	Ignorance of the actions of the other units	
	Projects limitations	
	Lack of information concerning the project	

5.4. Uncertainties Originating from the Operational Environment

A high level of uncertainty is related to the operational environment, including the municipal structure, a service network analysis, land use planning and estimates of the population growth. There was ambiguity considering the targets and the requirements in the project, such as the need of the extension premises in the service network analysis. The conclusions the analysis provides are based on prognoses, including the estimates of migration, population growth and the use, condition and refurbishment needs of the publicly owned school buildings. However, an estimate always contains uncertainty. In the beginning of the project planning phase, it was estimated that there was no need to increase the number of pupil places in the case campus. However, during the project planning, a new analysis was published, and the estimate of the requirement of the places for the pupils in

the school increased by 150. As the estimates changed so significantly, it can be assumed that a high uncertainty concerns the actual need of the pupil places in the campus. In addition, the estimates are more inaccurate the longer the term. Therefore, it is hard to estimate if the increase of 150 pupil places in the campus is sufficient or excessive over the coming decades.

The primary project targets were examined and finalised in the feasibility analysis, which was gathered up approximately five months before the beginning of the project planning. As some of the needs presented in this analysis had been changed, the project targets should have been redefined. However, the precise project targets were not set in the meetings, instead, the discussions focused on the needs and the requirements at a vague level. Additionally, another problem was connected with the targets, as it was unclear if the targets are realistic to implement or conflicting. For example, the size of the case site is rather small, and thus locating all the required operations and rooms there is challenging. In addition, the project team did not know if some of the space requirements could be revised, or if these requirements could be satisfied in other locations. If some project targets or requirements cannot be modified, there is a risk that the new campus will be compromised by many poor solutions.

Uncertainty was caused by a lack of knowledge about the municipal policy. The decisions to be made in the case project should follow municipal policy. However, there were several issues that were not yet decided at the upper municipal level. For example, there was uncertainty related to the meal servicing and food preparation in the campus. The network service analysis states that the new municipal food production solutions should be established and evaluated by the Real Estate Centre, i.e., the decisions considering the municipal food production are not concluded yet. As the overall outline is not set, it is hard to discover a proper solution for organising food preparation and meal servicing, including the size of the kitchen and location, in the case campus. There is a high risk that the selected solution will only be a short-term one, in addition to being unsuitable.

The Real Estate Centre tends to follow the policy which states that the new municipal service buildings should be larger than the earlier ones. According to the service network analysis, the larger-sized school buildings are economically more profitable than the smaller-sized buildings, in addition to the larger-sized building enabling more opportunities for education. However, the service network analysis highlights a lack of large-sized plots in expedient locations. Therefore, it is practically impossible to build a new school campus or day nursery in an unbuilt plot. A large-sized campus or day nursery can only be provided by building extensions in an existing campus. In the case project, this policy causes uncertainty considering the possibility of finding a feasible solution, as it was challenging to enlarge the day nursery in the rather small-sized site. According to the representative of early childhood education, there were no available free plots for the day nursery nearby. Therefore, the increased number of children need to be located in the case campus. However, a closer examination proves that the municipality has a number of unutilised plots nearby, but these are planned for other uses or are leased out. Other studies have shown that the strategy of enlarging campuses may have unfavourable consequences, including decreased learning results [75], noise [76] and congestions [76].

Usually, the decision-making process of implementing a major municipal refurbishment project lasts a long time, since the decisions are made in different municipal levels and phases. This time lapse causes uncertainties in the project as the initial data, the targets and the needs are advanced during that time.

Appropriation also caused uncertainty in the project. The project planning of the campus was already implemented twice before, but the actions were not enforced because of a lack of appropriation. There is a risk that this time, too, an appropriation is granted to the other projects. Major municipal refurbishment projects are included in the municipal long-term investment plan. The projects are prioritised on the basis of the plans, and the viability of the projects is evaluated. However, since the refurbishment needs of municipal buildings are high and exceed the appropriation, some of the buildings with an urgent repair need must have their repairs postponed. In addition, the municipal refurbishment decisions are usually based on investment costs as operating and maintenance costs

are ignored. These running costs are often challenging to estimate, which increases the uncertainty concerning the lifecycle costs of different solutions, as well as uncertainty concerning the accuracy of the decisions.

The sources of uncertainty concerning the municipal environment, as well as the potential outcomes, are summarised in Table 5.

Table 5. The sources and the potential outcomes of the uncertainty concerning the operational environment.

Key Source of Uncertainty	Contributing Factors	Potential Outcomes
Municipal policy	Lack of knowledge about the municipal policy Ignorance of the feasibility of the project targets Ignorance of the appropriation	Inappropriate facilities, short-sighted decisions, financial losses
Decision-making process	Prolonged decision-making process	Decisions are based on outdated information, poor decisions, prolonged duration of the project
Estimates and service network analysis Municipal employees and decision makers	Uncertain estimates of migration Unclear project requirements and needs Ignorance of the required competence Uncertainty of the employees' and decision makers' skills and competence	Unsuitable facilities for the purposes, financial losses Inappropriate decisions, financial losses

6. Discussion

The project team tended to find proper solutions for providing suitable and healthy spaces for the pupils, children and staff in the publicly owned school and the day nursery. In the project planning phase, multiple sources of uncertainty that might affect the project were identified. Generally, at the early phase of a project, the field of uncertainties is broad since the project does not yet have many limitations; the targets are set but only a few decisions are made.

The origins of the uncertainty of the case project are divided in this study into three categories as follows:

- The project, such as the existing buildings and campus, project targets, design and costs;
- The organisation, such as separately operating units;
- The municipal operational environment, such as the municipal policy, decision-making process and estimates.

This categorisation is relatively similar to the key sources Martinsuo et al. [77] presented regarding portfolio uncertainty. The first two categories can be considered internal uncertainties, whereas the third one is mainly an external uncertainty, since the sources originate from outside the project and are thus much more complicated to manage.

The management of uncertainty and risks was left uncompleted in the studied project deliberately. Nevertheless, some common phases of risk and uncertainty management could be identified. The case project features of the management process involved identifying and responding to uncertainty and risks. In addition, the project team emphasised the origins of uncertainty, which is considered a characteristic of uncertainty management rather than risk management [56]. Of the four commonly used risk response strategies, avoidance, mitigation and acceptance were used in the case project, but not transference [78]. The majority of the risks and uncertainties were not prioritised or evaluated, and the probability and the potential outcomes were not processed to a large extent. This is a significant difference from the typical process of risk management. Since the risks and uncertainties were not prioritised, the potential of serious risks and uncertainties were not discerned from the risks

and uncertainties with minor outcomes. This might significantly affect the reliability of the project decisions made.

Discussions, site visits, brainstorming, past experiences and reviews from similar projects were the methods used for uncertainty identification and treatment concerning the existing buildings and the campus. The use of these methods for identifying the risks and uncertainties of construction projects is in accordance with the other studies [79–81]. In the early project planning phase, the project team became aware of their lack of competence and knowledge regarding some technical issues. Therefore, they sought to reduce the uncertainties related to inadequate knowledge and skill by hiring experts to produce an analysis and share their experiences and knowledge in the meetings. In line with other studies [35,36,42], the uncertainty was considered only as a negative perspective as all the identified uncertainties were seen as threats, with the outcomes of uncertainties causing negative risks, in the case project. Since the targets of the project were rather accurately defined, the potential possibilities are harder to find as well as more challenging to utilise.

The existing buildings produced multiple sources of project uncertainties. The unknown condition of a building and the lack of a proper site survey for existing conditions are commonly recognised sources of risk which cause uncertainty in refurbishment projects, as reported in several other studies [44,46,49,50,82]. The project team focused especially on the striking technical sources with serious outcomes as noted in the beginning of the project planning phase. Some of these sources were transferred into risks as more information was gathered by scrutinising existing data, conducting condition assessments and implementing site visits. As more information was obtained, the sources became more manageable and predictable and the potential outcomes of these sources could be discovered. By enforcing this process, the uncertainty was reduced and the threats could be managed easier.

A significant challenge in this project was indecision, especially at the higher municipal level. The project team had to make a great amount of decisions and choices affecting the other projects, with only a little amount of information. The decision-making process should proceed progressively, from major lines into the more detailed levels. However, this study shows that sometimes the municipal decisions are concluded in reverse. The issues that have a major influence on the municipal operations are made at the project level as the upper level policy is not finalised yet. In addition, a high level of uncertainty was related to the project targets. Most of the sources of uncertainty essentially arose from the municipal environment and a deficient decision-making process as well as from financial sources. As the project targets were not well-defined early in the project, each project participant utilised the opportunity to contribute to the direction of the project during the later project planning phase. However, the interest and views concerning the targets varied between the project parties, because they were representing different municipal departments and units. The project planning process would become more simplified and easier to manage if the main lines had been finalised before, and if the project targets were clear in the beginning of the project planning phase. Thus, a project team could follow the municipal policy with the major lines and focus on more detailed decisions in the project's context. If the decisions that have a major impact on municipal operations are made at the project level, there is a high risk that the optimal solutions are not found as the big picture is not observed regarding the issues.

In addition, estimates concerning migration increased uncertainty as the project requirements were based on these prognoses. It has been reported that unclear or changing requirements in municipal construction projects have also caused difficulties in other studies [10]. The municipal building and refurbishment project is challenged by the rigidity of the process. The decisions are made at several levels in many phases. As the municipal decision-making process is a long-lasting one, uncertainty will increase; the initial situation and data, original project targets and needs will be modified as time passes. This also causes overlapping work, as the project targets and data need to be reconstituted in the later phases of the project. In addition, e.g., changing a town plan is a long-term process. Even if

the changes were worthwhile, the process would probably delay the project so much that it would not be undertaken.

As multiple sources of uncertainty initially arose from the municipal environment, increasing uncertainty at the organisational and project level, the authors submit suggestions to modify the current process. The modified process is presented in Figure 4.

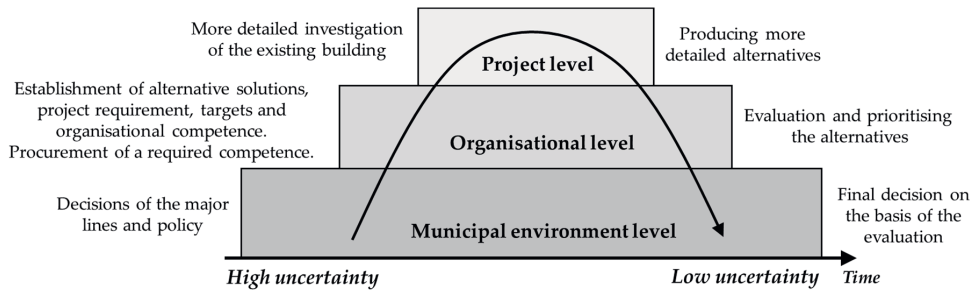


Figure 4. The proposal of a process for decreasing the uncertainty in an early phase of a municipal building refurbishment project.

The process of decreasing uncertainty in a refurbishment project starts at the municipal level, since there are multiple sources of uncertainty affecting individual projects. The major lines considering the projects should first be determined at that level. Then, the organisation describes more specifically the requirements and targets of the project, and settles the competence of the organisation. If needed, a higher level of competence is achieved through the hiring of experts. In addition, alternative solutions for satisfying the project targets are investigated. At the project level, the existing buildings, as well as the details of the targets and needs, are detected more accurately. Additionally, the implementation of the alternatives are discovered more precisely. As information and knowledge increases, some sources of uncertainty can be transferred into risks at this stage. After being carefully established, the alternatives are evaluated at the organisational level. Eventually, the final decision of implementation is concluded at the higher municipal level, on the basis of the evaluation and suggestions that the project organisation has made.

A notable finding in this study was the lack of the project targets in the project planning phase. The project budget was hardly discussed in the meetings, and even the targets concerning the facilities were rather unclear. The target of the project completion date was set, and the project schedule prepared. However, the project planning phase was behind the schedule. Additionally, a curious consideration in this project was starting the preliminary design even before the targets were clear. This was probably a result of a lack of information, and an aim to stay on schedule. Rarely, the decisions can be made with full information, therefore, the choices must be of limited rationality. In this project, multiple decisions were made in chaos as the project was complex and contained high levels of uncertainty. The project participants' approach for decision-making largely followed Herbert Simon's [83] famous decision-making concept, as they did not look for the best solution but rather a satisfying one. For example, the approach to organise the facilities as presented in the feasibility analysis and recommended by the city council, can be considered as a satisfying solution, as other solutions were not further examined during this phase. Thus, the search for further information concerning other alternatives was cancelled. Appropriate solutions were probably missed because of this approach. However, it saved human and financial resources, in this phase of the project.

7. Conclusions

This case study provides a holistic picture of where uncertainty originates from in municipal building refurbishment projects in the early project phase. In addition, the research presented how

some of those uncertainties were transferred into risks after more information was gathered. It also presents the approaches to the uncertainties and risks and the responses to them in this project.

The study divided the main sources of uncertainties, identified in the case project, into three categories:

- Uncertainty from the project, including the sources of uncertainty considering the existing buildings and the campus, the project targets, schedule and costs;
- Uncertainty from the organisation, including separately operating units, and the project stakeholders' competence;
- Uncertainty from the operational environment, including the municipal policy, estimates, needs and decision-making process.

The identified uncertainties impact the decisions regarding refurbishment actions of the school building and need to be confronted by the project parties to ensure the appropriate decision is made. In this project, most of the identified sources of uncertainty or risks were not evaluated, which is typically an important step for achieving a proper overall picture of the situation before the final decision. The interesting finding of the study was that a municipal environment provides many sources of uncertainty in refurbishment projects. In the municipal decision-making process, in particular, indecision and separate administrative units can cause project threats.

This study demonstrated how the project team focused on managing the project uncertainties that can be transferred into risks by gathering more information, whereas the external uncertainty and the organisational sources of uncertainty were mainly ignored. In addition, the features of risk and uncertainty management of the project focused on pinpointing the potential threats for successful project implementation instead of opportunities.

As this study demonstrated the process of transferring uncertainties into risks by gathering more information, it can provide value for practitioners involved in a complex building and refurbishment project. In addition, the authors' suggestions to modify the municipal building refurbishment process may help municipal employees develop their refurbishment projects. The findings may also provide practical value for the client's representatives regarding the decision of whether to undertake some refurbishment works.

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PUBLICATION IV

Investigating the Barriers to Laser Scanning Implementation in Building Refurbishment

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INVESTIGATING THE BARRIERS TO LASER SCANNING IMPLEMENTATION IN BUILDING REFURBISHMENT

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SUMMARY: *The use of the laser scanning technique has increased rapidly in the field of built environment, mainly because it produces highly accurate as-built data. However, the full potential of this technique is utilised only limitedly in building refurbishment projects. This research aims to investigate the barriers to the implementation of laser scanning in building refurbishment projects in Finland. Qualitative interviews were carried out to identify these barriers, and furthermore, to explore the current usage of the technique in building refurbishments. The study shows that many obstacles to implementations are related to challenges in laser scanning procurement, including a low level of competence in acquisition, limitations of the laser scanning technique in building refurbishments, and limitations and challenges in utilising the data in design work. This study is beneficial for building owners and practitioners as it presents the challenges and advantages that laser scanning can provide a refurbishment project. In addition, it offers suggestions to improve the early phase of a refurbishment project in order to achieve greater benefits with laser scanning. Furthermore, the findings may be utilised in the procurement process of laser scanning services in such projects, and the results may potentially solve practical challenges encountered in laser scanning work.*

KEYWORDS: *laser scanning, building refurbishment, refurbishment project, as-built, 3D data, project management, refurbishment management.*

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1. INTRODUCTION

The management of a building refurbishment project is, typically, challenging, as the project is influenced by unforeseen elements and changing factors (Arain, 2005). These variables generate a high level of uncertainty and multiple technical and economic risks to the project (Noori *et al.*, 2016; Oloke, 2017; Rahmat and Ali, 2010; Zolkafli *et al.*, 2012). Many of these risks are connected to deficient as-built data of the existing building, including incorrect measurements and deficient structural details (Oloke, 2017; Uotila *et al.*, 2020b, 2020a; Zolkafli *et al.*, 2012). These defects of as-built data increase project costs, cause errors in design and construction work, and even extend the project time (Love and Edwards, 2004; McKim *et al.*, 2000; Naaranoja and Uden, 2007). A majority of these negative consequences could potentially be diminished by using more accurate as-built data of the existing building.

Fatal decisions with the most detrimental consequences are made during the early phase of a refurbishment project. In particular, faults and decisions made in the design phase can have a substantial influence on costs, project times and the quality of the entire project (Chua *et al.*, 2003). Also, uncertain conditions of existing buildings result in limitations in the design phase, which significantly hinder the designer's ability to complete the design task before work starts at the site (Ali *et al.*, 2008). These design faults can be reduced, and the overall design phase streamlined, with improved initial data management of existing buildings (Cepurnaite *et al.*, 2017). Moreover, better management of the initial data can produce more reliable information for further stages of the building life cycle (Cepurnaite *et al.*, 2017). Thus, accurate as-built data, as well as proper information about the structures of the existing building, are essential for the success of a building refurbishment project.

Laser scanning (LS) has become a common and beneficial tool for the gathering of spatial data of existing buildings. It is used particularly for creating as-built BIM models. Fast and accurate data acquisition, including millions of measurement points of the existing building, is the feature why LS is preferred over conventional methods. In building refurbishment projects, the LS technique is also used for identifying deviations from design, real time monitoring (Brilakis *et al.*, 2010), quantity estimates, and quality control (Akinci *et al.*, 2006; Tang *et al.*, 2011; Wang, Sun, *et al.*, 2015).

Despite the great potential of LS, understanding of the utilisation of the technique in building refurbishment projects is still deficient in the field. The defects and challenges related to the adoption of laser scanning in data capturing of existing buildings are widely established by case studies. However, since these studies focus primarily on technical aspects and concern LS work and as-built creation in particular projects, these findings do not explain how these challenges effect the procurement of LS services. This motivates investigations regarding the barriers to LS implementation in building refurbishment projects in Finland. The study explores the topic by focusing on the viewpoints of clients and other project parties.

2. DATA CAPTURING IN BUILDING REFURBISHMENT PROJECTS

Knowledge of positions, geometries, sizes, shapes, and components of an existing building is needed as a starting point of building refurbishment. This information provides a framework for design, further construction analysis, and as-built modelling. Currently, multiple methods are used for capturing the spatial data of an existing building in a building refurbishment project. The choice of the survey technique relies, typically, on the intended use of the data and the need for data accuracy. But, the choice depends, also, on the complexity and size of the building, the budget, the required expertise of applications, and the equipment available (Historic England, 2018). Often, multiple parallel techniques are used to get more accurate spatial data of existing buildings (Historic England, 2018).

Since traditional manual methods, such as manual laser distance measurements, flexometers and calipers, are simple to use, they are, typically, suitable for capturing certain measures and locations, but impractical for large and complex structures (Historic England, 2018) and inefficient in gathering data for 3D models (Göçer *et al.*, 2016; Liu and Kang, 2014). Topographic methods, such as tacheometers and theodolites, are accurate but time-consuming in the field and producing the data into a 3D model is complex. A total station is usually used for recording precise measurements and georeferencing (Lachat *et al.*, 2017; Murtiyoso and Grussenmeyer, 2018; Sun and Cao, 2015). A global navigation satellite system (GNSS) is mainly used for geographic information system data collection and topographic work (Historic England, 2018).

The data acquisition methods for 3D data of existing buildings may be divided into two categories: the photogrammetrical techniques and the LS techniques (Historic England, 2018). As it is possible to collect millions of points quickly with these techniques, they are appropriate methods to use especially in more complex and larger-sized building refurbishments. This data can be used on several platforms for various purposes. Often, this accurate spatial data of an existing building is used for the creation of an as-built Building Information Model (as-built BIM), which, typically, refers to the representation of an existing building at the moment of the survey (Hichri *et al.*, 2013; Tang *et al.*, 2010). Even though BIM adaptation of existing buildings is still not as common as BIM implementation in new building projects, the use of BIM applications in refurbishment planning, as-built documentation, construction inspection, facility management and maintenance has increased recently (Nguyen and Choi, 2018; Volk *et al.*, 2014; Wang, Cho, *et al.*, 2015). As the creation of a BIM model for an existing building is known as an as-built BIM (Tang *et al.*, 2010), an HBIM refers to the as-built BIM of a heritage or historical building. An HBIM is based on a scan-to-BIM process that enables the generation of a 3D model from laser scan or photogrammetric survey data (Aicardi *et al.*, 2018; Allegra *et al.*, 2020; Capone and Lanzara, 2019; Dore and Murphy, 2012; Ebolese *et al.*, 2018). Contrary to an as-built BIM, an HBIM offers solutions for the parametric modelling of historic buildings and structures, as it includes a library of historic architectural objects for BIM software platforms (Aicardi *et al.*, 2018; Cheng *et al.*, 2015).

2.1 Photogrammetry

Photogrammetric techniques rely on images taken from different viewpoints to record the 3D geometry of a building or objects (Dore and Murphy, 2017). As these techniques are quick and easy to use, and the costs of devices are relatively low (Altman *et al.*, 2017; Brilakis *et al.*, 2010; Dobelis *et al.*, 2016; Ulvi, 2021; Yang *et al.*, 2020), the recording of existing buildings by photogrammetry has increased recently (Dore and Murphy, 2017; Yang *et al.*, 2020). Even though photogrammetry has several advantages compared to laser scanning, including high-quality imagery and colour information (Dore and Murphy, 2017), there are also multiple challenges related to this technique. The main difficulties include a time-consuming computational data process (Dore and Murphy, 2017; Fassi *et al.*, 2013; Ulvi, 2021), less accurate and dense point clouds than a laser scanner can provide (Altman *et al.*, 2017; Golparvar-Fard *et al.*, 2011; Lee *et al.*, 2015; Mellado *et al.*, 2020; Ulvi, 2021), and the requirement of proper lighting (Rocha *et al.*, 2020). For overriding the challenge of a laborious data process, photogrammetric techniques are evolving towards automatic post processing (Aicardi *et al.*, 2018; Dore and Murphy, 2017). However, the quality and accuracy of the results produced by these automatic techniques do not, yet, reach the level of manual or semi-manual procedures (Gruen, 2012).

2.2 Laser Scanning

Currently, terrestrial LS is one of the most common methods for gathering as-built data of existing buildings (Becker *et al.*, 2019; Dore and Murphy, 2017; Suchocki, 2020) due to the high accuracy and point density that the technique provides (Abdul Shukor *et al.*, 2015; Alomari *et al.*, 2016; Cheng *et al.*, 2015; Han, 2012; Hong *et al.*, 2015; Lee *et al.*, 2015; Sepasgozar *et al.*, 2015; Shanbari *et al.*, 2016; Volk *et al.*, 2014). A terrestrial laser scanner captures the geometry and textual information of an existing building by automatically recording millions of 3D points (Dore and Murphy, 2017; Rocha *et al.*, 2020). Laser scanners mainly use one of three different principles for measurements: triangulation, time-of-flight (ToF), or phase-comparison. Even though all of these methods produce a 3D point cloud, the range and accuracy of registered values vary between these methods (Dore and Murphy, 2017; Historic England, 2018; Suchocki, 2020). Typically, laser scanners operated by ToF or phase are used in the recording of building exteriors and interiors (Historic England, 2018).

The laser scanning technique has evolved rapidly in recent years. This progress has resulted in a launch of more compact platforms, including mobile, handheld, backpack and trolley LS devices (Chen *et al.*, 2019; Otero *et al.*, 2020). In particular, the handheld and backpack devices are suitable for indoor surveying due to their light weight and small size (Chen *et al.*, 2019; Otero *et al.*, 2020). These equipment are more efficient in use but provide a less dense and noisier point cloud than terrestrial LS (Kukko and Kaartinen, 2019; Lehtola *et al.*, 2017; Otero *et al.*, 2020; Previtali *et al.*, 2019). However, the operating time of these devices is rather similar to a terrestrial laser scanner, and these methods are suitable for data acquisition of buildings where accurate data is not required (Otero *et al.*, 2020; Previtali *et al.*, 2019). Even though these novel LS methods may offer multiple benefits in as-built data capturing of existing buildings, they are still not as common in data acquisition of existing buildings as the traditional terrestrial laser scanner (Kukko and Kaartinen, 2019).

Multiple studies present LS as overriding the other data gathering techniques in shorter survey duration (Le *et al.*, 2018; Sanhudo *et al.*, 2018; Ustinovichius *et al.*, 2018), improved accuracy (Sanhudo *et al.*, 2018), the possibility for an automated generation of BIM models (Bassier *et al.*, 2018; Gimenez *et al.*, 2015), and its possibility to capture complex shape geometries (Amano *et al.*, 2019; Sanhudo *et al.*, 2018, 2020). Despite the still increasing advantages due to the evolving LS technique, LS has several limitations. These downsides include required expertise (Sanhudo *et al.*, 2018; Shanbari *et al.*, 2016; Volk *et al.*, 2014), laborious further processes (Allegra *et al.*, 2020; Historic England, 2018; Sanhudo *et al.*, 2018, 2020; Tang *et al.*, 2010; Tkáč *et al.*, 2018; Xiong *et al.*, 2013), and expensive equipment (Alomari *et al.*, 2016; Altman *et al.*, 2017; López *et al.*, 2018; Sanhudo *et al.*, 2020; Volk *et al.*, 2014). In addition, laser scanners are not as flexible as cameras with regard to acquiring data (Historic England, 2018). However, the rapidly improving laser technology, such as more compact devices, may decrease these downsides concerning device costs and expertise.

As BIM models require accurate spatial information of building parameters, laser scanning is commonly adopted to collect this data (Badenko *et al.*, 2019). This approach that exploits laser scanning is referred to as a scan-to-BIM process (Bosché *et al.*, 2015). Appropriate 3D data for creating as-built BIM models can be produced by all types of laser scanning devices and techniques, including terrestrial, mobile and airborne methods (Badenko *et al.*, 2019).

2.3 Pre-Processing of Data and 3D Modelling

Images or range data of the existing building is often used for 3D modelling (Stamos and Allen, 2000; Volk *et al.*, 2014). First, this data, usually gathered by photogrammetric methods or laser scanning, needs to be processed (Murphy *et al.*, 2017). The initial pre-processing phase often involves cleaning and removing incorrect points and point cloud registration (Murphy *et al.*, 2017; Pătraucean *et al.*, 2015; Pocobelli *et al.*, 2018), whereas the following modelling phase contains meshing (Murphy *et al.*, 2009) and texturing (Pocobelli *et al.*, 2018). Even though a point cloud may be used independently, it is often used as a source of information for the creation of a 3D inventory model or a 3D surface model, and also for 2D drawings (Randall, 2011). Since the point clouds do not contain additional information about the registered objects, such as geometrical, topological, and semantic attributes, this information needs to be generated during the 3D modelling phase (López *et al.*, 2018). Although the pre-processing of data is becoming increasingly automated, the 3D modelling phase is still rather laborious due to heavy manual work (Dore and Murphy, 2017; Omar and Nehdi, 2016). However, semi-automatic and automatic modelling approaches can also be utilised in this process (Hong *et al.*, 2015; Liu, 2016; López *et al.*, 2018; Macher *et al.*, 2017). The traditional 3D CAD model contains only parametric and feature-based information, whereas BIM platforms enable having a vast amount of semantic information about building elements and their use and maintenance (Dore and Murphy, 2017; López *et al.*, 2018; Pocobelli *et al.*, 2018). Currently, there are various BIM software products, such as ArchiCAD, Revit and Tekla structures, available on the market for as-built BIM creation (Barazzetti, 2016; Logothetis *et al.*, 2015).

In Finland, the collected information and measures referring to objects of an existing building are commonly called an inventory model and the term 'BIM' typically signifies the body of information over the entire lifespan of a certain building (RT 10-11067, 2012). An inventory model is not necessarily presented in 3D form. It may be, for example, formed as a collection of documents, and each document contains information of a certain room (RT 10-11067, 2012).

3. METHODS

The primary purpose of this study was to investigate the barriers to laser scanning in building refurbishment projects in Finland. In order to better understand this theme, including project parties' viewpoints, qualitative semi-structured interviews were conducted. A semi-structured interview as a method is based on a list of themes that are covered during the interview (Greener, 2008). Qualitative interviews were selected as they provide in-depth information about the experiences of individuals (DiCicco-Bloom and Crabtree, 2006); give a better understanding of situations; are appropriate for describing the processes; and help the researcher to understand how events are interpreted (Weiss, 1995). In addition, since previous research on the topic is limited, this method allowed the researcher to collect data flexibly and ask elaborate questions during the interview (Hirsjärvi *et al.*, 2007).

Firstly, the selected themes considered acquiring measurement data of building refurbishment projects more broadly to examine the current situation in the field. Secondly, the focus was on the use of LS with the aim of

extending the understanding of the barriers to and current challenges of LS and data processes in these projects. These selected themes were the following:

- Measurement data of building refurbishment projects
- Measurement processes of building refurbishment projects
- Use of LS in building refurbishment projects

The questions were formulated in advance, but the order of the questions varied between the interviews, as some questions were partly answered in previous topics. A list of the themes and questions was sent to the interviewees in advance.

Since the use of LS is still rather rare in building refurbishment projects in Finland, the appropriate persons to interview were identified by searching through related publications and projects in which LS had been used, contacting pioneering organisations in the use of LS in refurbishment projects, and contacting participants of and organisations involved in LS training organised in Finland between 2016 and 2017. To get a wider perspective of the studied themes, the respondents were chosen from different Finnish companies and organisations, and also the respondents' job titles and work assignments vary. Nine persons with experience of LS in building refurbishment projects were interviewed between autumn 2017 and early winter 2018. The titles and responsibilities of the interviewees are presented in Table 1.

Table 1. The interviewees' titles and responsibilities

Title	Job description
architect	director of building information modelling team
architect	responsible for construction contracting
architect	specialised in building refurbishment
architect	project director
architect	point cloud expert
managing director	consulting and coordination of building information modelling
archaeologist	responsible for the management of digital documentation of buildings
modelling engineer, land surveyor	director of laser scanning team
manager	manager of maintenance of parish buildings

The interviewees' experience of LS in building refurbishment varied greatly as some had been involved in only one project where LS was utilised, and some had used it regularly over a period of ten years. Thus, there was considerable variation in the respondents' knowledge of this technique and their skill in using it. The interviewees represented both the public and private sector, and also among the projects they had gathered their LS experience from, there were both public and private ones. These projects include refurbishments of historic buildings; parish buildings; residential buildings; and municipal buildings, including schools, hospitals, and offices. These projects also include geometrically demanding buildings and buildings of considerable cultural and historical significance. The duration of each interview was 45–100 minutes, and each interview was digitally recorded. The gathered data were analysed thematically.

4. RESULTS

Multiple challenges in the use of laser scanning and barriers to its implementation were identified in the interviews. These barriers were divided into three categories as follows:

- barriers related to challenges in the procurement of LS services
- barriers linked to the limitations of the LS technique
- barriers related to the limitations to the utilisation of the data in design work



4.1 Barriers Related to Procurement of Laser Scanning Services

As expertise and tools are required in LS and the data process, they are typically purchased from a company. In a building refurbishment project, the simplest level of procurement is laser scanning of the building and a point cloud. This level is commonly used in projects, where the client's organisation or designer performs the further processing of the LS data. Other commonly used levels include procurement of the LS and data processing into 2D pictures or into an inventory model. Often, the company carrying out the LS task in a building does not process the data from a point cloud into further models. Instead, the company has a contract with another company that converts the LS data further into an inventory model or into 2D pictures.

The main challenge in the procurement of LS is the technical determination of the scanning. The principal designer is rarely involved in the project at the phase when LS is procured. Therefore, the technical specifications of the LS are, usually, determined by the client. As a consequence, the LS operation may be inappropriately specified, and the data may be incomplete or incorrect for the designer's software. Thus, the designer might not be able to use the data at all or the use of the data can be very inconvenient and time-consuming because of incompatible formats or technical details. Converting data into another format is possible but it is time-consuming, and some data might be lost in the process. The interviewees agreed that if the designer is not involved in the process of determining the contents of the LS, the client should know what type of as-built information, regarding, for example, data accuracy, can be utilised in certain design work. In addition, the client should build a vast knowledge of different data acquisition methods, including an understanding of the limits and the possibilities of each method.

In some refurbishment projects, the determination of the scope of the LS on the contract has been challenging. Into the content of the contract, it is often written that all visible surfaces will be scanned. However, the line between visible and non-visible surfaces is often ambiguous. For example, the roof and the attic are often included in the visible surfaces, but also sometimes in the non-visible. Furthermore, despite a clearly defined scope, the LS work has, occasionally, been sloppy, as recesses in rooms have been outside of the range of the laser, or attics, pipe ducts or lift shafts have been left out of the scan. According to the interviewees, the scope of the LS should be well defined in the conditions of contract in order to avoid ambiguity in the content.

Often, the client uses the publication series Common BIM requirements 2012, 'CBIMR', when purchasing LS in Finland. The CBIMR is a Finnish publication series that contains the basic principles, requirements, definitions and concepts that can be followed in BIM-based projects. For creating an inventory model or other as-built documentation, CBIMR instructs to laser scan all visible surfaces comprehensively by using a maximum noise error margin of $\pm 10\text{mm}$ and a point density of less than 5mm intervals (RT 10-11067, 2012). Often, the clients have used those levels of accuracy when purchasing LS. However, many interviewees emphasised that these accuracy levels of scanning are often inappropriate. For example, if all the visible surfaces of a large-sized building are scanned with 5 mm point density, the size of the files becomes so large that the use of the files might be inconvenient. A sparse accuracy level is appropriate, for example, in projects where only the surface of the structures will be repaired. In short, the major barriers related to the procurement of LS services are the following:

- the client does not have competence for technical determination; and
- the gathered data may be futile for design work.

4.2 Barriers Linked to the limitations of the Laser Scanning Technique

Mostly, LS data is utilised in the design work by processing the LS data into 2D pictures or into an inventory model. It is also utilised in building contracting, quantity surveying, visualisation of the existing building, and verification of the area of rooms for room leasing and sale purposes. Even though the interviewees considered LS to be useful in many projects, several challenges in its use and barriers to its implementation were identified. The key barriers and challenges are listed as follows:

- expensive to use in minor refurbishment projects and in projects where so accurate as-built data is not needed;
- challenges in data acquisition in a building when users are in residence;
- challenges when using LS outdoors during the summer and the winter; and
- challenges in collecting data from roofs and eaves.

LS is perceived to be beneficial especially in major building refurbishment projects, in which accurate as-built data of multiple rooms or an entire building is needed. In addition, it is considered to be essential in the conservation of historical buildings, and useful in buildings with complicated geometric shapes and with a lot of technical equipment and structures not recorded in drawings. However, the interviewees considered the use of LS to be rather inappropriate and expensive in projects with only minor repairs. In those projects, the use of drawings and conventional measurement methods were perceived to be more practicable. In addition, LS is considered to be useless in refurbishment projects where accurate as-built data is not needed.

The interviewees considered LS difficult to carry out in an occupied building, as people in the view of the laser scanner cover the surfaces to be measured. Thus, the view of the scanner to the room is not solid. In addition, the interviewees have met various challenges when using LS outdoors. Vegetation and snow lining a building façade, as well as windy weather conditions have hindered the LS operation. Furthermore, this data, containing empty areas due to obstructions, is later laborious to process. As a consequence, the spring and the autumn were suggested to be the most suitable times for LS outdoors.

When acquiring data of a façade, a laser scanner is usually operated on the ground. However, eaves of the building disturb data acquisition, and thus, the roof and some sections of eaves are often left in a blind spot. Therefore, another measuring method, such as drone photogrammetry, is often needed in those places. Sometimes, data of the roof is collected by using a laser scanner on the roof, but the use of the device on a sloping surface is found to be dangerous and may lead to accidents.

Basically, LS can be operated in places where the scanner fits. For example, LS can be used successfully for data acquisition in false ceilings by pushing the scanner up through a hole in the false ceiling, whereupon the laser scanner scans the inner part of the false ceiling. However, interviewees considered data acquisition of these cramped places, such as ducts and canals, often to be challenging, as locations from where to operate the laser scanner in these structures are, typically, hard to find.

4.3 Barriers Associated with Data Processing and Data Utilisation in Design work

The interviewees expressed several barriers to LS implementation related to data processing and design work. The main barriers are presented as follows:

- time-consuming and laborious data processing and modelling
- errors in models
- limited opportunities to utilise the data in design work, as critical places are hidden during LS
- large files
- limited opportunities to use the data in certain software products

The process from a point cloud into an inventory model is perceived to be time-consuming and error-prone, and according to the interviewees, the modellers do not always have a clear understanding of the designer's requirements. Errors and wrong objects in the model cause extra work for designers and may delay the project. For example, if the modeller has interpreted a false ceiling as an intermediate floor, the areas of the structures are incorrect. Often, the models also contain several negligence errors, such as objects in wrong places or missing columns. Moreover, as the predefined libraries of BIM modelling are planned for new constructions, the irregular shapes of existing buildings are challenging to model.

Laser scanned data is not usually used during a design development phase, because the data is not yet available. As a result, many corrections must be made in early designs during later phases. Usually, the designer does not receive a complete model at the beginning of the design phase. Instead, at the beginning of the design phase, the designer receives a model with only load-bearing structures, and the model is then completed during the designing process.

Since building refurbishment projects often contain alterations in rooms and system replacements, as-built data from above suspended ceilings, under floors and inside walls is needed. However, despite the large amount of structural demolition that the projects typically encompass, the as-built data is collected before the demolition actions. Thus, the items hidden behind the walls and under the floors are not included in the acquired data. Even though LS can be repeated after the demolition actions to gather the critical measures, it is rarely used at this phase, since it is considered to be too laborious and time-consuming.

5. DISCUSSION

The results of this study indicate that greater benefits of laser scanning are achieved in major refurbishment projects. However, the use of the technique is perceived to be inconvenient and expensive in projects with only minor refurbishment actions and in projects where so accurate as-built data is not needed. The results of this study indicate that the use of LS might be beneficial in the refurbishment projects of buildings that have already been renovated, since renovation actions are often poorly documented, and hence, the drawings of these buildings are inaccurate.

According to the interviewees, an inventory model is typically more time-consuming to produce by using laser scanned data than the drawings of the existing building. Often, drawings of buildings built since the late 1990s are rather extensive and accurate. Thus, LS is considered to be rather unnecessary when refurbishing a building that has proper documents and has been built in the past 20 years. Furthermore, this statement is supported by the aforementioned fact of greater benefits in larger refurbishments, since major refurbishments more often concern the older building stock than buildings less than 20 years old.

LS is, typically, procured before the designer is involved in the project. Hence, the acquired point cloud data is often rather inappropriate for the design, either in accuracy or in scope. However, the designer can, then, potentially use the data already in design development. Whereas, if LS is purchased after the designer has entered the project, the scope and details of the LS task can be determined in co-operation with the designer and measurers. Thus, the captured data benefits the designer as much as possible. However, the designer cannot then, usually, utilise the data in the design development phase, yet. As a result, many corrections to the early design must be made during later design phases.

These results indicate that a modification of the project preparation process is needed, as the designer's involvement during the early phase of the building refurbishment project appears to be vital. By involving the designer in the project preparation, the designer could assess the requirements concerning the as-built data of the existing building. In addition, the designer could contribute to the technical determination of LS, including describing the scope, content, levels of details, delivery formats, and accuracy of the data acquisition. By implementing LS at a very early phase of the project, the designer could use the data already in the design development, which may reduce overlapping work in later design phases. Consistent with previous research (Uotila *et al.*, 2020b), also project uncertainty may be reduced by using accurate data already in the early project phase. Furthermore, this modification to the project preparation process could reduce the needs concerning a client's competence to purchase as-built data.

Many challenges that reduce the interest towards LS are met during and after the process from a point cloud into an inventory model. These challenges, such as the use of a wrong format or producing an inconvenient model for the designer, could be reduced by including the process from a point cloud into an inventory model in the designer's contract. However, the results of this study imply that designers rarely have the competence or the interest in making inventory models. Thus, the best utilisation of the model is often achieved when the designer and the inventory modeller co-operate already at the beginning of the modelling process. Hence, it is important that the designer is involved in the project before the modelling phase starts.

As the project preparation phase requires modification, the phase of LS implementation can also be improved. Since it has been claimed that occupied buildings are difficult to scan, it might be advisable to plan the LS implementation schedule together with the building users. Thus, the LS can be operated in a systematic order without interruption and users in the rooms.

The results of this study imply that uncertainty related to the advantages of LS may restrain the use of this technique. Defects in the measurement plan may significantly reduce the usefulness of the data. For example, blind spots in the laser range significantly hinder as-built creation and may impede the designer's work and increase uncertainty related to the design. Therefore, great competence is needed when purchasing LS services. In addition, designers' reports of multiple faults in the models and LS producers' carelessness in their work might reduce clients' interest towards LS. Furthermore, despite the multiple advantages that the LS technique provides, other data acquisition techniques, such as a tacheometry, a drone or a laser range finder, are usually needed to be used in parallel with a laser scanner in refurbishment projects, as not all of the required measurements and information can be gathered with just a laser scanner.

The interviews revealed multiple restrictions and practical challenges concerning technical issues of LS in refurbishment projects. These features include the determination of the content and accuracy of LS, the use of different formats as well as shortages in modellers' understanding of building structures and designers' needs. Also, a lack of computing power when handling large point-cloud files was considered to be a challenge, corresponding to the findings of Shanbari et al. (2016). Coinciding with the studies of Cheng et al. (2015) and Tang et al. (2010), the as-built modelling of an existing building was perceived to be a laborious and time-consuming task, because of these technical challenges, and due to the as-built BIM's lack of pre-defined parametric objects suitable for existing buildings. These difficulties in creating an as-built model of existing or historical buildings have also been reported in other studies (Dore and Murphy, 2017). However, this problem could be, at least to some extent, overcome by using databases of elements of historic buildings, which have been created, for example, by Fai and Rafeiro (2014) and Murphy et al. (2013). These aforementioned technical challenges and the laboriousness in processing potentially reduce the interest towards the use of this technique in building refurbishment projects.

The interviewees' competence in utilising LS in building refurbishment projects varied significantly, as well as their understanding of the benefits and possibilities of the technique. This indicates that understanding of the benefits and limitations of the LS technique in building refurbishments might still be rather deficient. This limited understanding may become a barrier to implementing LS in building refurbishments. In particular, if clients and building owners are not aware of the potential of LS, they are not willing to pay for these services. Thus, increased understanding of this technique is needed especially at the beginning of projects. Broader knowledge of LS could increase the utilisation of the technique, and the method could be used in more useful ways.

The study shows that the full potential of laser scanning has not been utilised in building refurbishment projects. In Finland, as-built BIMs are not yet commonly used in refurbishment projects due to the laborious work of 3D modelling. However, since the modelling technique still evolves and more automation is adopted, the popularity of BIM implementation in existing buildings might increase. Hence, accurate spatial data will have particular importance, which may result in an increase in the use of laser scanning. Furthermore, more advanced laser scanning techniques, including compact devices, may also increase the popularity of this technique over the coming years.

6. CONCLUSIONS

The barriers to laser scanning implementation in building refurbishment projects were studied by conducting nine qualitative interviews. The study shows that the main barriers to the implementation are associated with clients' lack of competence to procure LS services. They are also linked to the limitations of the LS technique in building refurbishment; and to the limitations and challenges in utilising the captured data in design work. In addition, the rather varied quality of purchased inventory models, as well as laborious processes, may reduce interest in the technique.

Since the process from a point cloud into an inventory model is laborious, time-consuming and error-prone, the LS technique is perceived as being a rather unsuitable tool for projects with minor refurbishment work. Hence, this study indicates that a larger extent of refurbishment actions is connected to greater benefits of the technique. In addition, as the drawings of buildings built since the late 1990s are, typically, relatively appropriate and accurate, it is considered that an inventory model is less time-consuming and laborious to produce by using the drawings instead of a point cloud. Therefore, the benefits of the technique are fewer when refurbishing buildings built in the past 20 years compared to the benefits gained in the refurbishments of older buildings. The study also shows, that understanding of LS is still rather limited and insufficient among the stakeholders of building refurbishment projects, which potentially reduces the utilisation of the technique in these projects.

As this study was conducted through interviews, the results are majorly based on the respondents' perceptions and experiences. In order to identify the challenges for the use of laser scanning in building refurbishment projects in Finland, and to provide more information on how these obstacles can be overcome, the authors suggest further research. For example, case studies of building refurbishment projects, in which laser scanning is applied in data acquisition, data modelling and documentation, could provide even more detailed information of this theme.

Despite the limitations of this research, this study can be beneficial for building owners and practitioners, as the findings may be utilised in the procurement of LS and as-built models in building refurbishments. In addition, the suggestions that the study provides might be useful in improving the early phase of a refurbishment project.

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