DOCTORAL THESIS

# Readiness Assessment for BIM-based Building Permits Using Multiple Criteria Analysis

Kaleem Ullah

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY
TALLINN 2022

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58/2022

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This dissertation was accepted for the defence of the degree 16/06/2022


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**Defence of the thesis**: 18/10/2022, Tallinn

**Declaration:**
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for doctoral or equivalent academic degree.

Kaleem Ullah

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ISSN 2585-6898 (publication)
ISBN 978-9949-83-904-9 (publication)
ISSN 2585-6901 (PDF)
ISBN 978-9949-83-905-6 (PDF)
Printed by Koopia Niini & Rauam

TALLINNA TEHNIKAÜLIKOOL
DOKTORITÖÖ
58/2022

# BIM-i põhiste ehituslubade valmiduse hinnang hulgikriteeriumide analüüsi meetodil

KALEEM ULLAH

TALTECH KIRJASTUS

# Contents

## List of publications

The list of author’s publications, on the basis of which the dissertation has been prepared:

I Ullah, K., Lill, I., & Witt, E. (2019). An overview of BIM adoption in the construction industry: Benefits and barriers. In 10th Nordic Conference on Construction Economics and Organization. Emerald Publishing Limited. https://doi.org/10.1108/S2516-285320190000002052 (**Conference paper: ETIS classification 3.1**)

II Ullah, K., Raitviir, C., Lill, I., & Witt, E. (2020). BIM adoption in the AEC/FM industry–the case for issuing building permits. *International Journal of Strategic Property Management*, *24*(6), 400–413. https://doi.org/10.3846/ijspm.2020.13676 (**Journal paper: ETIS classification 1.1**)

III Ullah, K., Witt, E., & Lill, I. (2022). The BIM-Based Building Permit Process: Factors Affecting Adoption. *Buildings*, *12*(1),45. https://doi.org/10.3390/buildings12010045 (**Journal paper: ETIS classification 1.1**)

IV Ullah, K., Witt, E., Lill, I., Banaitienė, N., & Statulevičius, M. (2022). Readiness Assessment for BIM-Based Building Permit Processes using Fuzzy-COPRAS. *Journal of Civil Engineering and Management*. (**Journal paper: ETIS classification 1.1**)

V Ullah, K., Witt, E., & Lill, I. (2022). BIM adoption processes: findings from a systematic literature review. In 11th Nordic Conference on Construction Economics and Organization. Springer Proceedings in Business and Economics (**Conference paper: ETIS classification 3.1**)

## Author's contribution to the publications

Contribution to the papers in this dissertation are:

I The conceptualization of the research was done by Kaleem Ullah and Prof. Emlyn Witt. First draft of the paper was written by Kaleem Ullah in consultation with Prof. Emlyn Witt. The paper was improved and edited by Prof. Emlyn Witt and Prof. Irene Lill.

II The conceptualization of the paper was done by Kaleem Ullah, Prof. Irene Lill, and Prof. Emlyn Witt. The paper was drafted by Kaleem Ullah and improved and edited by Prof. Emlyn Witt and Prof. Irene Lill. Christopher Raitviir assisted in data collection and improving the paper.

III Conceptualization, Kaleem Ullah, Prof. Emlyn Witt and Prof. Irene Lill; writing – original draft preparation, Kaleem Ullah; writing – review and editing, Prof. Emlyn Witt and Prof. Irene Lill; supervision, Prof. Irene Lill and Prof. Emlyn Witt.

IV The concept of study was developed by Kaleem Ullah in collaboration with Prof. Emlyn Witt. Prof. Nerija Banaitienė and Mindaugas Statulevičius assisted in the research methodology. The paper was drafted by Kaleem Ullah, improved, and edited by Prof. Emlyn Witt and Prof. Irene Lill.

V Conceptualization of the paper was done by Kaleem Ullah and Prof. Emlyn Witt. Initial draft of the paper was written by Kaleem Ullah. Prof. Emlyn Witt and Prof. Irene Lill refined and edited the paper.

# Introduction

## Research problem statement

To improve its performance, the construction industry is currently undergoing digitalization in the form of adopting digital tools, such as Building Information Modelling (BIM), 3D printing, robotics, drones, etc. BIM is considered as the central phenomenon in this digitalization (Stojanovska-Georgievska et al., 2022). BIM is defined as "a digital representation of physical and functional characteristics of a facility, and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle" (National Institute of Building Sciences, 2022). BIM has the potential to be beneficially leveraged for many purposes, such as efficient design, cost estimation, site utilization, design and construction integration, facilities management, energy simulations, etc. (Azhar et al., 2011; Kreider and Messner, 2013). While the advantages of BIM are widely acknowledged in Architecture, Construction, and Engineering (AEC) firms, recent experiments and research have focused on exploring BIM application in other areas such as building permits (Kim et al., 2020; Noardo et al., 2022).

A building permit is an official document issued by the building control authorities, which allows the commencement of construction works once the design of the building complies with laws and regulations. The majority of construction projects require building permits excluding minor repairs, surface improvements, etc., however, this also depends on the local authority's regulations. The issuance of building permits is an important milestone for construction projects (International Code Council, 2018). A building permit is also an important component of the institutional factors that influence the success of a construction project. A building permit is one of the ten indicators used by the World Bank for measuring a country's business (World Bank, 2020). Most importantly the regulations for building permit ensure safe, energy-efficient, and accessible buildings (Noardo et al., 2020a).

Obtaining a building permit is a complex process with several steps, involving a large number of actors both from industry and authorities or municipalities (Olsson et al., 2018). In many countries, the building permit process is still analogue i.e., applicants submit required information in paper format and then manual checking of the designs is performed at the municipalities (Olsson et al., 2018). Recently, in several countries, the 2D design and other requirements can be submitted online in a digital file such as pdf, etc., by the applicant, while in the municipalities, the checking process remains manual (Shahi et al., 2019). Generally, these existing building permit procedures are considered as subjective, error-prone, costly, difficult to track, which leads to ambiguity, inconsistency, and delays in the overall construction process (Olsson et al., 2018).

Impressed with the ongoing digitalization in the construction industry and to improve its performance, municipalities are considering BIM potential applications in the building permit process. In a BIM-based building permit process, the applicant submits online BIM models along with other requirements, while at the municipality, automatic code compliance checking can be performed to grant a decision. BIM-based building permits can offer potential benefits, such as pre-checks by applicants, visualization, collaboration and integration, automatic code compliance checks, time-saving, efficiency, higher quality, and 3D data reuse (Noardo et al., 2020b). To date, the use of BIM-based building permits is not common but authorities in some countries, such as Singapore, Finland, The Netherlands, Austria, and Estonia, have taken solid steps towards BIM use in the building permits process (European Construction Sector Observatory, 2021; Shahi et al., 2019).

Though BIM-based building permits can offer potential benefits, BIM adoption itself is a complex phenomenon (Ngowtanasawan, 2017; Ma et al., 2019), and it can face various challenges (Georgiadou, 2019; Doan et al., 2021). Further, the benefits of BIM utilization are also reliant on the quality of the adoption process (Gurevich et al., 2017). The BIM adoption process in AEC firms has been investigated in many studies; in contrast, studies on the BIM adoption process in building permits are limited. The existing few studies are mostly focused on the technical context of BIM use in building permits, i.e., translation of laws and regulations into machine-readable form, automatic code checking, prototypes, etc.; but BIM is not just technology, it also involves people, information, process, and policies (Oesterreich and Teuteberg, 2019; Lee and Borrmann, 2020).

Meanwhile, for successful BIM implementation, organization readiness is also critical (Juan et al., 2017). Holt et al. (2007), defined readiness as "readiness collectively reflects the extent to which an individual or individuals are cognitively and emotionally inclined to accept, embrace, and adopt a particular plan to purposefully alter the status quo". Succar (2009), defined readiness as "the level of preparation, the potential to participate or the capacity to innovate". Liao et al. (2020), defined BIM implementation readiness as "the willingness or the state of being prepared for performing BIM implementation activities". In this research based on the aforementioned definitions, readiness of the BIM-based building permit process is defined as the state of an organization being prepared for using BIM in building permitting in terms of technology, people, process, and policies. There is a scarcity of research that assesses the readiness for BIM-based building permits in building control authorities/municipalities.

## Aim and scope of the research

The information-rich BIM models and the extracted data from them offer an opportunity for integrating them into the building permit process; however, it also depends on the preparedness of the building control authorities to successfully adopt BIM. Hence, the purpose of this doctoral research is to facilitate BIM adoption for building permits by assessing organizational readiness. To achieve this aim, the following overall research question was formulated: **How can BIM adoption readiness be assessed for building permits?** This was elaborated into four more specific research questions:

**Research question 1** – What are the BIM adoption processes in Architecture, Engineering, Construction, and Facilities Management (AEC/FM)?

**Research question 2** – What is the BIM adoption process for building permits?

**Research question 3** – What are the factors that affect BIM adoption for building permits?

**Research question 4** – How can readiness for BIM-based building permits be assessed?

A pragmatic research approach "what works" was adopted to investigate the various aspects of the overall research question further imbued in four specific research questions by applying mixed methods research and case study strategy.

The scope of this research is limited to the observation and exploration of BIM adoption readiness for building permits in three building control authorities from three countries, namely Estonia, Finland, and the United Arab Emirates.

## Research significance and contribution

This research evaluates the readiness for BIM-based building permits in building control authorities to facilitate effective BIM adoption for building permits. The results of the research will update and contribute to the body of knowledge on BIM adoption in AEC/FM firms generally and BIM adoption for building permits specifically. The research results provide factors affecting BIM adoption for building permits, which can inform the concerned stakeholders on what the enablers and challenges to BIM-based building permits are.

To the best of the author's knowledge, this is the first study to use Multiple Criteria Decision Method (MCDM) in exploring organizational readiness for BIM-based building permits. The results of this study provide the areas of focus to practitioners in terms of technology, people, process, and policies regarding BIM-based building permits. Overall, the study results will assist the stakeholders from building control authorities/municipalities to successfully adopt BIM for building permits.

## Outline of the dissertation

This doctoral dissertation consists of four chapters based on five (5) published papers. The introduction provides an overview of BIM for building permits and outlines the aim, questions, scope, and justification of the research. Chapter 1 describes the research subject from the perspective of the extant literature. The methodological approaches adopted in this research are discussed in Chapter 2. The results of the research are presented in Chapter 3, while the conclusions and recommendations are given in Chapter 4.

# Abbreviations

| | |
|---|---|
| AEC/FM | Architectural, Engineering, Construction, and Facility Management |
| BIM | Building Information Modelling |
| COPRAS | Complex Proportional Assessment |
| GIS | Geographic Information System |
| IFC | Industry Foundation Classes |
| MCDM | Multiple Criteria Decision Methods |
| TFN | Triangular Fuzzy Number |

## Terms

| | |
|---|---|
| BIM | BIM refers to the digital representation of the physical and functional characteristics of built objects such as buildings, roads, bridges, etc. to serve as a shared knowledge source enabling communication and collaboration and forming a reliable basis for decisions during a built asset's life cycle |
| BIM-based building permits | All building permits that are processed using BIM models |

## Symbols

| | |
|---|---|
| $x_i$ | $i^{th}$ criterion |
| $x_{ij}$ | Value of $i^{th}$ criterion for the $j^{th}$ alternative |
| $m$ | Number of criteria |
| $n$ | Number of alternatives |
| $N_j$ | Utility degree of the $j^{th}$ alternative |
| $Q_j$ | Efficiency of the $j^{th}$ alternative |
| $S_{+j}$ | Sum of maximizing attributes |
| $S_{-j}$ | Sum of minimizing attributes |

# 1 Literature review

## 1.1 Digitalization in the construction industry and BIM

The construction industry, one of the most important industries in a country's economy, is often criticized for its lack of innovation compared to other industries (Agarwal et al., 2016). Due to continuous pressure to improve its performance, the construction industry has begun digital transformation by potential utilization of digital technologies, such as 3D printing, artificial intelligence, augmented and virtual reality, BIM, Geographic Information System (GIS), laser scanning, robotics, and sensors (Olanipekun et al., 2021). According to Barbosa et al. (2017), digitalization in construction can potentially result in a 14 to 15 percent increase in productivity and 4 to 6 percent cost savings. BIM is one of the most important developments, which is considered central to digitalization in the construction industry (Stojanovska-Georgievska et al., 2022).

BIM applications in the AEC/FM industry offer benefits in the form of saving time and cost, improving quality, and facilitating collaboration (Bryde et al., 2013). Various studies have well documented the benefits of BIM throughout the building life cycle (Azhar et al., 2011; Eastman et al., 2011). These benefits are summarized in Table 1 from **Publication I**.

*Table 1: BIM benefits through building life cycle (adapted from Ullah et al., 2019).*

| Phases | Benefits of BIM use |
|---|---|
| Pre-Construction | • Improved concept and feasibility<br>• Efficient site analysis to identify environmental and resource-related issues<br>• Effective design reviews<br>• BIM-based energy simulations<br>• Clash detection<br>• Enables faster and accurate cost estimation |
| Construction | • Evaluation of the construction of complex building systems to improve the planning of resources and sequencing alternatives<br>• Efficient management of the storage and procurement of project resources<br>• Efficient off-site fabrication based on design model<br>• Allows better site utilization<br>• Reduces site congestion and improves site safety |
| Post-Construction | • BIM record model can help in decision-making about operations, maintenance, repair, and replacement of a facility<br>• Makes asset management faster, more accurate, and with more information<br>• Ability to schedule maintenance and easy access to information during maintenance |

One of the main benefits of BIM is that it can facilitate collaboration and communication due to the information-rich building model (Linhard and Steinmann, 2014; Poirier et al., 2017). Information-rich building information models offer the possibility to municipalities to integrate them into building permit processes (Nawari et al., 2017; Onstein and Tognoni, 2017; Ponnewitz and Bargstaedt, 2019). The next section discusses BIM and its potential application in building permits.

## 1.2 Building permits and BIM

Before the commencement of a construction project, its design and other details are checked by the relevant building authority; in the case that if it fulfils the requirements, a building permit is granted (Plazza et al., 2019; Fauth and Soibelman, 2022). Depending on the size and type of a project, a building permit is required for most of the construction projects with the exception of works such as surface improvements, minor repair and replacements, small structures, etc. The requirement and exemption of building permits in relation to construction work depend on the rules and regulations of the relevant building authority/municipality. Building permits are considered an important milestone for construction projects and their significance in the construction industry is well documented (Pedro et al., 2011; Fauth and Soibelman, 2022; Shahi et al., 2019). Building permits ensure safe, energy-efficient, and accessible buildings (Pedro et al., 2011; Jovanović et al., 2016). It is considered one of the institutional factors that affects the success of construction projects (Gudienė et al., 2014).

The basic characteristics of building permit processes, especially in European countries, are similar (Pedro et al., 2011). Typically, the applicant submits the design and required information to the concerned section of the municipality, an analyst at the municipality checks the compliance of drawings with local rules and regulations demands, and in the best case, the applicant receives a building permit. However, the detailed procedures of the building permits, such as administrative works, submission demands, processing time, the beginning of construction works, vary in European countries (Pedro et al., 2011). Overall, the existing building permit process is considered as subjective, error-prone, inconsistent, costly, involving paperwork, and it is time-consuming (Malsane et al., 2015; Olsson et al., 2018; Fauth and Soibelman, 2022). The issues associated with current building permit processes affect the overall productivity of the construction industry.

Since the real value of BIM lies in the "I", i.e., structured information about the built asset (Kjartansdóttir et al., 2017), it can also provide potential applications in the building permit processes. In a BIM-based building permit process, the applicant submits the BIM models along with other requirements to the municipality. On the municipality's side, in addition to visual examination, the BIM models provide the potential opportunity of automatic compliance checking against laws and regulations. If the building information models meet the local rules and regulations requirements, a building permit is granted. The structure of typical BIM-based permit processes is shown in Figure 1.

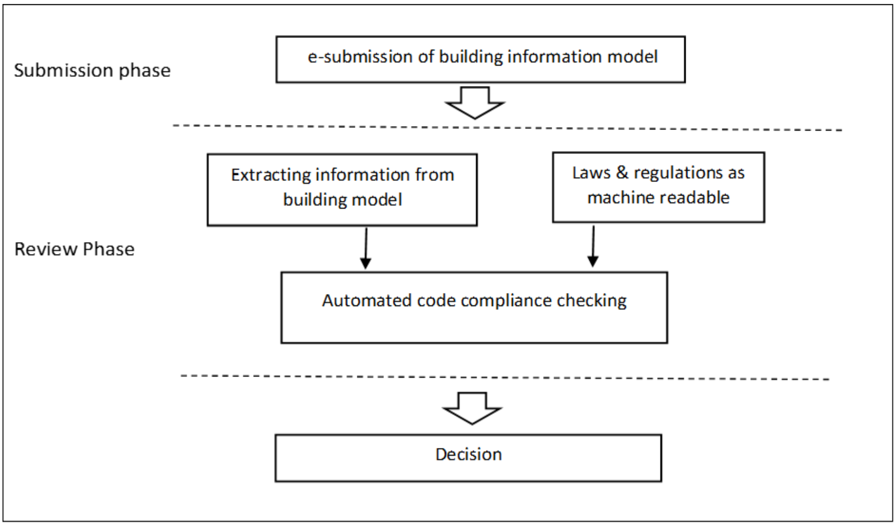


*Figure 1: General conception of the BIM-based building permit process (adapted from Shahi et al., 2019).*

Due to the potential benefits of BIM in building permitting, in recent years, some municipalities have integrated BIM into building permit processes to some level, for example, the City of Vantaa Finland and the Building and Construction Authority Singapore (Shahi et al., 2019). In Estonia, the Ministry of Economic Affairs and Communication is developing a BIM-based building permit process for municipalities. Similarly, the municipality of Dubai in the United Arab Emirates is developing BIM-e submission platforms to incorporate BIM into building permits. Meanwhile, municipalities in the Netherlands, Norway, Sweden, Austria, Italy, Germany and in other countries are also engaged in research projects/experiments to introduce BIM into building permits (Noardo et al., 2020b; Schranz et al., 2021; Garramone et al., 2021). Many studies have also examined BIM applications in building permit processes (Onstein and Tognoni, 2017; Chognard et al., 2018; Narayanswamy et al. 2019; Noardo et al., 2022). One of the main requirements for the BIM-based building permit process is that the laws and regulations should be in machine-readable form. Translating of laws and regulations from natural language to machine-readable form is a difficult task. It is considered as one of the main challenges to the BIM-based building permit process (Kim et al., 2020). The majority of the existing studies are regarding the technological aspect of BIM-based building permits. However, literature on BIM widely admits that BIM is not just a technology, but its potential benefits rely on the process and organizational aspects as well (Juan et al., 2017).

## 1.3 BIM adoption and readiness for BIM-based building permits

In the BIM-specific literature, different definitions are used for BIM adoption. Meanwhile, the term adoption is used as interchangeable with implementation and diffusion (Hochscheida and Halinb, 2019; Succar and Kassem, 2015). A universal agreement on the definitions of these terms is lacking in the literature related to BIM. Roger (1983) defined adoption as “a decision to make full use of an innovation as the best course of action available”. Based on Roger’s diffusion of innovation theory, Hochscheida and Halinb (2019), described BIM adoption as a five-stage process. Awareness (first stage) occurs when the organization/potential adopter/decision-making unit is exposed to BIM or becomes aware of BIM. In the intention (second stage), the organization shows interest in the BIM and gathers further information. In the decision stage (third stage), the organization decides whether to adopt or reject BIM. In the implementation stage (fourth stage), the organization undertakes a set of actions to deploy BIM, and the confirmation stage (fifth stage) concentrates on the evaluation and further improvement. According to Succar and Kassem (2015), BIM adoption begins when an organization successfully adopts object-based modelling tools and workflows after a period of planning and preparation. The BIM adoption process in municipalities for the building permit process can be conceptualized as all the actions and steps required to take in order to use BIM for building permits.

For successful BIM adoption, organizational and industry readiness are significant. “Readiness collectively reflects the extent to which an individual or individuals cognitively and emotionally inclined to accept, embrace, and adopt a particular plan to purposefully alter the status quo” (Holt et al., 2007). According to Liao et al. (2020), BIM implementation readiness of a project team is the willingness or the state of being ready for performing BIM implementation activities. Succar (2009), defined readiness as “the level of preparation, the potential to participate or the capacity to innovate”. BIM readiness is the pre-implantation status showing the tendency of an organization or organizational unit to adopt BIM technology, and “BIM capability” as the wilful implementation of BIM tools, workflows, and protocols that are considered as the minimum ability of an organization or a team to deliver measurable outcomes (Succar and Kassem, 2015). On the bases of the mentioned readiness definitions, the readiness for BIM-based building permits is conceptualized as the state of being prepared for using BIM in the building permit process in terms of technology, people, process, and policies.

# 2 Research methodology

Research methodology is the broad term that refers to principles, practices, and procedures systematically devised to govern research (Kazdin, 2003). Creswell (2009) described methodology as the entire process of performing research. The next section of this chapter describes the philosophical position of the research and the overall research design used in this study.

## 2.1 Research philosophy

Amaratunga and Baldry (2001), stated that research should be based on a philosophical position. Saunders et al. (2009), defined research philosophy as a set of beliefs and assumptions of the researcher about the development of knowledge. Researchers have certain beliefs and assumptions (whether consciously aware of them or not) during their research (Burrell and Morgan, 1979), which influence the design of research questions, selection of data collection methods, and the interpretation of findings (Crotty, 1998). There is much discussion whether a researcher should adopt a particular philosophical position (positivism, critical realism, interpretivism, postmodernism, constructivism, pragmatism, etc.,) or consider a multi-dimensional set of continual positions (Saunders et al., 2009; Niglas, 2010). Since the aim of this research is to facilitate BIM adoption for building permits by assessing organizational readiness, it is considered suitable to adopt a pragmatic research position as the aim is towards "what works" for solving practical problems. Pragmatism research philosophy concerns actions, situations, and consequences (Cresswell, 2009). A pragmatic researcher is concerned with "what" and "how" in the research (Cresswell, 2009). According to Saunders et al. (2009), research that is based on a pragmatism perspective begins with a problem and seeks to provide practical solutions that also inform future practice.

As research philosophy is a set of assumptions that inform and influence the way to perform research, it can be considered in terms of ontology, epistemology, and axiology. Ontology refers to "the study of being" (Crotty, 1998), and it concerns assumptions about the nature of reality and existence (Crotty, 1998). Saunders et al. (2009), positioned objectivism and subjectivism on two sides of the continuum in ontological notation. Objectivism is "the assumption that social reality that we research is external to social actors" (Saunders et al., 2009). Subjectivism assumes that social reality is made from the perceptions and actions of social actors (Saunders et al., 2009). Epistemology is the study of knowledge that concerns the assumptions about the development and nature of (what constitutes acceptable and valid) knowledge, and how knowledge can be conveyed to others (Burrell and Morgan, 1979). Epistemologically, positivists believe that observable and measurable facts constitute knowledge (i.e., knowledge is objective) (Saunders et al., 2009). Critical realists hold the epistemological relativism position (Reed, 2005) that knowledge is historically situated, and facts are socially constructed (subjectivism) (Bhaskar, 2008). Epistemologically, interpretivists believe that humans interpret their experiences of and in the world, and it constitutes knowledge (i.e., knowledge is subjective) (Hiller, 2016; Constantino, 2008; Pascale, 2011). Axiology refers to the role of values in research (Saunders et al., 2009). The values and beliefs of the research have an important role in building the research narrative, and they can either influence the research (rising interpretivist research) or the researcher can remain unbiased regarding values (positivist research).

The nature of inquiry in this research involves the assessment of preparedness for BIM adoption for building permits in municipalities, and as such interpreted through experiences and perceptions of stakeholders related to it. It can be argued that the reality about readiness for BIM-based building permits in municipalities is internal to individuals and therefore suggesting ontological subjectivism. Epistemologically, in this research, the development and nature of knowledge is considered subjective implying interpretivism; thus, gathered data is largely qualitative using semi-structured interviews, literature review, and document observations. As qualitative research is inherently value-laden, the pragmatism position in this study has led to adoption of a mixed-method approach, which attempts to keep the integrity of results free from any possible interference of personal values.

## 2.2 Research design

The research design refers to the plan and procedures for conducting research that covers the decisions from broad assumptions to detailed data collection and analysis methods (Creswell, 2009). According to Fellows and Liu (2008), research design is about the way in which a researcher finds answers to research questions, and it covers the type of research, research approach, empirical design, data collection methods, and data analysis methods. The selection of research design relies on the research problem, the researcher's personal experience, and the community for whom the research will be performed (Creswell, 2009).

Due to the explorative and then followed by the descriptive nature of this research, a mixed-method research approach (using both qualitative and quantitative approaches to collect and analyse data) is adopted to answer the research questions. Exploratory research is a study that explores phenomena or areas that are little known (Kumar, 2011) and identifies variables and generates hypotheses for further research (Fellows and Liu, 2008). Descriptive research is about systematically describing and documenting a phenomenon of interest (Fellows and Liu, 2008). The selected research design offered an in-depth understanding of the nascent subject in this research. The research design allowed the study to be concluded within a reasonable period of time and the collection of quality data.

## 2.3 Research process

Figure 2 shows the research process of this study. To achieve the aim of the research, an overall research question was formulated, and the overall research question was broken down into four specific research questions in a way that the systematic answers to these four specific questions lead to an answer of the overall research question. The research started with a systematic literature review of BIM adoption in AEC/FM industry, which derived a generic model for BIM adoption processes. This was followed by a case study to elaborate the BIM adoption process for building permits and the factors affecting it, using a qualitative method (documents, participant observation, and interviews). Using case studies and collecting data through online questionnaires and from relevant documents, readiness for the BIM-based building permit process was assessed based on multiple criteria decision analysis. The next section describes the literature review and the case study research processes.

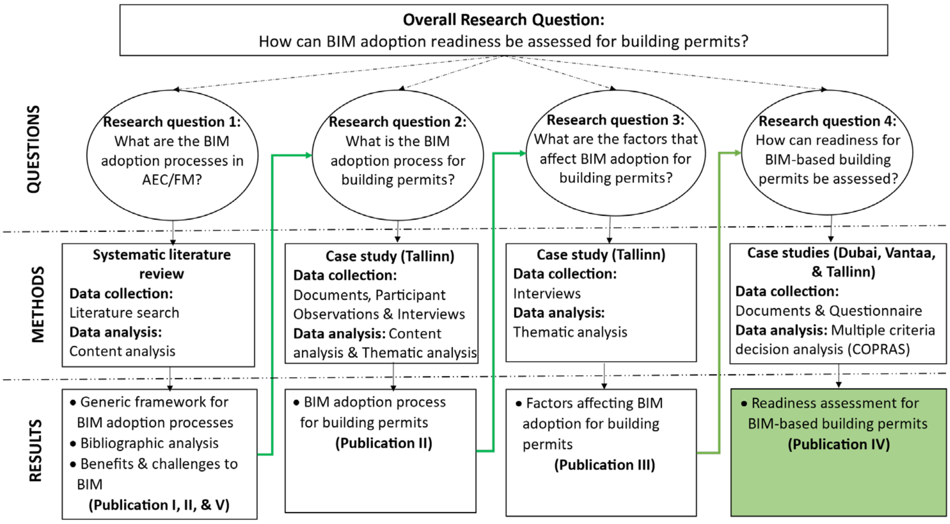


*Figure 2: Research process.*

### 2.3.1 Systematic literature review

Systematic literature reviews refer to thoroughly designed and performed literature reviews that aim to identify, analyse, and synthesize all the available high-quality scientific evidence in order to answer a particular research question (Torgeson et al., 2017). The systematic literature review was carried out following the recommendations and guidelines of Gough (2007), and Bearman et al. (2012). The review was performed in two phases; the aim of the first phase was to capture an overview of BIM adoption in the construction industry to understand better the global scenario of BIM adoption in different countries, applications of BIM in the building lifecycle, and obstacles to BIM adoption. The second phase of the systematic literature review was specifically focused to answer research question 1: What are the BIM adoption processes in AEC/FM?

The literature search was carried out in November 2018 and updated in 2019. Keywords were searched in six databases: Scopus, Web of Science (Clarivate Analytics), ASCE Library, EBSCOhost Web, Science Direct, and Emerald Insight. These databases were selected for their inclusive coverage of peer-reviewed journal articles and conference proceedings. The articles returned from database searches were then listed in order of relevance to the search strings. The articles were screened based on their titles, and if necessary, on their abstracts, to determine relevant articles to the research question. The relevant articles were then transferred to Mendeley Reference Manager and duplicate articles were removed using Mendeley software. The literature search resulted in a total of 319 relevant papers and in the content analysis, NVivo was used; findings were drawn and an analytical framework for BIM adoption processes was derived (Ullah et al., 2020).

### 2.3.2 Case study

Case study research is defined by Yin (2003) as “an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”. According to Robson (2002), a case study is a research strategy focusing on explaining in detail a particular contemporary phenomenon within its setting, using a variety of data collection methods, such as interviews, observations, documents, questionnaires, etc. Using a variety of data sources provides the opportunity that the phenomenon to be examined through a multitude of lenses compares to one lens, allowing for the exploration of various aspects of the phenomenon (Baxter and Jack, 2008). Saunders et al. (2009), stated that a case refers to the specific unit of study or analysis, which can be a person, an institution, an event, a place, a thing, a process, etc. Case study is one of the most powerful research approaches to achieve both practical and theoretical aims and it offers a level of flexibility compared to other approaches (Ebneyamini et al., 2018). The case study approach was adopted to find answers to research questions 2, 3, and 4.

Single case study was used to answer research question 2 (*What is the BIM adoption process for building permits?*) and research question 3 (*What are the factors that affect BIM adoption for building permits*?). The case study was carried out in the Tallinn City Government, a municipal organization responsible for granting building permits. The Tallinn City Government is adopting a BIM-based building permit process under a project by the Ministry of Economic Affairs and Communication, Estonia. It is important to note that the project by the Ministry of Economic Affairs and Communication is a national-level project, to enable BIM-based building permits in all municipalities. However, the scope of this case study was limited to the Tallinn City Government. Data were collected via document analysis, participant observations, and five face-to-face interviews with experts during January and February 2020. The content and thematic analysis of the collected data revealed the BIM adoption process for building permits in the case of the Tallinn City Government (research question 2) on the basis of the analytical framework derived in the initial stage of the research from the literature (Ullah et al., 2020).

To answer research question 3, 7 semi-structured interviews were carried out with stakeholders related to the BIM-based building permits process in the Tallinn City Government during December 2020 and January 2021. The interviewees were purposively selected, and the online interviews lasted between 45 and 60 minutes. The interviews were audio-recorded, transcribed, and analyzed with the help of NVivo software. The thematic analysis of the gathered data not only identified the factors affecting BIM adoption for building permits but also revealed the details on how these factors affect BIM adoption for a building (Ullah et al., 2022). The identified factors were then categorized into three groups: technology, organizational and environmental factors using the Technology-Organizational-Environmental framework (Tornatzky et al., 1990).

*A Multiple case studies* strategy was adopted for research question 4 (*How can readiness for BIM-based building permits be* assessed?). In order to assess readiness for BIM-based building permits, three cases were selected: Dubai Municipality (United Arab Emirates), Tallinn City Government (Estonia), and the City of Vantaa (Finland). These municipalities were selected on the basis of their projects related to BIM-based building permits. For the readiness assessment of BIM-based building permits, a method of Multiple Criteria Decision Methods (MCDM) was used. MCDM deals with the evaluation of a set of alternatives in the presence of multiple, usually conflicting, decision criteria (Zavadskas et al., 2014), to order the alternatives on the basis of preferences (Roy, 1996). There are many MCDM methods; in this research Complex Proportional Assessment (COPRAS) developed by Zavadskas et al. (1994), was used under fuzzy logic. The COPRAS method determines the priority and the utility degree of alternatives based on the criteria weights and the criteria rating with respect to alternatives (Zavadskas et al., 1994). The general decision-making matrix of the COPRAS method is shown in Table 2.

*Table 2: The general decision-making matrix (adapted from Zavadskas et al., 1994).*

| Criteria | * | Units of measure | Weights | Alternatives | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | … | $j$ | … | $n$ |
| $x_1$ | $z_1$ | $m_1$ | $q_1$ | $x_{11}$ | $x_{12}$ | … | $x_{1j}$ | … | $x_{1n}$ |
| $x_{i2}$ | $z_2$ | $m_2$ | $q_2$ | $x_{21}$ | $x_{22}$ | … | $x_{2j}$ | … | $x_{2n}$ |
| … | … | … | … | … | … | … | … | … | … |
| $x_i$ | $z_i$ | $m_i$ | $q_i$ | $x_{i1}$ | $x_{i2}$ | … | $x_{ij}$ | … | $x_{in}$ |
| … | … | … | … | … | … | … | … | … | … |
| $x_m$ | $z_m$ | $x_m$ | $q_m$ | $x_{m1}$ | $x_{m2}$ | … | $x_{mj}$ | … | $x_{mn}$ |

For readiness assessment, a list of criteria related to BIM-based building permits was determined. Some of the criteria were from the findings of research question 3, and then additional criteria were included from an extensive literature search. In total, 25 criteria were determined and grouped into technology, people, process, and policies. The weights of the criteria were determined through the expert's survey. The questionnaire was designed on the fuzzy set theory to avoid uncertainty in judgments. The experts were asked to rank the importance of the criteria in relation to BIM-based building permits in linguistic terms. Before conducting the survey, the fuzzy numbers for linguistic terms were set, using the Triangular Fuzzy Number (TFN). Twelve experts on BIM and building permits participated in the survey. After the survey, the linguistic terms were transferred into TFN and then de-fuzzified, and using the COPRAS method, weights of the criteria were determined. A number of criteria values or ratings with respect to alternatives (Dubai Municipality case, City of Vantaa case, and Tallinn City Government case) were also determined through the expert survey based on the fuzzy set theory. In total, six experts (from within the group of twelve experts) participated in this part of the survey and rated the criteria status for their corresponding case/municipality. Once the criteria weights and the criteria values for the corresponding three cases were determined, equations from COPRAS were applied, and readiness for BIM-based building permits in the selected three cases was assessed.

# 3 Findings

This chapter presents the major results from the research activities. The study sets out to explore how BIM adoption readiness can be assessed for building permits.

## 3.1 Analytical framework for BIM adoption processes

This section responds to research question 1: What are the BIM adoption processes in the AEC/FM? The analytical framework for BIM adoption processes in AEC/FM industry given in Table 3 is derived from the synthesis of the subject literature. The purpose of the analytical framework is to find out which areas are to be focused on while adopting BIM.

The analytical framework uncovers the detailed practices undertaken by stakeholders for adopting BIM in AEC/FM organizations. The framework consists of four stages: initiation, planning, execution, and evaluation. Each stage is further elaborated with steps, which mostly refer to the actions undertaken by stakeholders once they have decided to adopt BIM. Since the analytical framework is developed from the literature review, it is important to mention that it was difficult to draw a line between the steps of initiation and planning. For example, some studies included steps such as IT requirements, BIM training in the initiation stage, while other studies included these in the planning stage. Thus, in Table 2, the steps are compiled according to the author's best understanding and the frequency of these steps under stages in the previous studies.

The initiation stage includes the context study of the organization to identify strengths and weaknesses. Further, the initiation stage included actions regarding technical context and opportunities offered by BIM tools. In the planning stage, goals and milestones are set and the plan of action is defined. The execution stage contains the actual BIM implementation, and the evaluation points out the improvement of the deliverables. Further details regarding the analytical framework for the BIM adoption process may be found in **Publication II** and **Publication V**. In the next section, this analytical framework is used as a reference to explore the BIM adoption for building permits.

*Table 3: Analytical framework for the BIM adoption process.*

| Stages | Detailed steps | Ozener et al. (2020) | Rivera et al. (2019) | Sodangi (2019) | Almuntaser et al. (2018) | Kouch (2018) | Hochscheid and Halin (2018) | Ahn et al. (2016) | Machado et al. (2016) | Khosrowshahi & Arayici (2012) | Arayici et al. (2011) | Gu and London (2010) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initiation | Reviewing organization current situation and practices | | ✓ | | | ✓ | ✓ | | | | ✓ | |
| | Defining objectives of the organization for adopting BIM | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | ✓ |
| | Identifying challenges | ✓ | | | | | | | ✓ | ✓ | | |
| | Addressing challenges | | | | | ✓ | | | | | | |
| | Determining IT requirements | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | ✓ |
| | Providing BIM training | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | |
| | Analysis of the current resources | | ✓ | | | ✓ | | | | | | |
| | Selecting BIM team & establishing roles | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | | |
| | Developing new business model | ✓ | | | | ✓ | ✓ | ✓ | | | ✓ | |
| | Determining best practices for BIM | | | | | | | | ✓ | | | |
| | Providing financial resources for BIM software and training | | ✓ | | ✓ | | | ✓ | | | | |
| | Analysing improvement/financial gains | | | | | | | | ✓ | | | |
| Planning | Determining areas for BIM implementation | | ✓ | | ✓ | | | | | | | ✓ |
| | Developing organizational BIM implementation strategy | | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ |
| | Planning procurement with software vendors and IT consultants | | | | ✓ | | | | | | | |
| | Documentation of BIM implementation path | | ✓ | | | | | | | | ✓ | |
| | Establishing effective communication between all stakeholders | | | | ✓ | | | ✓ | | | | |
| | Identification of potential risks and ensuring quality of deliverables | | | | ✓ | | | | | | | |
| Execution | Actual implementation of BIM, including piloting BIM implementation on projects | | ✓ | | | | ✓ | ✓ | ✓ | | ✓ | |
| | Creation and coordination of the BIM model | | | | ✓ | ✓ | | | | | | |
| | Monitoring and controlling BIM adoption to ensure that objectives are achieved | | ✓ | | ✓ | ✓ | | | | | | |
| Evaluation | Handovers of all BIM deliverables | | | | ✓ | | | | | | | |
| | Assessment of project with the aim to improve the implementation approach | | ✓ | | ✓ | ✓ | ✓ | | ✓ | | | |
| | Evaluation of the BIM implementation project to outline the benefits and gains from it | | | | ✓ | | ✓ | | ✓ | | | |

## 3.2 BIM adoption process for building permits

This section answers research question 2: What is the BIM adoption process for building permits? A case study of the municipality in Estonia, i.e., the Tallinn City Government was chosen to explore and understand the BIM adoption process for building permits. The case study provided insight to the actions regarding adopting BIM-based building permits; these activities are summarized and classified in the initiation, planning, execution, and evaluation stages below.

### 3.2.1 Initiation stage

Implementation of BIM for building permits was initiated with a thorough assessment of the organization current situation and practices, which guide towards defining objectives and milestones. In the case of the Tallinn City Government, the existing permitting process is an "e-permitting system", which enables the applicants to submit 2D drawings in pdf form; however, in the municipality, these are manually reviewed for compliance checking with laws and regulations. This manual process is complex, and the various departments of the municipality involved in the building permits are not properly integrated. In order to overcome these inefficiencies in the existing building permit processes, the municipality is integrating BIM into building permits. The results showed that the focus is to use BIM models in open formats, such as Industry Foundation Class (IFC) instead of 2D drawing and then at the municipality automatic code compliance checking. The municipality is aiming for maximum of automatic checks. Further, cost-benefit analyses were performed and according to the project documents, both the potential time saving and financial savings of BIM-based building permits for the municipality were found substantial.

Since BIM adoption is a challenging process, the Tallinn City Government is faced with many challenges while adopting BIM. These challenges are related to organizational structure, workforce, and technical issues. To deal with workforce challenges, the municipality is providing different levels of BIM training to its employees. These training were not only important for the capacity building of employees for using BIM-based permits technology but also to create awareness regarding it. The technology for the BIM-based building permit system to be used by the Tallinn City Government is being developed by the Ministry of Economic Affairs and Communication through a software firm.

### 3.2.2 Planning stage

Effective implementation of BIM-based building permits rests upon proper planning. Planning includes developing an organizational strategy for BIM implementation. In the Tallinn City Government case, inputs of different stakeholders, i.e., from the ministry and a local university, are incorporated. The main web-based environment, which enables the submission of BIM models for building permit applicants and then potential automatic code compliance checking, will be provided by the ministry. However, any additional IT requirements are planned to be procured from the private sector. Further, it is planned to establish effective communication among different departments involved in processing building permits through the e-construction platform. Meanwhile, the municipality identified the potential risks associated with BIM-based building permits, both organizational and technical. The municipality is ensuring that all the departments involved in issuing building permits have the required level of technology and skills.

### 3.2.3 Execution stage

At the time of the case study data collection, the developed web-based environment for BIM-based building permits was having the capacity of 60 checks for building permits, such as building maximum height, evacuation routes, facade materials, maximum ground area, location in the zoning plan, safety barriers, space minimum door width, Maximum story above ground. Piloting of the system was carried out with BIM models of a 5-storey apartment submitted in IFC format. After processing of the BIM model, the results of the automatic checks were extracted. The pilot project demonstrated that a number of checks were working properly. It also showed shortcomings in some checks that require improvements. The pilot project was considered as a big milestone to demonstrate the BIM-based building permit process and solid steps towards the actual BIM models utilization for building permits by the municipality.

At the time of data collection for this study, the municipality was focusing on the technology (which also includes translating laws and regulations into a machine-readable form) for BIM-based building permits and building employee’s skills for BIM-based building permits. The municipality stakeholders stated that this will be followed by accepting BIM models from applicants for building permits for real projects.

### 3.2.4 Evaluation stage

The interviewees from the case study stated that based on the pilot project the developed system is evaluated to indicate the shortcomings. However, a full evaluation is feasible once the BIM-based building permits system will be used for real projects by the applicants. Then the system can be improved with both user feedback and internal assessment.

The BIM adoption for building permits using the case of the Tallinn City Government is outlined in detail in **Publication II**.

## 3.3 Factors affecting BIM adoption for building permits

This section responds to research question 3: What are the factors that affect BIM adoption for building permits? Adopting BIM in any organization is a complex process, as BIM has multidimensional contexts; beyond the technology, it involves people, information, and process (Oesterreich and Teuteberg, 2019). As a socio-technical phenomenon, various factors affect BIM adoption. To identify the factors affecting BIM adoption for building permits, a case study of the Tallinn City Government was carried out. From the thematic analysis of interviews, the following factors were identified.

### 3.3.1 Complexity of the BIM-based building permit systems

The findings illustrated that the complexity lies in the development of the BIM-based building permit system and apart from that, using the BIM-based building permit is another challenge. In the development of BIM-based building permit systems, one of the complex tasks is the translation of laws and regulations into machine-readable form, which is central to automatic or partially automatic code compliance checking. Further, in the case of the Tallinn City Government, it was observed that the aim is to develop a web-based environment in which the municipality’s employees can perform the checks on the submitted BIM models, without requiring any external additional software. Thus, in order to develop such a system, additional efforts are required.

The interviewees highlighted that another challenge is from the user's point of view because the majority of the municipality employees are familiar with the existing system of building permits (which is based on a 2D drawing in pdf form), which means that the majority of employees might not have BIM skills.

### 3.3.2 Relative advantages/disadvantages of BIM for building permits

The interviewees stated that the potential advantages offered by BIM-based building permits, such as visualization, collaboration & integration, automation, 3D data reuse, efficiency, acted as an enabler for adopting BIM for building permits.

### 3.3.3 The existing building permit system

In the case of the Tallinn City Government, the building permits are held through an "e-permitting system" from 2016, which is capable of accepting 2D drawings in pdf form; the element of digitalization on a small scale is already existing. According to the interviewees, due to the benefits offered by the existing system compared to that based on paper submission, it acted as an enabler for further digitalization in the form of BIM-based building permits.

### 3.3.4 Management support

The findings showed that management support is a key for successful BIM-based building permits. The top management role is important not only for the arrangement of the required technology but also for arranging BIM training, BIM awareness, etc.

### 3.3.5 Organizational culture

Organizational culture includes the attitudes, values, norms, and behaviors of the organization members. Organizational culture is important for the adoption of any innovative technology because some members will show interest due to its perceived usefulness while others might not because of the perceived complexity. In the current case study, the results showed that the majority of the people were found interested in BIM-based building permits. The interviewees stated that apart from training, the technical development of the BIM-based building permit system was aimed to be user-friendly, and this plays a role in creating a positive attitude towards the new system.

### 3.3.6 Awareness about BIM-based building permits

For successful BIM-based building permits, BIM awareness among the organization's employees is significant. BIM awareness is also associated with creating positive organizational culture toward BIM adoption. The interviewees stated that introductory programmes and BIM training were aimed to create awareness regarding BIM-based building permits.

### 3.3.7 Training and learning for the BIM-based building permit process

The findings showed that in the case of the Tallinn City Government, different levels of training programmes (from basic to advance) regarding BIM-Based Building Permit were performed and are planned for the future. It was observed that training is one of the main enablers for BIM-based building permits since it also minimizes some of its challenges.

### 3.3.8 Lack of experts on the BIM-based building permit process

The interviewees highlighted that since the exiting building permit system is based on 2D drawing, one of the challenges is the lack of experts on the BIM-Based building permit process.

### 3.3.9 External pressure

Since BIM adoption in AEC/FM is on the rise and the BIM-based building permit provides a potential possibility of using those BIM models in building permit applications. The ongoing experiments on BIM-based building permits in other countries and the momentum of BIM adoption in AEC/FM industry were found as motivation in the current case study.

### 3.3.10 Legal context

According to the interview results, the legal context cannot be ignored for building permits. However, in the current case study, the BIM-based building permit is in its initial stage. Once it is fully used and evaluated to improve it, it can be mandated for certain sizes and types of projects in future.

The identified factors affecting BIM adoption for BIM-based building permits were grouped into technological, organizational, and environmental factors using the Technology–Organization–Environment framework (Tornatzky et al., 1990) shown in Table 4. Further details are given in **Publication III**.

*Table 4: Factors affecting BIM adoption for the building permit process.*

| | |
|---|---|
| **Technological factors** | Complexity in developing and using BIM-based building system |
| | Relative advantages/disadvantages of BIM for building permits |
| | Existing building permit system |
| **Organizational factors** | Management support for BIM-based building permit |
| | Organizational culture |
| | Awareness about BIM-based building permits |
| | Training and learning for the BIM-based building permit process |
| | Lack of experts on the BIM-based building permit process |
| **Environmental factors** | External pressure |
| | Legal context |

## 3.4 Readiness assessment for BIM-based building permits

This section presents the results for research question 4: How can readiness for BIM-based building permits be assessed? The results are achieved from the multiple case studies: Dubai Municipality (Case 1), Tallinn City Government (Case 2), and City of Vantaa (Case 3). First multiple criteria for BIM-based building permits were determined, and then using Fuzzy-COPRAS the readiness for BIM-based building permits in the three selected cases/municipalities was assessed. The results of the readiness assessment are presented in Table 5.

*Table 5: Readiness assessment for the BIM-based building permit processes.*

| Criteria | | * | Units | Weights | Alternatives | | |
|---|---|---|---|---|---|---|---|
| | | | | | Case 1 | Case 2 | Case3 |
| Technology | Simplicity of the BIM-based building permit system | + | Rating | 0.0411 | 0.3000 | 0.3667 | 0.3333 |
| | Compatibility with existing building regulations and codes | + | Rating | 0.0447 | 0.3448 | 0.3448 | 0.3103 |
| | Interoperability with relevant systems and databases | + | Rating | 0.0404 | 0.3214 | 0.3571 | 0.3214 |
| | Maintainability | + | Rating | 0.0378 | 0.2885 | 0.2885 | 0.4230 |
| | Supporting open standards | + | Rating | 0.0461 | 0.3333 | 0.3333 | 0.3333 |
| | Cost (e.g., capital, running, etc.) | - | Rating | 0.0314 | 0.4167 | 0.2500 | 0.3333 |
| | BIM implementation in the local construction industry | + | Rating | 0.0375 | 0.2308 | 0.3462 | 0.4230 |
| People | Top management support | + | Rating | 0.0440 | 0.3333 | 0.3333 | 0.3333 |
| | Availability of employees with BIM skills | + | Rating | 0.0404 | 0.2250 | 0.2250 | 0.5500 |
| | Qualifications of the professionals dealing with building permits | + | Index | 0.0368 | 0.5714 | 0.1429 | 0.2857 |
| | Availability of training programmes | + | Rating | 0.0400 | 0.2500 | 0.3750 | 0.375 |
| | Willingness of employees to use a BIM-based building permit process | + | Rating | 0.0440 | 0.2632 | 0.3509 | 0.3859 |
| | Building permit applicants' interest in using a BIM-based building permit process | + | Rating | 0.0411 | 0.2353 | 0.3333 | 0.4313 |
| Process | Comprehensiveness of code compliance checks | + | Rating | 0.0425 | 0.3400 | 0.3600 | 0.300 |
| | System allows pre-submission checks of BIM models by applicants | + | Rating | 0.0378 | 0.3333 | 0.3333 | 0.3333 |
| | Efficiency of existing/ previous (not BIM-based) building permit process | + | Score | 0.0310 | 0.3617 | 0.3327 | 0.3056 |
| | Potential time saving | + | Rating | 0.0414 | 0.2553 | 0.4255 | 0.3191 |
| | Potential cost saving | + | Rating | 0.0368 | 0.2727 | 0.3864 | 0.3409 |

*Table 5: Readiness assessment for the BIM-based building permit processes (Continued)*

| Criteria | | * | Units | Weights | Alternatives | | |
|---|---|---|---|---|---|---|---|
| | | | | | Case 1 | Case 2 | Case3 |
| Policies | Level of information standardization (BIM standards, BIM protocol, classification systems, etc.) | + | Rating | 0.0432 | 0.2727 | 0.3636 | 0.3636 |
| | BIM model submission guidelines for the BIM-based building permit process | + | Rating | 0.0411 | 0.3158 | 0.2982 | 0.3859 |
| | BIM mandate in the local construction industry | + | Rating | 0.0404 | 0.3333 | 0.2667 | 0.4000 |
| | Support by government | + | Rating | 0.0429 | 0.3333 | 0.3333 | 0.3333 |
| | Clarity and easy access to building laws, regulations and building permit requirements | + | Index | 0.0418 | 0.3333 | 0.3333 | 0.3333 |
| | e-governance | + | Index | 0.0371 | 0.3113 | 0.3447 | 0.3439 |
| | Legal framework of the BIM-based building permit process | + | Rating | 0.0389 | 0.2045 | 0.4091 | 0.3863 |
| | The sum of weighted normalised maximining $S_{+j}$ | | | | 0.2927 | 0.3220 | 0.3485 |
| | The sum of weighted normalised minimizing $S_{-j}$ | | | | 0.0130 | 0.0078 | 0.0104 |
| | Significance of the alternatives $Q_j$ | | | | 0.3045 | 0.3361 | 0.3594 |
| | Priority of Alternatives | | | | **3** | **2** | **1** |
| | Utility degree of alternatives $N_j$ | | | | 84.76 | 93.55 | 100 |

The results indicated that supporting open standard, compatibility with existing building regulations and codes, and support from the top management are the most important criteria for BIM-based building permits. The results showed that case 3: the City of Vantaa was found more prepared for BIM-based building permits, followed by the Tallinn City Government and then the Dubai Municipality. It is important to note that the readiness assessment was not aimed to identify the best technical solution or software for BIM-based building permits, as the readiness for BIM-based building permits was investigated in the selected municipalities from a multi-dimensional context.

Since Finland is one of the early adopters of BIM, the high values of criteria, such as BIM implementation in the local construction industry, BIM mandate in the local construction industry, maintainability of the system, BIM training, are understandable for the City of Vantaa case. In the technical criteria, which are directly connected to the BIM-based building permit system, it was found that in all three cases, the focus is on BIM models in open standards such as IFC. Further, in all three cases, an approximately similar trend of values was observed for criteria, such as top management support, system capability, to perform pre-checks by applicants, and clarity and easy access to building laws regulations and other requirements.

Full details regarding readiness assessment for BIM-based building permits are reported in **Publication IV**.

# 4 Conclusions and recommendations

## 4.1 Conclusions

The construction industry is undergoing a major transition in the form of adopting digital tools and Building Information Modelling (BIM) is considered as the center of this change. Inspired by the ongoing digitalization in the construction industry and with the potential opportunities offered by BIM, building control authorities or municipalities are attempting to use BIM for an efficient building permit process.

The aim of this doctoral research was to facilitate BIM adoption for building permits by assessing organizational readiness. The research adopted pragmatic research philosophy and explored the subject of the study from different perspectives using a mixed-method research approach.

On the basis of a systematic literature review, an analytical framework was developed for the BIM adoption process in the AEC/FM industry. The analytical framework presented an overview of different steps that can be taken to adopt BIM. The research identified the BIM adoption process for building permits using case study and gathering data through a qualitative approach. The research also determined several factors that affect BIM adoption for building permits through a qualitative approach – collecting data through semi-structured interviews and classified the identified factors into technological, organizational, and environmental factors. Some of the identified factors were found as enablers to BIM-based building permits while others were found as challenges regarding BIM-based building permits. The research identified a list of 25 criteria related to BIM-based building permits, categorized them into technology, people, process, and policies, and determined their importance level through a questionnaire survey. Finally, the research assessed the readiness for BIM-based building permits in three selected municipalities/organizations responsible for issuing building permits, using a multiple criteria decision method, i.e., Fuzzy-COPRAS.

This study concludes that BIM can potentially be leveraged for an efficient building permit process; however, adopting BIM is a complex task and it can face various impediments. Municipalities aiming for the BIM-based building permit process must develop technological and organizational capabilities to achieve appropriate outcomes. The technical solution or software accepting and processing BIM models for building permits should be easy to use and capable of exchanging data in open standards. Further, the developed technical solution should be capable of performing a maximum number of automated code compliance checks. The organization management role is vital for achieving the BIM-based building permit process. Similarly, BIM training for the employees responsible for the building permit process are significant. Since applicants are important stakeholders in the building permit process, the benefits of BIM utilization in building permits are also reliant on the widespread implementation of BIM in the local construction industry. The government can play a role in BIM use in building permits by providing funds and appropriate legislation.

As a theoretical and practical contribution of this research, the identified analytical framework could be used to facilitate BIM adoption in AEC/FM organizations. The research results on BIM adoption for building permits and factors influencing it will assist municipalities, in particular on better understanding of BIM use in building permits and how to successfully adopt BIM for building permits. The importance level of criteria for BIM-based building permits guides the stakeholders, which should be the focus and priority in terms of BIM-based building permits. This research would contribute to the existing body of knowledge on building permits and achieving an efficient building permit process.

## 4.2 Limitations

The analytical framework was identified from a systematic literature review; during the literature research, some relevant articles might have been missed out. The BIM adoption process for building permits and factors affecting it was explored through a single case study. Using multiple case studies might have resulted in a more detailed BIM adoption process for building permits. The data used in the readiness assessment for BIM-based building permits was mainly collected through expert's survey and the sample size of experts was small. However, the experts who participated were well-informed and the author is confident that the study results are robust.

## 4.3 Recommendations for future research

The analytical framework for BIM adoption processes can be used in future studies for exploring BIM adoption in any other organization. The multiple case studies approach can be used to further explore the BIM adoption process for building permits. Future studies can update the list of criteria and can assess the readiness for BIM-based building permits using any other MCDM methods, such as Analytical Hierarchy Process, Analytical Network process. The developed readiness assessment tool can be used to assess readiness for BIM-based building permits in other municipalities. The research results can be used to develop a decision support system that enables recommendations for BIM-based building permits depending on the input data.

# List of figures

## List of tables

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# Acknowledgements

I would like to thank my supervisors Professor Irene Lill and Professor Emlyn Witt for the valuable guidance, tremendous support, encouragement, and all the kindness that I received during my PhD journey. Your efforts for the successful completion of my PhD study meant a lot to me. You are the best supervisors, thank you!

To Moonika Mändla, I thank you for all the administrative support and your cheerful attitude. A word of thanks to Professor Roode Liias, Professor Raido Puust, and Associate Professor Tiina Nuuter for comments on my research work.

I would like to thank the Government and people of Estonia for providing me state funded PhD programme and Tallinn University of Technology for providing me facilities for my study. I acknowledge the Research Administration Office, TalTech for administrative assistance during my study. I acknowledge the Department of Construction Management and Real Estate, Vilnius Tech, Lithuania for providing me the opportunity of exchange programme. I would also like to thank Riigi Kinnisvara AS, MTÜ XRP Ledger Trust, and The Education and Youth Board for granting me scholarships during my PhD journey. I acknowledge Estonian Ministry of Economic Affairs and Communication, the Tallinn City Government, Dubai Municipality, and the City of Vantaa.

I acknowledge my friend Dr. Theophilus Olowa at the Department of Civil Engineering and Architecture for all the support and discussions during this PhD journey. I appreciate the support from Christopher Raitviir, especially for his efforts in one of the publications. I am grateful to all my friends, especially Waqas, Obaid, and Tariq who supported me throughout this journey.

My heartfelt appreciation to my beloved parents, my brother and sister, my nephews, and my nieces for all the supports, patience, encouragements, prayers, and kindness.

I acknowledge the research supports by the BIM-enabled Learning Environment for Digital Construction (BENEDICT) project (grant number: 2020-1-EE01- KA203-077993), Integrating Education with Consumer Behavior relevant to Energy Efficiency and Climate Change at the Universities of Russia, Sri Lanka, and Bangladesh (BECK) project (grant number: 598746-EPP-1-2018-1-LT-EPPKA2-CBHE-JP), Building Resilience in Tropical Agro-Ecosystems (BRITAE) project (grant number: 610012-EPP-1- 2019-1-LK-EPPKA2-CBHE-JP) and Strengthening University-Enterprise Collaboration for Resilient Communities in Asia (SECRA) project (grant number: 619022-EPP-1-2020-1-SEEPPKA2-CBHE-JP) all co-funded by the Erasmus Programme of the European Union.

# Abstract

## Readiness assessment for BIM-based building permits using multiple criteria analysis

To improve its performance, the construction industry is adopting digital technologies such as Building Information Modelling (BIM). BIM refers to the digital representation of the physical and functional characteristics of built objects such as buildings, roads, bridges, etc. to serve as a shared knowledge source enabling communication and collaboration and forming a reliable basis for decisions during a built asset's life cycle. BIM constitutes a paradigm shift in the construction industry and has the potential to be beneficially leveraged for many purposes such as efficient design, cost estimation, site utilization, design and construction integration, facilities management, energy simulations, etc. The scope of this research concerns the potential applications of BIM for building permits.

Municipalities grant permission for the construction of buildings once they have checked and confirmed the compliance of the designs and other required information with the local building rules and regulations. This permission takes the form of an official document known as a building permit. Building permits are an integral part of the design and construction process, with a critical role in ensuring the safety and long-standing of buildings. Obtaining a building permit is a complex process involving many stakeholders and procedures which are often unclear, error-prone, bureaucratic, resource-intensive, difficult to track, and time-consuming. Inspired by the ongoing digitalization in the construction industry and to address the issues associated with the traditional building permit process, municipalities are adopting BIM to improve their building permit process. However, despite its many potential advantages, adopting BIM in any organization is challenging.

The purpose of this doctoral research is to facilitate BIM adoption for building permits by assessing organizational readiness. To achieve the research purpose, the overall research question was formulated as: How can BIM adoption readiness be assessed for building permits? This was elaborated into four more specific research questions:

**Research question 1** – What are the BIM adoption processes in Architecture, Engineering, Construction, and Facilities Management (AEC/FM)?

**Research question 2** – What is the BIM adoption process for building permits?

**Research question 3** – What are the factors that affect BIM adoption for building permits?

**Research question 4** – How can readiness for BIM-based building permits be assessed?

For research question 1, a systematic literature review of BIM adoption processes in AEC/FM was performed and content analysis of the literature resulted in the derivation of a generic framework for BIM adoption processes.

Research question 2 was approached using a case study methodology with data collection through the examination of documents, participant observations, and interviews. This led to a process of BIM adoption for building permits in a municipality being outlined.

Interviews were carried out in response to research question 3 and this resulted in the identification of the factors affecting BIM adoption for building permits.

For research question 4, cases of BIM-based building permits were selected from three countries, and data were gathered through document analysis and a questionnaire survey. Analysis using a Multiple Criteria Decision Method (MCDM) enabled the readiness assessment for BIM-based building permits in the selected cases.

This research has demonstrated how BIM can be adopted in municipalities for building permitting to overcome the problems associated with traditional building permit procedures. In addition, it has revealed the enablers and challenges of BIM adoption for building permits. A key contribution of this research is that it has developed a tool to assess readiness for BIM-based building permits.

These research results have both theoretical and practical implications. They contribute to the small but growing body of knowledge regarding BIM-based building permits and, more broadly, to the existing research on BIM adoption in the AEC/FM industry. From a practical perspective, the research results provide guidance to stakeholders and practitioners, mainly in municipalities, who seek to efficiently adopt BIM for building permits.

The limitations of this study include that it considered only one case for demonstrating a BIM adoption process for building permits and three cases for assessing readiness for BIM-based building permits. In addition, the sample size of interviews and the questionnaire survey were relatively small.

Future research is recommended to consider multiple cases of municipalities adopting BIM to generate a more comprehensive knowledge on the subject. Further, the developed tool for readiness assessment can be used in future studies in other municipalities which are adopting BIM-based building permits.

**Keywords**: Building Information Modelling (BIM), Building permit, BIM adoption, Multiple Criteria Decision Method (MCDM), readiness, municipalities, AEC/FM

# Lühikokkuvõte

## BIM-i põhiste ehituslubade valmiduse hinnang hulgikriteeriumide analüüsi meetodil

Ehitusala toimimise parendamiseks võetakse kasutusele uusi tehnoloogiaid, nagu ehitusinfo modelleerimine (BIM). BIM viitab ehitiste, nagu hooned, teed, sillad jne, füüsiliste ja funktsionaalsete omaduste digitaalsele esitusele, olles jagatud teadmiste allikas, võimaldades osaliste suhtlemist ja koostööd ning kujundades seeläbi usaldusväärse aluse otsustele läbi terve ehitiste elukaare. BIM kujutab ehitusala paradigmade muutust. Sellel on potentsiaali edukaks kasutamiseks ehitusala mitmes valdkonnas, nagu tulemuslik projekteerimine, eelarvestamine, tööde korraldamine ehitusplatsil, projekteerimise ja ehitamise integreerimine, kinnisavarakorraldus, energiakasutuse simulatsioonid jne. Käeoleva uurimuse käsitlusala keskendub BIM-i võimalikule kasutamisele ehituslubade menetlemisel.

Kohalikud omavalitsused väljastavad hoonetele ehitusloa pärast seda, kui on kontrollinud projekti ja muu nõutava teabe vastavust kehtivatele eeskirjadele ja seadustele. See luba muutub ametlikuks dokumendiks ehk ehitusloaks. Ehitusluba on projekteerimis- ja ehitusprotsessi lahutamatu osa, mille peamine roll on tagada hoonete ohutus ja pikaajaline püsivus. Ehitusloa taotlemine on keeruline protsess, millesse on kaasatud palju osalejaid ja protseduure, mis on sageli ebaselged, ekslikud, bürokraatlikud, ressursimahukad, halvasti jälgitavad ja aeganõudvad. Inspireerituna jätkuvast ehitusala digitaliseerimisprotsessist ja lahendamaks traditisoonilise ehitusloa väljastamisega kaasnevaid probleeme, kaasavad kohalikud omavalitsused loamenetluse parendamiseks BIM-i. Hoolimata rohketest potentsiaalsetest eelistest, on BIM-i kasutuselevõtt igas organisatsioonis keeruline.

Käesoleva doktoritöö eesmärk on kaasa aidata BIM-i kasutuselevõtule ehituslubade menetlemisel, hinnates organisatsioonilist valmisolekut. Uurimuse eesmärgi täitmiseks formuleeriti põhiline uuringuküsimus: Kuidas saab BIM-valmidust hinnata ehituslubade väljastamisel? Seda arendati edasi neljaks spetsiifiliseks uuringuküsimuseks:

**1. uuringuküsimus:** Millised on BIM-i kasutuselevõtu protsessid arhitektuuri- ja konstruktsiooniosa projekteerimisel ning ehitamisel ja kinnisvara korralduses?

**2. uuringuküsimus:** Milles seisneb BIM-i kasutuselevõtu protsess ehituslubade menetlemisel?

**3. uuringuküsimus**: Millised tegurid mõjutavad BIM-i kasutuselevõttu ehituslubade menetlemisel?

**4. uuringuküsimus:** Kuidas saab hinnata valmisolekut BIM-I põhiste ehituslubade kasutuselevõtuks?

**Esimesele** uuringuküsimusele vastamiseks koostati süstemaatiline kirjanduse ülevaade BIM-i kasutuselevõtu protsessidest ja sisu anlüüsi tulemusena koostati BIM-i kasutuselevõtu protsesside üldine raamistik.

**Teisele** uuringuküsimusimusele vastamiseks kasutati juhtumiuuringu meetodit ja koguti andmeid dokumentidest, osalejate tähelepanekutest ja intervjuudest. Selle tulemusel saadi ülevaade tüüpilise kohaliku omavalitsuse BIM-i kasutuselevõtu protsessist.

**Kolmandale** uuringuküsimusele vastamiseks intervjueeriti osalejaid ja selle tulemusel selgitati välja tegurid, mis mõjutavad BIM-põhiste ehituslubade väljastamist.

**Neljandale** uuringuküsimusele vastamiseks valiti kolmest riigist BIM-i põhiste ehituslubade juhtumid, mille andmed saadi dokumentide analüüsimisel ja küsimustikest. Valitud juhtumite valmisolekut BIM-põhiste ehitulubade kasutuselevõtuks analüüsiti hulgikriteerimide meetodil (MCDM).

Käesolev uuring demonstreeris, kuidas kohalikud omavalitsused saavad väljastada BIM-põhiseid ehituslube ja vältida traditsioonilise menetlusega kaasnevaid probleeme. Lisaks selgusid puudused ja kitsaskohad BIM-i rakendamisel. Käesoleva uuringu võtmepanus on töövahendi loomine hindamaks BIM-põhistele ehituslubadele ülemineku valmidust.

Uuringutulemustel on nii teoreetilised kui ka praktilised väljundid. Need panustavad seni vähese, kuid kasvava teadmistepagasi parendamisse BIM-põhiste ehituslubade menetlemisel ja veelgi üldisemalt BIM-i kasutuselevõtule arhitektuuri- ja konstruktsiooniosa projekteerimisel, ehitusprotsessis ja kinnisvarakorralduses. Praktika seisukohast annavad uuringutulemused juhiseid huvitatud osalejatele ja eelkõige kohalike omavalitsuste töötajatele, kes otsivad tulemuslikke võimalusi BIM-põhiste ehituslubade menetlemiseks.

Uuringus piirduti ühe juhtumiuuringuga kirjeldamaks BIM-põhise ehitusloa väljastamise protsessi ning kolme juhtumuuringuga hindamaks BIM-põhise ehitusloa väljastamise valmidust. Lisaks oli näidisuuringu valimi maht küsitlustest ja intervjuudest ülevaate tegemiseks suhteliselt väike.

Jätkuuuringutes tuleks BIM-i põhiste ehituslubade valmidushinnangute üldistusvõime suurendamiseks laiendada kohalike omavalitsuste valimit. Käesoleva uuringu raames välja töötatud hinnangumeetodit saab kasutada teistes omavalitsustes, kes soovivad juurutada BIM-põhiste ehituslubade väljastamist.

**Võtmesõnad**: ehitusinfo modelleerimine (BIM), ehitusluba, BIM-i kasutuselevõtt, hulgikriteerimide meetod, valmisolek, kohalikud omavalitsused, projekteerimine, ehitamine, kinnisvarakorraldus

# Appendix

**Publication I**

Ullah, K., Lill, I., & Witt, E. (2019). An overview of BIM adoption in the construction industry: Benefits and barriers. In 10th Nordic Conference on Construction Economics and Organization. Emerald Publishing Limited. https://doi.org/10.1108/S2516-285320190000002052 (**Conference paper: ETIS classification 3.1**)

# An Overview of BIM Adoption in the Construction Industry: Benefits and Barriers

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## Abstract

**Purpose** – Building Information Modeling (BIM) is a revolutionary innovation in the construction industry to virtually design and mange projects throughout the building lifecycle. Although Estonia is one of the foremost countries in the Information and Communications Technology (ICT) sector, BIM adoption in the Estonian construction industry is still lagging behind other countries. This paper is part of doctoral research that aims to determine the barriers to BIM adoption and develop a framework for effective implementation of BIM in the Estonian construction industry. The purpose of this paper is to examine the status of BIM adoption, BIM benefits and common barriers to BIM adoption in the construction industry worldwide.

**Design/Methodology/Approach** – The methodology used in this study is a literature review of journal articles, conference proceedings and published reports from various sources.

**Findings** – This study showed BIM benefits through building lifecycle phases and explored the BIM adoption rate in the construction industry of various countries. Eighteen barriers to BIM adoption were also identified.

**Research Limitations/Implications** – The study presented is limited to a literature review – some related literature may have been missed.

**Practical Implications** – The main practical significance of this study is that the findings can be used to inform a further survey to model the barriers to BIM adoption in the Estonian construction industry.

**Originality/Value** – This study offers information on BIM adoption in the construction industry and will form the basis of further research.

**Keywords** Building Information Modeling, Virtual design and construction, Construction industry, BIM adoption, Benefits, Barriers

*All papers within this proceedings volume have been peer reviewed by the scientific committee of the 10th Nordic Conference on Construction Economics and Organization (CEO 2019).*

This research was supported by the Integrating Education with Consumer Behaviour Relevant to Energy Efficiency and Climate Change at the Universities of Russia, Sri Lanka and Bangladesh (BECK) project co-funded by the Erasmus+ Programme of the European Union. The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



Emerald Reach Proceedings Series
Vol. 2
pp. 297–303
Emerald Publishing Limited
2516-2853
DOI 10.1108/S2516-285320190000002052

## 1. Introduction

The construction industry is a significant contributor to the socio-economic development of any country. Nevertheless, owing to the complexity of the construction industry, it faces several challenges such as low productivity, poor quality, rising cost, construction waste, delays and lack of information sharing among project stakeholders. BIM offers the potential to address these challenges and improve construction industry performance. BIM is an innovative technology and process to virtually design and manage construction projects (Azhar, 2011a).

BIM has been adopted in the construction sector over the last two decades and it has the capacity to transform and enhance performance by decreasing inefficiencies, improving productivity and increasing collaboration among project stakeholders (Abanda *et al.*, 2018). Adoption of BIM offers the visualisation of design, fast creation of alternative designs, automatic examination of model reliability, production of reports and building performance forecasting (Sacks *et al.*, 2010). Despite the potential benefits of BIM, its implementation rate has been slow owing to various barriers (Walasek and Barszcz, 2017).

As in other countries, BIM is gaining the attention of Estonian construction practitioners. However, there are many challenges which affect BIM adoption in Estonia (Karafin *et al.*, 2016). Tüvi (2017) states that there is a need to investigate the barriers to BIM adoption in the Estonian construction sector. This paper examines the status of BIM adoption, BIM benefits and the common barriers to the adoption of BIM in the global construction industry as a basis for developing a framework for effective implementation of BIM in the Estonian construction industry.

The structure of the paper is organised as follows: the methodology is presented in Section 2, and BIM adoption in various countries of the world is explained in Section 3; in Section 4, potential benefits are illustrated. Section 5 shows common barriers to BIM adoption and the conclusion is drawn in Section 6.

## 2. Methodology

It is imperative in a literature review to describe clear boundaries to limit the research (Seuring and Muller, 2008). The literature considered for this study was published between 2008 and 2018 and in English. The literature review was not restricted to particular journals. The Scopus search engine was first used to identify scholarly work containing BIM benefits and barriers to BIM adoption. The Scopus search engine was considered because it is one of the largest databases; it has a high level of quality control and covers multidisciplinary research areas. In order to collect relevant papers for this study, the following keywords and Boolean phrases were used: ([Building information modelling OR Building information modelling OR BIM OR Virtual design and construction OR VDC OR 3D modelling] AND (Adoption) AND [Benefits OR Advantages] AND [Barriers OR challenges] within [Title/ Abstract/ Keywords]). 63 relevant papers were collected. In addition, to increase the relevant literature, particularly for information on BIM adoption rates, some non-Scopus papers, survey reports and academic theses were also considered. Thus, a total of 88 publications were examined to address the purpose of this study.

## 3. BIM Adoption Global Scenario

BIM adoption means “the successful implementation whereby an organisation, following a readiness phase, crosses the ‘Point of Adoption’ into one of the BIM capability stages, namely, modelling, collaboration and integration" (Succar & Kassem 2015). The BIM adoption has significantly increased around the globe particularly in the developed countries over the past years.

The United States is one of the pioneers in BIM development and adoption in the construction industry (Wong *et al.*, 2010). In the US, the General Services Administration (GSA) in 2003 launched the "National 3D-4D program" with the goal to form strategy to gradually implement 3D, 4D and BIM for all major public projects (Wong *et al.*, 2010). In 2007, the GSA included BIM for spatial program validation for all its projects (Burgess *et al.*, 2018).

In 2014, the European Commission announced directive 2014/24/EU, which recommends member states' use of specific electronic tools such as BIM for public works contracts and design contests (European Parliament, 2014). In the United Kingdom, the government has mandated a minimum of Level 2 collaborative BIM on all publicly financed projects from 2016 (Burgess *et al.*, 2018).

The Scandinavian countries are at the forefront in BIM adoption (Smith, 2014). In the Netherlands, the Government Buildings Agency has mandated the use of BIM for public projects in 2011 (Cheng and Lu, 2015). Research conducted in Germany, France, Brazil and Austria showed that BIM is gaining wide adoption in these countries (Matarneh and Hamed, 2017). In Estonia, a survey was carried out among 297 firms and revealed that 51 per cent of respondents are already using BIM or planning to adopt it over the next 5 years (Usesoft AS, 2016).

Singapore and South Korea lead BIM adoption in Asia and mandated the use of BIM in all public funded projects by 2015 and 2016, respectively (Cheng and Lu, 2015).

In Hong Kong, the government mandated the use of BIM in the design and construction phases of all public projects (Development Bureau Hong Kong, 2017). The Japan Federation of Construction Contractors (JFCC) formed a BIM Specific section under its Building Construction Committee to promote BIM adoption (Jin *et al.*, 2015).

According to Yang and Chou (2018), the BIM adoption rate is less than 30 per cent in the Middle East. Gerges *et al.* (2017) state that BIM adoption is relatively low in Africa. Table 1 indicates the BIM adoption rate in different countries.

## 4. Potential benefits of BIM adoption

Various research studies have been performed relating to BIM adoption in construction projects which have found many advantages over traditional construction practices. Table 2 shows BIM benefits in different phases of the building lifecycle.

| Country | BIM adoption rate (year and source) |
|---|---|
| Australia | 67%, 2016 (Red Stack BIM services, 2016) |
| Canada | 78%, 2018 (MaCabe *et al.*, 2018) |
| China | 67%, 2014 (Jin *et al.*, 2015) |
| Czech Republic | 25%, 2016 (Malleson, 2016) |
| Denmark | 78%, 2016 (Malleson, 2016) |
| Estonia | 51%, 2015 (Usesoft AS, 2016) |
| Japan | 46%, 2016 (Malleson, 2016) |
| Poland | 23%, 2015 (Juszczyk *et al.*, 2015) |
| United Kingdom | 74%, 2018 (Malleson, 2018) |
| United States | 79%, 2015 (Gerges *et al.*, 2017) |

**Table 1.** BIM Adoption Rate in Various Countries

| Phases | Benefits of BIM use |
|---|---|
| Pre-construction | • Better concept and feasibility (Eastman *et al.*, 2011)<br>• Effective site analysis to understand environmental and resource-related problems (Azhar *et al.*, 2011b)<br>• Improve effectiveness and accuracy of existing conditions' documentation (Kjartansdottir *et al.*, 2017)<br>• Effective design reviews leading to sustainable design (Khosrowshahi, 2017)<br>• Enhancement of energy efficiency (Eastman *et al.*, 2011)<br>• Resolve design clashes earlier through visualizing the model (Latiffi *et al.*, 2016)<br>• Enables faster and more accurate cost estimation (Khosrowshahi, 2017) |
| Construction | • Evaluation of the construction of complex building systems to improve planning of resources and sequencing alternatives (Kjartansdottir *et al.*, 2017)<br>• Effective management of the storage and procurement of project resources (Eastman *et al.*, 2011)<br>• Efficient fabrication of various building components offsite using design model as the basis (Enshassi *et al.*, 2018)<br>• BIM allows better site utilization (Deshpande and Whitman, 2014)<br>• Reduce site congestion and improve health and safety (Khosrowshahi, 2017) |
| Post construction | • BIM record model can help in decision-making about operations, maintenance, repair and replacement of a facility (Kjartansdottir *et al.*, 2017)<br>• Makes asset management faster, more accurate and with more information (Husain *et al.*, 2014)<br>• Ability to schedule maintenance and easy access to information during maintenance (Enshassi *et al.*, 2018) |

**Table 2.**
BIM Benefits Through the Building Life Cycle

### 5. Barriers to BIM adoption

Elmualim and Gilder (2014) examined the hindrances to adoption of BIM in the USA, Canada, the UK, Ghana, South Africa, China, India and Australia. Their findings showed that the main barriers are deficiency of capital, BIM benefits not outweighing the implementation costs, unwillingness to start new workflows and BIM being too risky from a liability perspective.

A survey by Enterprise Ireland revealed that barriers in BIM adoption are the lack of client interest, insufficient expertise, lack of training, unavailability of standardised tools and protocols and issues related to data ownership (McAuley *et al.*, 2017).

Ismail *et al.* (2017) examined BIM adoption in China, India, Pakistan, Sri Lanka, Malaysia, Indonesia, Thailand and Vietnam. They highlighted that the main barriers to BIM adoption were cultural resistance, longer processes, high investment cost, lack of awareness and demand and uncertainly about the return on investment (ROI).

Hosseini *et al.* (2016) described the barriers to the adoption of BIM in Australia. The barriers were sub-contractors not having sufficient knowledge about BIM, clients' lack of awareness about BIM benefits, high cost of BIM implementation, high cost of training and unwillingness to change current construction culture. Obstacles to BIM adoption in the construction industry of New Zealand are high initial cost, training issues and cultural resistance (Harrison and Thurnell, 2015).

The literature review shows that both developed and developing countries faces barriers in BIM adoption. Table 3 summaries the barriers to BIM adoption in the construction industry.

| Barriers | Reference |
|---|---|
| High initial cost | (Ismail *et al.*, 2017) |
| Lack of awareness about BIM benefits | (Latiffi *et al.*, 2016), (Gerges *et al.*, 2017) |
| Inadequate training on the use of BIM | (Eadie *et al.*, 2014) (Park and Kim, 2017) |
| Resistance to change current construction industry culture | (Ganah and John, 2015) (Sahil, 2016) |
| Insufficient governmental support | (Enshassi *et al.*, 2016) |
| Legal issues | (Bosch-Sijtsema *et al.*, 2017) |
| Lack of interest from clients | (Sahil, 2016) |
| Lack of support from top management | (Ganah and John, 2015) |
| Doubts about ROI | (Eadie *et al.*, 2014) |
| Lack of BIM experts | (McAuley *et al.*, 2017) |
| Data ownership issues | (Park and Kim, 2017) |
| Longer process (takes longer time to develop the model) | (Ismail *et al.*, 2017) |
| Lack of demand from the contractors | (Gerges *et al.*, 2017) |
| Sub-contractors are not interested in using BIM | (Hosseini *et al.*, 2016) |
| Absence of contractual requirement for BIM implementation | (Ahmed *et al.*, 2014) |
| Complexity of the BIM model | (Ahmed *et al.*, 2014) |
| Interoperability between software programs | (Park and Kim, 2017) |
| Lack of standardized tools and protocols | (McAuley *et al.*, 2017) |

**Table 3.** Barriers to BIM Adoption

## 6. Conclusions

This study overviewed the current situation of BIM adoption, benefits and common barriers to BIM adoption in the construction sector. The literature review shows that BIM is an emerging technology and process in the construction industry and can offer numerous benefits to the construction stakeholders. It can be observed that the BIM adoption rate varies from country to country. Some countries like the US, the UK, the Scandinavian countries and Singapore lead BIM adoption. Despite the benefits of BIM, there are various barriers which affect the BIM adoption rate. The findings of this study will be used to develop a survey instrument for determining potential barriers to BIM adoption in the Estonian construction industry. The next phase of this research will involve a large-scale survey of construction industry stakeholders and the development of a framework for effective BIM implementation.

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**Publication II**

Ullah, K., Raitviir, C., Lill, I., & Witt, E. (2020). BIM adoption in the AEC/FM industry–the case for issuing building permits. *International Journal of Strategic Property Management*, *24*(6), 400–413. https://doi.org/10.3846/ijspm.2020.13676 (**Journal paper: ETIS classification 1.1**)

International Journal of Strategic Property Management
ISSN: 1648-715X / eISSN: 1648-9179
2020 Volume 24 Issue 6: 400–413
https://doi.org/10.3846/ijspm.2020.13676

# BIM ADOPTION IN THE AEC/FM INDUSTRY – THE CASE FOR ISSUING BUILDING PERMITS

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Received 01 May 2020; accepted 06 August 2020

**Abstract.** BIM adoption is a complex process and relatively little information exists on the BIM adoption processes of public authorities. This research aims to address this gap by examining how a contemporary public authority is approaching BIM adoption for their building permitting process. Firstly, a systematic literature review was carried out to understand extant descriptions of BIM adoption processes and the factors affecting adoption success. This resulted in the derivation of a generic BIM adoption process and the classification of factors that affect BIM adoption with reference to the Technology Organization and Environment (TOE) framework. The case of the BIM adoption process and the factors affecting its implementation in a contemporary public authority were then analysed in terms of the generic adoption process and factor classification derived from the literature. The findings reveal the planning strategies and execution steps for BIM adoption and the factors affecting them. This study provides a systematic approach to investigating BIM adoption in a public authority. It contributes to the understanding of BIM adoption processes and factors affecting them and is anticipated to be useful for AEC/FM professionals in understanding and facilitating successful BIM adoption.

**Keywords:** Building Information Modelling, AEC/FM industry, BIM adoption, building permits, public authorities, systematic literature review, case study.

## Introduction

Construction projects normally require a building permit from a regulatory authority, and it can be considered as an important milestone for projects. Typical building permitting procedures are complicated, unclear, error prone and inefficient (Eirinaki et al., 2018; Nawari & Alsaffar, 2017) so that building permits are subject to delays in processing and issuing. Building Information Modelling (BIM) as an innovative technology has changed the way construction projects are conceived, designed, constructed and operated (Husain et al., 2018; Hardin, 2009) and is widely recognized as having the capacity to improve project performance (Franz & Messner, 2019; Whyte & Hartmann, 2017). BIM can be beneficially leveraged for several purposes e.g. design and construction integration, cost estimation, scheduling, coordination, energy simulation, safety, and facility management. This study concerns the potential for BIM use in the building permit process.

A building permit is a document issued in the form of an administrative decision which gives legal permission for the commencement of construction works in accordance with the appropriate laws, regulations and codes (Krajewska et al., 2014; Leśniak et al., 2019). The issuance of a building permit is an important step for any construction project (International Code Council, 2018). Building permits can influence spatial property development, as they prevent undesirable developments which are not in compliance with the city planning (Samsura et al., 2015; Eika, 2019). The building permitting process is also an important component of the institutional factors that significantly influence the success of construction projects (Gudienė et al., 2013, 2014) and the number of building permits issued is a key indicator in microeconomic fundamentals (Meulen et al., 2014) and of construction sector performance (Kildienė et al., 2011). In a typical building permitting process, if a property owner or developer decides to apply for a building permit, it requires filling in various forms and providing different supporting documents. For the public authority, it requires checking the submitted application and associated files against various codes and regulations and requires coordination among various departments. It is therefore a time-consuming, difficult to track process subject to errors (Eirinaki et al.,

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2018). This calls for digitalization that could improve the efficiency of the building permitting process and BIM has the potential to simplify and automate the process if it is adopted by the regulatory authorities that deal with building permits (Nawari & Alsaffar, 2017; Olsson et al., 2018).

A few existing studies, including those by Nawari and Alsaffar (2017), Olsson et al. (2018) and Narayanswamy et al. (2019) have addressed BIM use for building permits. These have referred to BIM capacity for building permits and investigated automated code checking procedures. There is, however, a lack of studies that systematically show the BIM adoption process by public authorities or organizations responsible for building permits. The BIM adoption process (the actions that should be taken in adopting BIM) is an important aspect as the outcomes of BIM usage are reliant on the quality of the adoption process (Gurevich et al., 2017). Thus, there is a significant need to investigate the BIM adoption process by public authorities dealing with building permits and the aim of this paper is to do so.

In contrast to the limited academic research on the BIM adoption of public authorities, there are numerous studies concerning BIM adoption in the AEC/FM industry generally and these can be drawn on to derive a framework with which to investigate and understand the BIM adoption process of public authorities and their building permitting processes.

This research therefore commences with a systematic review of the literature regarding BIM adoption and the factors that affect it. From the extant literature identified, a generic BIM adoption process is derived as is a classification of factors that affect BIM adoption. Together, these provide a framework with which to investigate the BIM adoption process in a specific case - that of the Tallinn City Government (TCG) which is the public authority responsible for processing and issuing all building permits in the Estonian capital city, Tallinn.

A description of the literature review and case study methodology follows in section one. An overview of the BIM adoption literature is presented in section two and the generic BIM adoption process and classification of factors affecting BIM adoption which emerge from the synthesis of the literature are described in section three. Within the framework of this generic process and classification, the TCG case study is carried out and it is presented in section four. Conclusions and recommendations are then drawn in the final section.

## 1. Methodology

A literature review was first carried out in order to identify the various contemporary views on BIM adoption and the observed and theorised BIM adoption processes in the AEC/FM industry as well as the factors that influence these. The data from the literature were then synthesized into a generic BIM adoption process and factor classification system which could be used as a framework with which to analyse the BIM adoption process with respect to a specific, current case of a public authority (that of TCG). The case study was then undertaken and reported in accordance with the derived analytical framework.

Kitchenham and Charters (2007) defined systematic literature review as "A form of secondary study that uses a well-defined methodology to identify, analyse and interpret all available evidence related to a specific question in a way that is unbiased and to a degree repeatable". The systematic literature review process applied in this case was inspired by that of (Gough, 2007) and described in nine steps by Bearman et al. (2012) as follows:

1. Formulating the review question – in our case: What are the existing BIM adoption processes in the AEC/FM industry and what factors affect them?
2. Determining inclusion and exclusion criteria: Only relevant journal and conference papers published in English were considered with no geographic limitation and no restriction on year of publication.
3. Establishing the search strategy, including information sources: The Boolean phrase: ("Building Information Mode?l*" OR "BIM") AND ("Adoption" OR "Implementation") was used and the following online databases were searched:
   - Scopus;
   - Web of Science (Clarivate Analytics);
   - ASCE Library;
   - EBSCOhost Web;
   - Science Direct;
   - Emerald Insight.
4. Screening the articles to check whether they meet the inclusion and exclusion criteria: Titles and, where necessary, abstracts were screened for relevance to review question. The Mendeley Reference Manager was used to identify and remove duplicated articles.
5. Reporting the results of the search strategy. Table 1 shows the results of the search and screening.

Table 1. Number of articles returned from online databases

| Databases | Articles returned from databases search | Relevant articles after screening |
|---|---|---|
| Scopus | 2055 | 181 |
| Web of Science | 1316 | 153 |
| EBSCOhost Web | 718 | 105 |
| ASCE Library | 1322 | 52 |
| Emerald Insight | 821 | 36 |
| Science Direct | 407 | 30 |
| Overall (with duplicates removed) | N/A | 319 |

6. Extracting relevant data: The relevant articles were exported to NVivo Plus (v.12) software from Mendeley Reference Manager and subjected to qualitative content analysis.

7. Evaluating the quality of the included studies: Quality was considered adequately ensured through the status of the included articles as being published in peer reviewed journals and conference proceedings that are indexed in reputable databases.
8. Synthesising the collective evidence of the included studies to answer the review question: The evidence regarding BIM adoption processes and factors affecting them was synthesised using a qualitative procedure of identifying relevant content of the selected articles and coding them according to emergent themes (for example: process stages and factor types). This process was carried out using NVivo Plus (v.12) and the generic BIM adoption process and classification of the factors that affect it are presented in section 2 below.
9. Drawing conclusions and communicating the findings.

Gerring (2004) defined case study as "an intensive study of a single unit with an aim to generalize across a larger set of units". Case study is a strategy that seeks to explain and offer rich information about a particular contemporary phenomenon within its context, typically through a number of data collection methods including interviews, questionnaires, observations, document analysis, and others (Robson, 2002). However, according to Almuntaser et al. (2018) the limitation of case study is that it cannot be used to make generalizations. The data collection methods employed in the TCG case study for this research were interviews with TCG officials, content analysis of TCG reports and documents and participant observation in TCG meetings by one of the co-authors who has been embedded with TCG in order to understand their processes and help develop a BIM-enabled building permitting process. Specifically, face-to-face interviews were carried out with 5 TCG officials and participation in 15 group meetings held by TCG regarding BIM adoption. All the interviewees had more than 10 years of experience in the field. The findings from the case study are reported through analysis of interviews and content analysis of the reports and documents from TCG. The case study data were analysed and reported on the basis of the analytical framework developed from the literature and the results are presented in section 3.

## 2. The AEC/FM industry BIM adoption literature

### 2.1. Theoretical perspectives on BIM adoption

There is a general consensus in the literature that BIM adoption is a social phenomenon. Various social theories, frameworks and models have been used for examining BIM adoption processes and the factors that influence them. The most common theoretical perspectives applied were found to be: Diffusion of Innovation Theory and the Technology Acceptance Model. Other theoretical perspectives adopted included: Institutional Theory, Task Technology Fit, Theory of Reasoned Action, Theory of Planned Behaviour, and Unified Theory of Acceptance and Use of Technology. Diffusion of Innovation (DOI) theory is the most widely used theory to explain IT and BIM adoption (Hameed et al., 2012; Ahmed & Kassem, 2018). DOI theory was proposed by Everett Rogers in 1962 and explains how new ideas (innovations) move through a particular social system. It suggests a five-stage process for diffusion of an innovation which includes awareness, interest, decision, implementation, and confirmation (Rogers, 1983). In the literature reviewed, it was used for investigating the BIM adoption process e.g. by Gledson and Greenwood (2017), for digital innovation (BIM) diffusion e.g. by Shibeika and Harty (2015) and for factors affecting BIM adoption e.g. by Xu et al. (2014).

The Technology Acceptance Model (TAM) proposed by Davis (1989) explains the behaviour of users in acceptance of information technologies. TAM has two key perceived attributes namely "Perceived Usefulness" (PU) and "Perceived Ease of Use" (PEU). PU refers to "the degree to which a person believes that using a particular system would enhance his or her job performance", while PEU is "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989). Among the studies reviewed in this research, TAM was primarily used for identifying factors influencing BIM adoption e.g. by Sanchís-Pedregosa et al. (2020) and Qin et al. (2020).

### 2.2. AEC/FM industry BIM adoption processes

In this research, "BIM adoption process" refers to the actions, techniques, methodologies or steps undertaken by stakeholders in order to adopt BIM in their organizational/project contexts. In the literature review, a lack of studies systematically describing the BIM adoption process by public authorities or organizations responsible for building permits was observed. However, specific BIM adoption processes have been proposed by various authors in the AEC/FM industry.

Hochscheid and Halin (2019) described the BIM adoption process as a five-stage process, based on Roger's Diffusion of Innovation theory. The first stage, Awareness, occurs when an organization is exposed to or becomes aware of BIM. In second stage, Intention, the organization starts seeking further information about it. The decision stage refers to the organization deciding whether to adopt or reject BIM. During Implementation, BIM is utilised, and, in the Confirmation stage, the organization has started using BIM and confirms its commitment to continue its use.

Almuntaser et al. (2018) developed a BIM adoption framework based on the case study of an architectural firm in Saudi Arabia. Their framework draws on the Project Management Institute Standards Committee (2013) five project management processes as follows: Initiating: the organization's vision, objectives, deliverables and milestones for BIM adoption are defined, a BIM team is selected, all stakeholders are identified, and financial resources are provided. Planning: Different areas for BIM implementation are selected, the scope of work to be carried out for BIM adoption is defined, potential risks and quality assurance measures are identified, procurement is planned and effective communication between all stakeholders is established. Executing: This phase includes creation and coordination of the BIM model between all disciplines. Monitoring and controlling: Monitoring BIM adoption to ensure that the objectives are being achieved within the set time and cost and BIM deliverables are within the scope defined. Closing: The last phase involves handovers of all deliverables and measuring BIM performance in the organization, the project and the team for improvement.

Based on a literature review Kouch (2018) developed a three step BIM implementation framework consisting of understanding, planning, and piloting. Understanding includes gaining BIM knowledge, developing strategies for short-term and long-term goals, financial support for BIM implementation, addressing challenges and assigning BIM teams. In the planning step, the BIM teams analyse the current process of activities and resources (human, tools, etc.) in order to develop new, BIM-based processes. Kouch (2018) states that during planning the available standards and guidelines for BIM implementation can also be considered. Piloting is a practical step implementing what is planned and includes model creation, monitoring and control, and handover.

Ahn et al. (2016) illustrated BIM adoption process through case studies of four construction companies in the USA. The process starts with hiring BIM experts and selecting areas for BIM implementation. Investing in BIM software and hardware. Developing a BIM implementation plan and strategies for collaboration with subcontractors and design teams. Based on the BIM implementation plan and guidelines, an organization can begin BIM implementation for real projects. Once BIM implementation has been incorporated in the work process, the next step is the coordination with other stakeholders for maximizing the benefits of BIM implementation. The BIM adoption process presented by Ahn et al. (2016) also includes BIM education and training of organization employees.

Machado et al. (2016) presented a rational, 5-stage approach to BIM implementation in a UK-based SME. In the first stage, establishing best practice knowledge in BIM: a literature review determined best practices of BIM in the UK and semi-structured interviews were conducted to explore the drivers, steps for implementation and the challenges of BIM implementation. The second stage, review and analysis of the organization's current situation: the organization's current business processes and workflows were reviewed to understand ICT systems and infrastructure, file formats and information exchanges used in the organization and thus identify the areas where BIM could be used for supporting the organizational objectives. Stage three, developing BIM-based collaborative strategy: This stage included analysing improvement gains, determining required IT systems, formulating a training plan for employees and developing the organizational BIM implementation strategy. Stage four, implementation of BIM based strategy: includes the deployment of a BIM pilot project to put in practice the new business process which was planned. Finally, stage five: Project review, evaluation, and dissemination: which includes the assessment of the project on which BIM was used.

Hochscheid and Halin (2018) examined BIM implementation in various architecture firms. The BIM implementation approach consisted of four steps: Firstly, Context study: reviewing the organization's current situation and practices. Planning: developing new business processes and a strategy for BIM implementation. Execution: piloting BIM implementation based on the developed strategy. Transfer: the fourth and final step in which the pilot project is assessed with the aim of further improving BIM use.

Arayici et al. (2011) studied BIM adoption in an architecture firm through case study. The BIM adoption process proposed by Arayici et al. (2011) comprises four stages: firstly, reviewing and assessing the current practices of organization and identification of benefits from BIM implementation; secondly, designing a new business model and documentation of the BIM implementation path. The third stage is the actual implementation of BIM and it also includes piloting BIM implementation on projects and training the employees. The final stage is the evaluation of the project aimed at assessing the net benefits from it.

A roadmap for implementation of BIM was presented by Khosrowshahi and Arayici (2012) from the results of a questionnaire survey amongst contractors in the UK. Before the questionnaire survey, interviews were carried out with construction professionals from Finland to determine BIM implementation best practices. The BIM implementation roadmap comprises identifying challenges in BIM implementation, developing an effective strategy for implementing BIM and providing professional guidelines to BIM adopters.

To support decision making in BIM adoption, Gu and London (2010) developed a Collaborative BIM Decision Framework. The developed Collaborative BIM Decision Framework consists of four parts. Part 1: defining scope, identifying purposes, establishing roles, extent of BIM and map to project phases. Part 2: Developing work process roadmaps within and across organizations. Part 3: Identifying technical requirements of BIM. Part 4: Collaborator capabilities evaluation.

The literature also revealed existing elaborations of certain parts of the BIM adoption process. For example, Chunduri et al. (2013) developed three procedures for assisting facility owners in BIM adoption planning through literature review and case studies. The procedures consist of BIM organizational strategic planning, BIM project procurement planning, and BIM organizational execution planning. In strategic planning, an organization assesses their status and needs, sets objectives and goals and determines the area of focus for BIM implementation. Procurement planning includes the development of a well-defined

BIM contract language for achieving the goals and objectives, team selection, contract procurement and execution requirements and execution planning provides implementation guidance for BIM implementation.

Lin et al. (2016) developed a detailed BIM execution plan for BIM implementation in Facilities Management (FM) consisting of seven core elements: 1) establishment of team for BIM-FM implementation, 2) development of a strategy for successful BIM implementation, 3) developing BIM-FM documents which show areas for BIM implementation and management of the BIM model, 4) development of the BIM-FM process which includes describing the current processes, designing new BIM processes, and developing transition processes for achieving BIM usage, 5) formation of BIM-FM information collection which shows the information needs of the organization and the information to be displaced and integrated with the BIM model, 6) development of inspection mechanism for BIM models and 7) development of rules for BIM model usage in FM.

### 2.3. Factors affecting BIM adoption

BIM adoption factors are the determinants which can enable or inhibit the adoption of BIM in an AEC/FM industry organization. The literature review showed that numerous academic enquires from many different countries have already been made (predominantly using questionnaire surveys) to identify factors that affect BIM adoption. Factors influencing BIM adoption are generally similar, but a difference in their impact level can be observed among countries (Kim et al., 2016).

Through questionnaire surveying of BIM experts in China, Ma et al. (2019) studied BIM adoption influencing factors. They concluded that project leadership and software functionality are two fundamental factors influencing BIM adoption as they also affect the other factors directly or indirectly. Gledson and Greenwood (2017) investigated 4D BIM adoption in the UK construction industry through a questionnaire survey among construction planning practitioners and found that the relative advantage of BIM is the most prominent factor for 4D BIM adoption. According to Eadie et al. (2013) applications offered by BIM and client or competitive pressure were the main factors driving BIM adoption in UK contractors. Son et al. (2014) surveyed the factors influencing BIM adoption in South Korean architecture firms and found that the primary influencing factor was top management support. Kim et al. (2016) and Lee and Yu (2017) also investigated factors influencing BIM acceptance in the South Korean construction industry. In India, Ahuja et al. (2016) studied factors impacting BIM adoption and concluded that expertise, trialability, and management support were the most critical factors. Based on a qualitative and quantitative approach, Hong et al. (2016) explored factors affecting BIM adoption decisions in small and medium size construction organizations (SMOs) in Australia. Awareness and innovativeness were among the main factors influencing the BIM adoption decision.

Different typologies were found to be used by researchers for factor classification. Ma et al. (2019) classified factors influencing BIM adoption into institutional and technology factors. Liao and Teo (2019) grouped the factors according to people, process, technology, and external environment aspects. Hong et al. (2016) categorized influential factors for BIM adoption in three groups: adoption motivation, organizational competency, and ease of implementation. Gu and London (2010) grouped the factors affecting BIM adoption into technical and non-technical areas.

## 3. Analytical framework derived from the literature

The findings from the literature review in terms of observed and proposed BIM adoption processes in the AEC/FM industry were then synthesised into the generic BIM adoption process shown in Table 2. This draws together and organises all of the detailed process steps described in the extant literature and frames them in a four-stage process of initiation, planning, execution and evaluation. It is important to note that, although this has the appearance of a simple, linear process, the authors acknowledge that BIM adoption does not necessarily take place in a simple, linear fashion and, indeed, some of the literature specifically points this out, e.g. (Whyte & Hartmann, 2017).

Similarly, the factors identified during the literature review have been collated and categorized in Table 3 using the Technology, Organization and Environment (TOE) framework for adoption of innovation developed by Tornatzky et al. (1990). The technological context encompasses both internal and external technologies connected to the organization and includes the characteristics of technology to be adopted. The organizational context refers to the characteristics and resources of the organization in which the technology will be adopted. The environmental context includes the industry, the organization's competitors and the regulators that shape the macro environment in which that organization exists.

Tables 2 and 3 thus provide a generic framework based on the literature with which to analyse the BIM adoption process for the purpose of issuing building permits taking place within the case study organization (TCG) and the factors that are affecting it.

## 4. Case study

### 4.1. The case study organization: Tallinn City Government

In this case study, the BIM adoption process by a municipal public authority, Tallinn City Government (TCG) was investigated. TCG has two major roles in the AEC/FM industry: it is a public authority as the issuer of building permits, certificates of occupancy and demolition permits. It is also a client through its real estate department responsible for managing construction projects owned by TCG, but this client role is beyond the scope of this case study.

Table 2. AEC/FM industry BIM adoption process

| Stages | Detailed steps | Ozener et al. (2020) | Rivera et al. (2019) | Sodangi (2019) | Almuntaser et al. (2018) | Kouch (2018) | Hochscheid and Halin (2018) | Ahn et al. (2016) | Machado et al. (2016) | Khosrowshahi and Arayici (2012) | Arayici et al. (2011) | Gu and London (2010) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initiation | Reviewing organization current situation and practices | | ✓ | | | ✓ | ✓ | | | | ✓ | |
| | Defining objectives of the organization for adopting BIM | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ | ✓ |
| | Identifying challenges | ✓ | | | | | | | ✓ | ✓ | | |
| | Addressing challenges | | | | | ✓ | | | | | | |
| | Determining IT requirements | | ✓ | ✓ | | | | ✓ | ✓ | ✓ | | ✓ |
| | Providing BIM training | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | | |
| | Analysis of the current resources | | ✓ | | | ✓ | | | | | | |
| | Selecting BIM team and establishing roles | ✓ | ✓ | ✓ | ✓ | | | ✓ | | | | |
| | Developing new business model | ✓ | | | | ✓ | ✓ | ✓ | | | ✓ | |
| | Determining best practices for BIM | | | | | | | | ✓ | | | |
| | Providing financial resources for BIM software and training | | ✓ | | ✓ | | | ✓ | | | | |
| | Analysing improvement/financial gains | | | | | | | | ✓ | | | |
| Planning | Determining areas for BIM implementation | | ✓ | | ✓ | | | | | | | ✓ |
| | Developing organizational BIM implementation strategy | | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | | ✓ |
| | Planning procurement with software vendors and IT consultants | | | | ✓ | | | | | | | |
| | Documentation of BIM implementation path | | ✓ | | | | | | | | ✓ | |
| | Establishing effective communication between all stakeholders | | | | ✓ | | | ✓ | | | | |
| | Identification of potential risks and ensuring quality of deliverables | | | | ✓ | | | | | | | |
| Execution | Actual implementation of BIM, it also includes piloting BIM implementation on projects | | ✓ | | | | ✓ | ✓ | ✓ | | ✓ | |
| | Creation and coordination of the BIM model | | | | ✓ | ✓ | | | | | | |
| | Monitoring and controlling BIM adoption to ensure objectives are achieved | | ✓ | | ✓ | ✓ | | | | | | |
| Evaluation | Handovers of all BIM deliverables | | | | ✓ | | | | | | | |
| | Assessment of project with aim to improve the implementation approach | | ✓ | | ✓ | ✓ | ✓ | | ✓ | | | |
| | Evaluation of BIM implementation project to outlines the benefits gains from it | | | | ✓ | | ✓ | | ✓ | | | |

Table 3. Factors affecting BIM adoption

| Factors | | References |
|---|---|---|
| Technological factors | Compatibility | Ngowtanasawan (2016), Ma et al. (2019), Qin et al. (2020) |
| | Complexity | Ahuja et al. (2016), Chen et al. (2019) |
| | Trialability | Ngowtanasawan (2016), Kim et al. (2016) |
| | Relative advantage | Ngowtanasawan (2016), Chen et al. (2019) |
| Organizational factors | Top management support | Lee and Yu (2017), Liao and Teo (2019), Chen et al. (2019) |
| | Behavioural intention | Ding et al. (2015), Ngowtanasawan (2016), Liao and Teo (2019) |
| | Training and learning | Ngowtanasawan (2016), Liao and Teo (2019), Ma et al. (2019) |
| | Leadership | Liao and Teo (2019), Ma et al. (2019) |
| | Innovativeness | Eadie et al. (2013), Hong et al. (2016), Ma et al. (2019) |
| | Awareness | Ngowtanasawan (2016), Hong et al. (2016), Ma et al. (2019) |
| | Motivation | Ding et al. (2015), Hong et al. (2016), Cao et al. (2017) |
| | Trust | Ahuja et al. (2016), Liao and Teo (2019), Ma et al. (2019) |
| | Organizational culture | Liao and Teo (2019), Ma et al. (2019) |
| Environmental factors | Client pressure | Eadie et al. (2013), Chen et al. (2019), Ahuja et al. (2016) |
| | Competitive pressure | Eadie et al. (2013), Chen et al. (2019) |
| | Partner pressure | Chen et al. (2019), Ahuja et al. (2016) |

As a public authority, TCG is responsible for issuing building permits, certificates of occupancy and demolition permits in the area of administration of Tallinn city. In 2019, approximately 1800 building permits and 1500 certificates of occupancy are issued. A number of departments are involved in the permits issuing process as shown in Figure 1 lead by the City Planning department. The current work process suffers from issues of intricacy, inaccuracy and inefficiency and TCG is adopting BIM for building permits in order to improve the work process, increase collaboration among different departments and effectively respond to time and cost pressures.

The BIM adoption process by TCG is presented in the following sections in accordance with the generic BIM adoption process developed from the literature (and shown in Table 2).

### 4.2. Initiation

**Reviewing organization current situation and practices**

Currently, the permitting process by TCG is still being done manually and consists of uploading PDF format documents and 2D drawings. After the submission, the documents are reviewed by city planning officials, comparing their compliance with laws, regulations and standards. There is a huge amount of complex regulatory material but no central database where that information could be stored and made visible for all the stakeholders in the permit issuing process. This makes the flow of information slow within the building permit process. Co-ordination information between different departments is exchanged via e-mail and telephone. Interviews with TCG officials indicate that many working hours are used in finding necessary information about the project, which makes it a lengthy process and subject to human error.

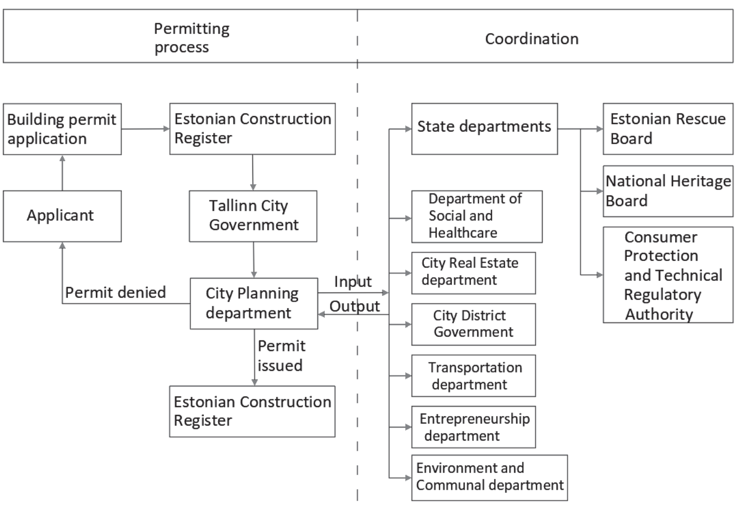


Figure 1. The structure of Tallinn City Government in building permitting process

### Defining objectives of the organization for adopting BIM

The objective of BIM adoption by TCG is to simplify and improve the process and issuing of building permits. The current focus of the organization is on BIM model-based permit issuing in the form of: Building permit, issued based on preliminary BIM project (IFC format); certificate of occupancy, issued based on as-built BIM project (IFC format); demolition permit, based on demolition BIM project (format not yet classified). Nevertheless, design criteria for the model in the phase of detailed planning must also be included as, without BIM adoption for design criteria, full implementation of other described objectives is not possible.

### Identifying and addressing challenges

TCG has several challenges regarding its BIM adoption process. These challenges can be divided into three main groups: organizational structure related, workforce qualification related and hardware-software related challenges. The last challenge can also be addressed as determining IT requirements.

The organizational structure needs to be analysed and adjusted accordingly to support the BIM adoption process. Guidance materials and a permit issuing checklist must be created to standardise process outcomes.

Workforce qualification needs to be enhanced for a BIM based building permitting process. Most TCG officials have to go through a BIM training program for creating BIM awareness and learning to use necessary BIM tools. An extra position of BIM coordinator in the Tallinn City Planning Department has to be created because training cannot provide sufficient skill levels for the current workforce to coordinate the BIM adoption process.

The difficulty level of the hardware-software challenge for TCG is still unknown. TCG is in cooperation with the Estonian Ministry of Economic Affairs and Communications (MoEAC) in this BIM adoption process. MoEAC will provide the digital environment to store BIM projects and cloud-based software working on open BIM standards for permit issuing to TCG and other Estonian municipalities. Therefore, the necessity for high end computers and large-scale BIM software (Autodesk, Graphisoft, Solibri, Tekla etc.) is very low. Only the BIM coordinator has the need for an upgraded IT solution. Detailed software packages will be determined at a later stage of this BIM adoption process.

### Providing BIM training

Three different types of BIM training have been provided to TCG employees. Basic BIM training has been delivered twice, advanced BIM training once and BIM Model Checks (BMC) training five times. The purpose of basic BIM training was to create awareness about BIM and its benefits in AEC/FM industry. Advanced BIM training focused on the nature of BIM and global case studies. BMC training courses were provided as a training series consisting of working with BIM models from the perspective of the building permit issuer and using Solibri Model Checker (SMC) software. SMC was selected as a result of the software solution provided by the MoEAC being incomplete. That solution is currently in Proof of Concept (POC) phase.

### Analyses of processes related with BIM adoption in the organization

In order to implement the BIM adoption successfully, several sub-processes (subsurface data analyses, regulatory and legal analyses, developing standards and norms, etc.) need to be in place. The processes necessary for BIM-based building permitting are shown in Figure 2. The centre of all these processes is the e-construction platform

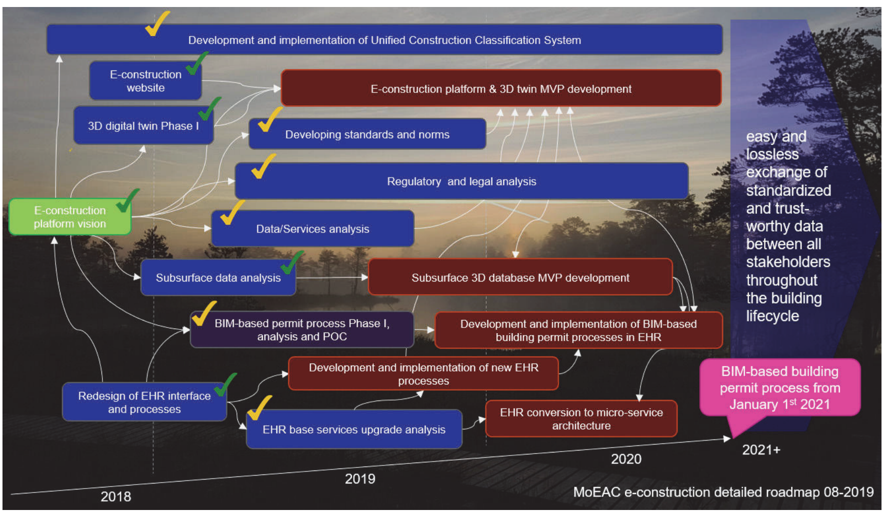


Figure 2. MoEAC detailed roadmap for BIM-based building permit process (source: Estonian Ministry of Economic Affairs and Communication)

provided by the MoEAC where all construction related information will be stored. Processes shown in Figure 2 with green ticks have been completed, while processes with yellow ticks are ongoing but not yet finished. Processes shown with a red background are planned but have not yet started.

### Developing new business model

For successful BIM adoption, a new business model for the organization must be developed. This business model, based on BIM for TCG, is described in Figure 3. The primary task for TCG is to map the functions of the departments involved in the permit issuing process. Completion of that task enables the creation of detailed checklists for comparing relevant application project parameters against the national building code. IFC format minimum requirements for permit issuing emerge from that checklist. Additionally, an effective IT solution for automated BMC can only be determined once the checklists have been developed.

Automated BIM Model checking is possible if the submitted BIM project is standardised. Therefore, it is necessary to create national BIM standards for designers. These standards must include IFC format minimum requirements, national classification system (CoClass for this case study) and LOD specification for the BIM elements in specific project phases. If these requirements are met, then the new business model can be implemented.

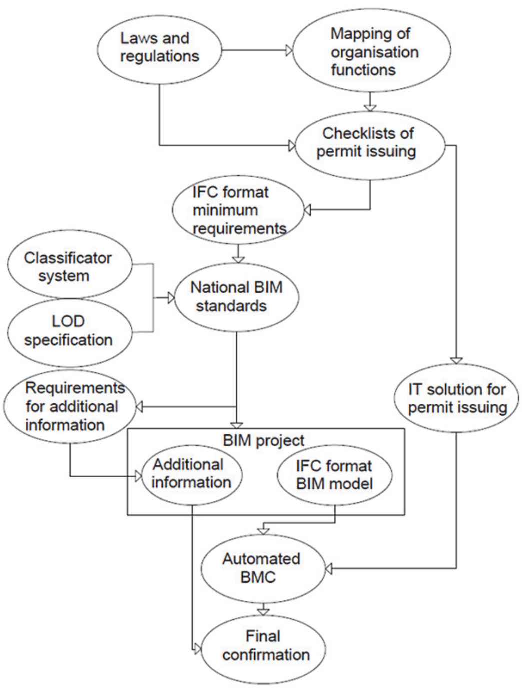


Figure 3. New business model of TCG for BIM-based permit issuing

### Providing financial resources for BIM software and training

TCG is funded by taxpayers and has a stable financial income. Budgetary decisions are made once a year, meaning no sudden allocation of non-emergency financial resources is possible. TCG has financial resources for BIM training within its budget. If BIM software packages or extra personnel are required, application for necessary funds must be made on time. The need for extra financial resources is, as yet, unclear as the software solution is to be provided by MoEAC, but this is still in an early (POC) phase of development. If the need for financial resources arises, these are likely to be allocated as the Mayor of Tallinn is highly supportive of BIM adoption in TCG.

### Analysing improvement/financial gains

Rough estimates of potential savings have been made based on the average time spent processing permits in TCG. The averages shown in Table 4 were collected from interviews with TCG officials. Based on a notional time-saving of 60% and an average hourly wage of 11€ in Estonia, the potential savings per year are 181,587€ for the building permit and certificate of occupancy. This calculation assumes estimated savings for simple buildings would be lower (40%) than for complex buildings (80%) since the automatic checks will be much more helpful for the complex buildings.

Interviews with TCG permit issuing officials and the stakeholder consultation suggest that actual savings could be significantly higher. In addition, this calculation only considers the building permit and certificate of occupancy. There are more permits and processes which will benefit from an automated BMC solution.

Table 4. Rough estimates of financial gains from BIM adoption in TCG

| | Average time spent (h) | Average time saved (h) | EUR saved per permit | Number of permits | Estimated EUR saved per year |
|---|---|---|---|---|---|
| Building permit | | | | 1822 | 98,176.58 € |
| Simple building | 7.3 | 1.8 | 19.27 € | 947 | 18,250.58 € |
| Complex building | 17.3 | 8.3 | 91.34 € | 875 | 79,926.00 € |
| Cert. of occupancy | | | | 1550 | 83,410.27 € |
| Simple building | 7.4 | 1.8 | 19.54 € | 888 | 17,347.97 € |
| Complex building | 18.9 | 9.1 | 99.79 € | 662 | 66,062.30 € |
| Total saving | | | | | 181,586.86 € |

### 4.3. Planning

#### Determining areas for BIM implementation

The most beneficial area for BIM implementation to TCG is the process of permit issuing. This will enable TCG to automate this process in the long term and make the permit issuing process cost-effective in the short term. In addition to saving time and financial resources, BIM adoption in the permit issuing process enables the collection of data for creating a digital twin of Tallinn city.

#### Developing organizational BIM implementation strategy and documentation of BIM implementation path

The BIM implementation strategy for TCG has been formulated and is being documented in cooperation with a local university. In the time period 2019–2020 proof of concept, user experience and user interface are to be created and piloted. Simultaneously, BIM training for TCG officials involved in the BIM adoption process is delivered. In 2021, the BIM-based permitting process will be operational. The focus then shifts to correcting any evident flaws in the process and creating an automatic regulation-linked update system. In addition, initiation of BIM adoption for FM starts. In 2022 BIM adoption for FM will reach the planning phase and evaluation of BIM adoption for permit issuing will be finalised and conclusions for further action drawn.

#### Planning procurement with software vendors and IT consultants

The primary software needed for BIM-based permit issuing will be provided to TCG by the MoEAC. This software, created by MoEAC in collaboration with TCG, is without direct cost for TCG. IT consultation regarding the use of the software will also be provided to TCG by MoEAC. However, procurement of IT consultants for adjusting the information flows between the software and different departments of TCG, is planned to be outsourced to the private sector.

#### Establishing effective communication between all stakeholders

The main purpose of BIM-based permit processing is to create a convenient and secure exchange of standardized and accurate data between all stakeholders throughout the building lifecycle. For ensuring the effectiveness of communication, MoEAC is creating an e-construction platform (referred to in Figure 2) through which all information through the building lifecycle will be communicated. Furthermore, it will store the guidance information, legislation, regulations and standards required for specific procedures.

#### Identification of potential risks and ensuring quality of deliverables

A large number of different systems and organizations involved in permit issuing need to ensure simultaneous BIM adoption in the environment created by the MoEAC. For example, BIM adoption for permit issuing involves running an automated BMC for a BIM project in IFC format against the spatial planning concerning that building. The BIM project must meet criteria set by detailed area plans, which are still in non-BIM-compatible file formats so, until digitalization of area planning, BIM adoption cannot be complete. Similarly, the connections between building projects and the infrastructure networks of the city pose risks as water, heating and electrical network connections are controlled by private sector companies whose level of BIM adoption is variable.

### 4.4. Execution

#### Pilot BIM implementation project

The first step of BIM implementation is a joint pilot project between TCG and the MoEAC. The MoEAC is developing the Proof of Concept (POC) for the permit issuing software. Piloting is carried out on a BIM project of an apartment complex located in Tallinn. For this project, all the necessary documents, including the detailed spatial plan in CityGML format, is provided and coordinated by TCG. Consultation of TCG BIM implementation process is provided by a local university.

The POC (see Figure 4) is based on the use of open standards: IFC, CityGML and BCF, and also visualisation standards like WebGL 2. On request from the MoEAC, the React JavaScript framework is used. Everything is based on open buildingSMART and W3C guidelines and standards.


Figure 4. The interface of POC (source: Estonian Ministry of Economic Affairs and Communications)

When an IFC dataset is checked in, it is sent to a BIM server. After check-in, the geometry is calculated by the IfcOpenShell plugin running inside BIMserver. Results of that are being stored in the BIM server database. The next step is that the geometry is sent to the Voxel server for voxelization and further analyses. Results of the analyses are stored as 'extended data' in BIMserver.

Finally, the data is streamed back to the GUI for visualisation. 3D information is streamed in binary format to visualise in BIM Surfer. Text data is shown using the React framework which is also used for the implementation of the new building registry system.

**Coordination of the BIM model between all disciplines**

In spite of the fact that TCG is not involved in the design phase of the BIM model, coordination between all disciplines is still essential due to the complex structure of TCG departments (refer to Figure 1). Every department must collect data from different aspects of the construction project documentation, in this case from a certain discipline-specific BIM model. The BIM coordinator extracts the information needed by the permit issuer from the BIM model and an automated BMC checks that information against the regulatory requirements. In addition, correct coordination of the BIM model between all disciplines is necessary in the design phase before the BIM model is submitted for permit issuing. Coordination failures can render automated BMC impossible.

**Monitoring and controlling BIM adoption to ensure objectives are achieved**

TCG has an ongoing contract with a local university for monitoring their BIM adoption process. The achievement of objectives is monitored and controlled through weekly meetings, reports and working groups. Furthermore, a BIM coordinator position will soon be created within TCG allowing for correct evaluation and to continue the work done by the consultants from the local university.

### 4.5. Evaluation

The BIM adoption process in TCG is still in the execution phase. Therefore, evaluation is not yet feasible. Once execution is achieved to a greater extent, the BIM coordinator or a manager of TCG will be able to carry out evaluation tasks, point out shortcomings, analyse benefits of BIM adoption and offer recommendations for necessary corrections.

### 4.6. Factors affecting BIM adoption in TCG

During interviews, the TCG officials were asked about factors affecting their BIM adoption process (At this stage of the study no attempt was made to measure the relative impact of the factors). Table 5 illustrates the factors BIM adoption process in TCG.

Table 5. Factors affecting BIM adoption in TCG

| Factors | | Comments from interviewees |
|---|---|---|
| Technological factors | Compatibility | The new BIM based permit process needs to be compatible with the building registry and with the new e-construction platform |
| | Complexity | Complexity of BIM tools affects BIM adoption; however, it is expected that the building permit process will become more efficient with BIM |
| | Trialability | The piloting in the execution phase offers the opportunity to try out the BIM based system before using it in real work. The positive impact of trialability is observed in the overall BIM adoption process |
| | Relative advantage | Relative advantage is among the main drivers for BIM adoption by TCG as it is expected that the new system will offer potential savings in time and cost and would be more efficient |
| Organizational factors | Top management support | Strong support is provided by top management of TCG towards BIM adoption from the initial stage, thus it has a positive impact |
| | Training and learning | Intensive BIM training programs are offered to TCG employees (dealing with building permits) for creating BIM awareness and learning to use the necessary BIM tools |
| | Leadership | TCG is a municipal level organization, the local mayor is strongly supportive towards BIM adoption in TCG |
| | Innovativeness | Organizational innovativeness is observed in the form of the initial decision by TCG top management to adopt BIM for building permits instead of continuing with current traditional practice |
| | Awareness | In the beginning of the BIM adoption process (2018) many TCG employees were not aware of BIM use for building permits. However, training programs were very useful for creating awareness about BIM |
| | Motivation | Various perceived advantages in using BIM tools motivated TCG officials to adopt BIM |
| | Trust | There was an issue of trust on BIM tools – to what extent this new BIM based building permitting process would be useful after full adoption of BIM |
| | Organizational culture | In the beginning (2018) there was some resistance towards BIM adoption, however, with the training programs, this has been addressed and the organizational culture is supportive of BIM adoption |
| Environmental factors | Client pressure | The traditional building permits process was time consuming, thus there was a pressure to move towards a more efficient process |
| | Competitive pressure | In general, there was no such competitive pressure on TCG. However, the BIM based process in Singapore and some Scandinavian countries were motivational towards BIM adoption by TCG |
| | Partner pressure | There was no partner pressure on TCG towards BIM adoption |

## Conclusions

The objective of this paper was to investigate the BIM adoption process in the AEC/FM industry and, specifically with regard to building permits issuing by public authorities. BIM enabled building permits is an emerging area of research as a result there are limited studies available on BIM use for building permits. To gain a broad understanding of BIM adoption processes and the factors that affect them, a systematic literature review on BIM adoption in the AEC/FM industry was carried out.

From content analysis of existing studies, a generic model BIM adoption process was derived with four stages: initiation, planning, execution and evaluation and each stage further elaborated by detailed steps. In addition, all the factors affecting the BIM adoption process revealed in the extant literature were collated and classified on the basis of the Technology, Organization and Environment (TOE) framework. Together, the generic BIM adoption process and classification of factors affecting it provided an analytical framework with which to examine and understand the BIM adoption process in the case of Tallinn City Government (TCG).

The TCG case study showed that, after the initial steps and planning, the TCG is now implementing a pilot project and can be considered to be in an execution stage of its BIM adoption process. Organizational review is essential to determine the available resources and establishing clear objectives of BIM adoption. The case study shows that a well-defined implementation strategy is required for successful BIM adoption. The case study confirms that training programmes are critical for BIM adoption. As the BIM adoption in TCG is currently in the pilot part of the execution stage, the piloting can assist in improving the designed new business model for BIM enabled building permits. Once the execution stage is completed the evaluation stage will be performed which is critical for improving the process and assessment of the overall BIM adoption process. The case study showed that, for successful BIM adoption, both technical and non-technical factors are important. Trialability, relative advantage, top management support, and organizational awareness were considered to have a positive effect on BIM adoption. Although, the analytical framework (generic BIM adoption process and factors affecting BIM adoption) was derived from studies focused on more general BIM adoption processes in the AEC/FM industry, it was found to be practically applicable to investigating BIM adoption by a specific organization dealing with building permits. In addition, it has the potential to be applied for studying the BIM adoption process in other organizations in AEC/FM industry. Meanwhile, the developed model shown in Figure 3 for BIM enabled building permits process can also provide guidance to other organizations that plan to adopt BIM for issuing building permits.

Whereas this study has provided an overview of the BIM adoption process at TCG and identified factors affecting it, future studies will aim to explore these factors affecting BIM adoption in public organizations to a greater depth. It is also notable that the specific challenges in relation to BIM adoption for the purpose of processing building permits call for further investigation and, once the TCG nears completion of the execution stage, opportunities for investigating the value of a BIM based building permitting process in terms of cost, time and efficiency perspectives will arise.

## Acknowledgements

This research was supported by the Tallinn City Government and "Integrating Education with Consumer Behaviour relevant to Energy Efficiency and Climate Change at the Universities of Russia, Sri Lanka and Bangladesh (BECK)" project No. 598746-EPP-1-2018-1-LT-EPPKA2-CBHE-JP, Grant Agreement No. 2018-2489/001-001 co-funded by the Erasmus+ Programme of the European Union. The European Commission support for the production of this publication does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

## Disclosure statement

No potential conflict of interest.

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**Publication III**

Ullah, K., Witt, E., & Lill, I. (2022). The BIM-Based Building Permit Process: Factors Affecting Adoption. *Buildings*, *12*(1), 45. https://doi.org/10.3390/buildings12010045 (**Journal paper: ETIS classification 1.1**)

*buildings*

MDPI

*Article*

# The BIM-Based Building Permit Process: Factors Affecting Adoption

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**Abstract:** Public organizations responsible for building permits are increasingly considering the potential applications of Building Information Modelling (BIM) in their workflows, but BIM adoption still remains a complex challenge. This research aims to investigate the factors affecting BIM adoption for building permits through a case study of a public organization currently developing and piloting a BIM-based building permit process. A thematic analysis of semi-structured interview data revealed ten factors that influence BIM adoption for building permits: complexity (in both development and use) of a BIM-based building permit system; relative advantages/disadvantages of BIM for building permits; the existing building permit system; management support for a BIM-based building permit process; organizational culture; BIM awareness; training and learning; available expertise for a BIM-based building permit process; external pressure; and legal context. The findings are important for public authorities' understanding of both the enablers and challenges of the BIM-based building permit process, and have practical implications for professionals in public authorities in particular, and also the Architecture Engineering Construction/Facilities Management (AEC/FM) industry in general, to guide their steps towards adopting BIM. This research also highlights the potential benefits of BIM adoption for the building permit process.

**Keywords:** building permit; Building Information Modelling; BIM adoption; building regulatory authorities; case study; thematic analysis



**Citation:** Ullah, K.; Witt, E.; Lill, I. The BIM-Based Building Permit Process: Factors Affecting Adoption. *Buildings* **2022**, *12*, 45. https://doi.org/10.3390/buildings12010045

Academic Editors: Ricardo Codinhoto and Heng Li

Received: 25 October 2021
Accepted: 27 December 2021
Published: 4 January 2022



## 1. Introduction

A building permit is necessary to initiate construction projects, particularly in urban areas. It is an official document granted by public authorities that gives permission for the commencement of construction works (to build new or make changes to an existing structure) in accordance with the relevant laws, regulations, and codes. Permits are also required for reconstructing or demolishing a building. The issuance of building permits is considered to be one of the indicators for measuring a country's business [1] and a major component of the institutional factors that influence the success of construction projects [2]. In addition, the building permit process plays a vital role in the efficient use of land, and is necessary for ensuring building safety and quality, as well as achieving sustainable and smart cities [3].

Obtaining a building permit involves a complex process with a large number of stakeholders, several steps, and, in many countries, this process is still analogue, with the information exchanged in paper format. In some countries, the information is handled through e-submission of digital files, such as pdf and dwg. The existing building permit process is considered to be subjective, prone to human error, time consuming, difficult to track, and unpredictable due to ambiguous regulations [4]. Inefficient building permit procedures result in delays to the overall construction process. Rapid urbanization has also led to an increased demand for constructing new buildings, and this has added pressure on local regulatory authorities by increasing the number of building permit applications. In response, public authorities are adopting BIM to facilitate the exchange of information between stakeholders, and make the overall process more efficient. BIM is "a digital representation of physical and functional characteristics of a facility, and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle" [5]. As a revolutionary technology for effective information management and collaboration, BIM offers an important opportunity for municipalities to handle building permits more efficiently.

A BIM-based building permit process enables the submission of BIM models instead of 2D drawings, and offers the possibility of automated code compliance checking instead of manual reviews. Currently, the use of BIM in the building permit process is not widespread, but municipalities in some countries, such as Singapore, Finland, and Norway, have taken solid steps towards integrating BIM in the building permit process [4]. In addition, in recent years, a number of studies have been carried out to examine the potential use of BIM for building permits, for example, Olsson et al. [6], Kim et al. [7], and Ciotta et al. [8]. These studies have introduced different prototypes and frameworks for BIM-based building permit processes, but there has been relatively little research on how public regulatory authorities can successfully implement them.

Though a BIM-based building permit process offers potential advantages, BIM adoption itself is a complex phenomenon affected by many factors that may be considered from multiple (e.g., technological, organizational, external) perspectives. Investigating the factors affecting BIM adoption can play a vital role in designing a framework for successful adoption of BIM by organizations, and a number of studies have examined factors impacting BIM adoption in the AEC/FM industry generally [9–11]. There is, however, a lack of research to date that systematically investigates the factors that affect the BIM-based building permit process. To help fill this gap, this research is focused on examining the factors affecting BIM adoption by public authorities for their building permit process. This study investigates the case of the Tallinn City Government (TCG), a public organization responsible for building permits in Tallinn, the capital city of Estonia.

A literature review to describe the principal concepts of the BIM-based building permit process and factors affecting BIM adoption is reported in Section 2. The methodology used in this study is explained in Section 3, and followed by the case study description in Section 4. The findings of the study are reported in Section 5, and discussed in Section 6, before conclusions are drawn in Section 7.

## 2. Background

This section introduces the role of BIM in the building permit process, and factors that affect BIM adoption in the AEC/FM industry.

### *2.1. BIM and Building Permits*

BIM, as an innovative technology, has become very popular in both the construction industry and in academic research, particularly in the last decade, as it offers promising advantages and applications for construction activities. It is believed that BIM has changed the way construction projects are conceived, designed, constructed, and operated [12,13]. The concept of BIM as a comprehensive information database anchored to a digital model is central to BIM use in the building permit process.

Shahi et al. [4] categorized the development of building permit systems in a four-level framework. Level 0 represents the traditional permit process which is based on the submission of physically transmitted papers by applicants and their manual review in municipalities. Level 1 refers to basic e-permit systems, in which 2D drawings and other files are submitted in digital form (rather than paper documents) through a web interface, and then there is a manual review of those digital files by authorities. Level 2 refers to BIM use in the permit process. Instead of digital 2D drawings, a comprehensive BIM model of a facility can be submitted, and then automated code compliance checking takes place. Level 3 is described as the future of the permit process, with full integration of BIM and GIS into the building permit system, so that a building is not only analyzed as an individual object, but also evaluated in the context of its urban setting and its relationship with nearby buildings. The potential integration of geoinformation with BIM for the building permit process is investigated by Olsson et al. [6] and Noardo et al. [14].

In a typical BIM-based building permit process, as shown in Figure 1, the applicant submits building information models, usually created by the designer. Since BIM adoption among architecture firms is already quite considerable, this phase in the development of a BIM-based building permit system is not particularly challenging, although certain additional requirements and guidelines must be set for model submission to ensure the compatibility/correctness of the models for the building permit process. On the authority's side, the building model is then checked against laws and regulations through an automated code compliance checking approach in order to make a decision. If the design and other details in the digital building model satisfy the terms and conditions defined in laws and regulations, the building permit is granted. Automated code compliance checking requires translating the rules and regulations from their natural language to computer readable format. According to Olsson et al. [6] and Preidel and Borrmann [15] due to technical and legal constraints, this is one of the main difficulties in developing BIM-based building permit systems. Several studies, including those by Nawari and Alsaffar [16], Malsane et al. [17] and Lee et al. [18] have investigated the technical aspects of code compliance checking, presenting different methods (for example, artificial intelligence and mark-up language) to facilitate the translation of laws and regulations to machine-readable formats. In general, BIM-based building permit processes are considered to be efficient, user friendly, highly accurate, and achievable.

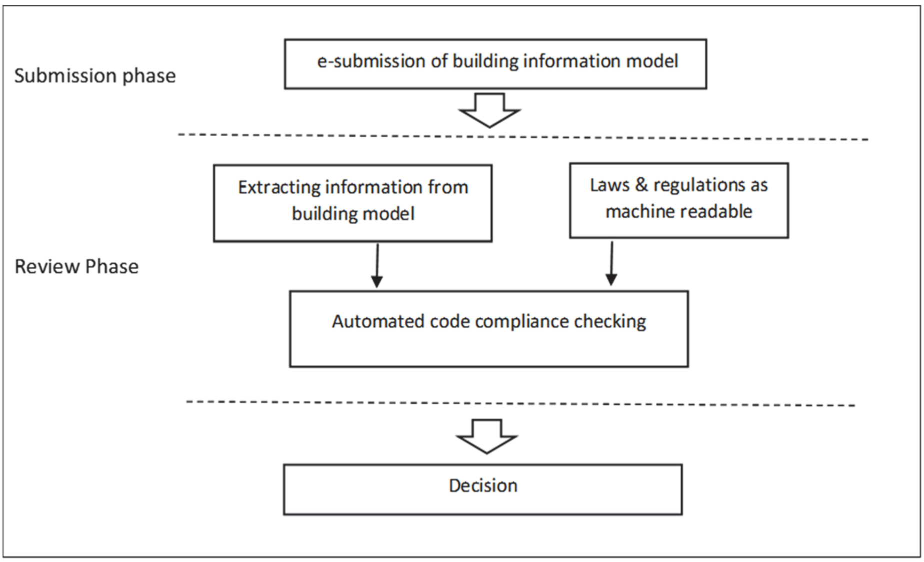


**Figure 1.** General conception of the BIM-based building permit process (adapted from Shahi et al. [4]).

Due to multiple potential advantages of BIM-based building permit processes over traditional procedures, various authors have recently made efforts to examine them. Guler and Yomralioglu [3] proposed a reformative framework focusing on the applications of digital building models, formulated in international standards, such as IFC, CityGML, etc., for issuing building permits in Turkey. Their proposed framework is also aimed at facilitating the process of property ownership through 3D registration. A study by Lee et al. [18] was focused on translating Korean building legislation into a machine-readable format through a rule-making method for its use in evaluating building permit requirements.

Park et al. [19] also focused on developing methods for translating laws and regulations for automated code compliance checking in Korea. Kim et al. [7] established a framework for a prototypal system called KBIM submission, which supports the submission of an IFC data model for the permit process. Choi and Kim [20] investigated an automated pre-checking system based on open BIM for the building administration process. Meanwhile, Narayanswamy et al. [21] presented a prototype for automated design checking of residential and small buildings based on BIM models for building permit issuance. Plazza et al. [22] investigated the potential applications of BIM implementation for building permits in public authorities.

Although digital solutions capable of accepting BIM models for building permit processes by regulatory authorities are not currently common, some public authorities and municipalities in different countries have either incorporated building information models into the permit process to some degree, or have undertaken pilot projects for the research and development of such systems. The CORENET e-Submission system of the Building and Construction Authority, Singapore is considered to be a pioneer of BIM e-submission for building permit applications. The CORENET e-Submission system is capable of accepting architectural, structural, mechanical, electrical, and plumbing (MEP) BIM models [23]. In Finland, based on the success of the KIRA-digi project, the building control department of Vantaa is also accepting BIM models in IFC format, and using Solibri Model Checker to perform checks [24]. Other countries, such as Norway, The Netherlands, Sweden, and Italy, also have projects supported by public authorities related to the use of BIM models for building permit processes [25].

### *2.2. Prevailing Research on Factors Affecting BIM Adoption*

Adopting BIM in any organization is a challenge [26], as BIM is not just software, but also involves people, information, and process [27]. As a sociotechnical system, various factors affect BIM adoption, and the identification and analysis of these factors are essential, as the outcomes of BIM utilization are a function of the quality of its adoption process.

The review of the literature on BIM-based building permit processes in Section 2.1 shows that attention is mostly given to investigating potential applications of BIM for building permits, developing and testing prototypes, approaches for translating rules and regulations into machine-readable forms, and the development of different conceptual frameworks for BIM-based building permit processes. However, research focused on studying the factors that affect BIM adoption in public organization for building permits is scarce.

Though research specifically focused on BIM-based building permits is limited, many studies have been performed in numerous countries on the factors affecting the BIM adoption process in the AEC/FM industry generally. These include studies carried out in Australia [28], China [10], Finland [29], Norway [30], Singapore [31], South Korea [32], United Kingdom [33], and USA [34]. In an earlier study [35], a systematic review and analysis of existing research on factors affecting BIM adoption in AEC/FM was carried out, which resulted in the identification of various influencing factors categorized using the Technology–Organization–Environment framework as shown in Table 1.

**Table 1.** Factors affecting BIM adoption in the AEC/FM industry, adapted from ref. [35].

| Factors Affecting BIM Adoption in AEC/FM Industry | |
|---|---|
| Technological factors | Complexity |
| | Relative advantage |
| | Compatibility |
| | Trialability |
| Organizational factors | Top management support |
| | Behavioural intention |
| | Training and learning |
| | Awareness |
| | Organizational culture |
| | Leadership |
| | Innovativeness |
| | Motivation |
| | Trust |
| Environmental factors | Client pressure |
| | Competitive pressure |
| | Partner pressure |

## 3. Methodology

As factors influencing BIM adoption in public organizations for the building permit process have scarcely been examined, an exploratory research design was adopted. According to Fellows and Liu [36], the main feature of exploratory research is the exploration of knowledge about processes for which limited information is available. A single case study strategy was used in this research, as it offers deeper understanding, and details the existence of a particular phenomenon [37]. The single case study strategy has been employed in various BIM-related studies, for example, Bråthen and Moum [38], Gledson [39] and Shibeika and Harty [40]. A case study investigates and offers rich information about a contemporary phenomenon in its real-world context, using data collection techniques, such as interviews, questionnaires, observations, document analysis, and others [41]. Case studies are useful, as they provide a unique way of problem solving [42], and gather meaningful descriptions about real-life events [38]. The case used in this study is the adoption of BIM by the Tallinn City Government (TCG) for their building permit process.

Previous studies [10,28,31,32] on factors impacting BIM adoption in AEC/FM industry predominantly used quantitative approaches through questionnaire surveys. In this study, a qualitative approach through semi-structured interviews was used to gather data. Semi-structured interviews do not limit the interviewees to strictly follow interview protocols, and they allow for additional questioning as required for further explanation or clarification [43]. To fulfil the aim of this study (i.e., examining the factors affecting BIM adoption by public authorities for building permits), interview questions were designed as open-ended questions, which allowed interviewees to openly express their opinions. The general concept of interview questions was derived from previous studies on BIM adoption in AEC/FM industry; however, questions were not directly based on the factors observed in the literature review in order to avoid restricting or leading the interviewees' responses. Rather, they were asked broad questions as follows:

- Describe the difficulties/challenges in adopting a BIM-based process for building permits, and how these challenges were dealt with/solved.
- Describe the factors which enabled the adoption of a BIM-based process for building permits.

The interviewees were selected through purposive sampling following desk-based research about their background information and involvement in the case, which allowed the selection of interviewees focusing on their particular experiences and perceptions. The interviewees were stakeholders from TCG, the Ministry of Economic Affairs and Communications (MoEAC), and from a software development organization. Initially, 15 interview invitations were sent out; however, only 7 people accepted the invitations and were subsequently interviewed. According to Farrell [44], the number of interviewees required for robust results is not a definite number; rather, it depends on the context and the research objective. Wilmot [45] suggests that, for a purposive, non-random sample, the selection criteria of interviewees is more important than the number of interviews. Considerable efforts were made to maximize the number of interviews; however, seven interviews were considered sufficient to achieve the aim of this research. This is also in line with the suggestions that the point of data saturation and establishing meaningful themes can be achieved with a minimum of six interviews [46,47]. The interviewee's profiles and years of experience in their occupations are shown in Table 2.

**Table 2.** Profile of interviewees.

| # | Interviewee Code | Role in the Organizations | Experience |
|---|---|---|---|
| 1 | Interviewee 1 | Head of Department | 16 years |
| 2 | Interviewee 2 | Analyst | 5 years |
| 3 | Interviewee 3 | BIM Manager | 8 years |
| 4 | Interviewee 4 | CEO | 23 years |
| 5 | Interviewee 5 | BIM Manager | 7 years |
| 6 | Interviewee 6 | Head of Division | 28 years |
| 7 | Interviewee 7 | Analyst | 12 years |

The interview invitations included information regarding the aim of the study, and all participants were assured that their anonymity would be maintained. The interviewees were given the option of face-to-face or online interviews, but all the interviews were carried out using the online platforms Skype, Microsoft Teams, and Google Meet. To increase the reliability of the collected data, and minimize errors, all interviews were audio recorded with the consent of every participant. Thematic analysis of the gathered data was carried out following the guidelines by Braun and Clarke [48]:

- Familiarization with the data: transcribing the interview data, reading multiple times, and noting initial ideas.
- Making initial codes: systematically selecting important and relevant text from the entire data set.
- Searching for themes: gathering codes into potential themes.
- Reviewing themes for refinement.
- Defining and naming themes.
- Reporting the results of thematic analysis.

The data gathered from seven interviews were transcribed manually. A thematic analysis of the transcribed data was carried out using NVivo software to identify factors affecting BIM adoption for the building permit process. In the thematic analysis of the gathered data, the transcripts were first thoroughly read to get familiar with them. The important phrases in the text were highlighted, and relevant or matched phrases were coded to identify themes related to the research aim. Figure 2 illustrates the methodological flow chart of the study.

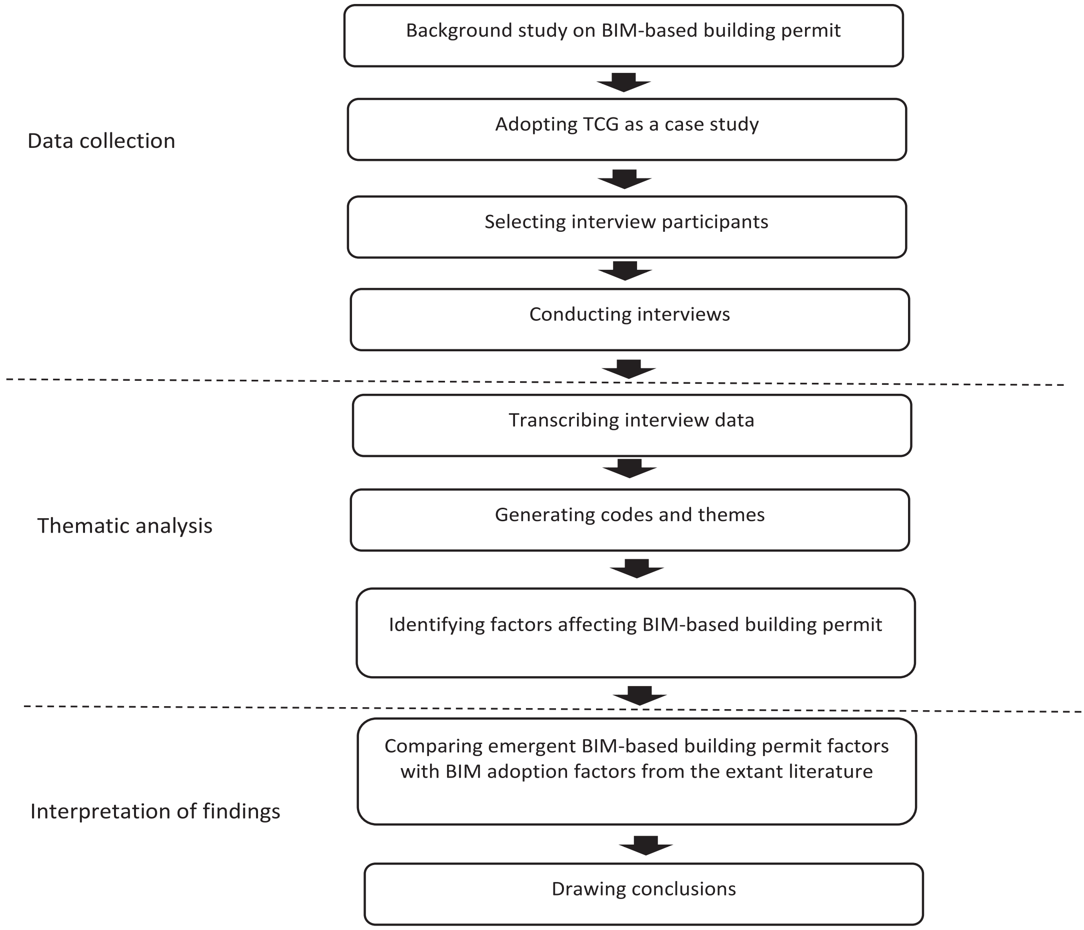


**Figure 2.** Methodological flow chart.

## 4. Case Study

The case studied here is the BIM-based building permit process of TCG. The planning department of TCG is responsible for issuing building permits, usage permits, and demolition permits. Before 2016, the building permit process was paper-based, and applications were submitted physically along with 2D drawings and other files for officials in the planning department to manually review. This was very time consuming and inefficient. From 2016, TCG has handled building permits through an online platform, the "Register of Buildings", which is managed by the Ministry of Economic Affairs and Communications (MoEAC), as the construction sector falls under the remit of the MoEAC. In the existing building permit process, the applicant submits digital 2D drawings and other pdf documents through the "Register of Buildings" platform electronically. These are then manually reviewed by city planning officials for compliance with codes, laws, and regulations. To make the building permit process more efficient, cost-saving, free of human errors, and transparent, the project "BIM-based process for building permits in Estonia" was initiated under a new e-construction platform vision in 2018. The BIM-based building permit process in the TCG project also belongs within this program. It is currently ongoing, and the roadmap for the BIM-based building permit process is shown in Figure 3.

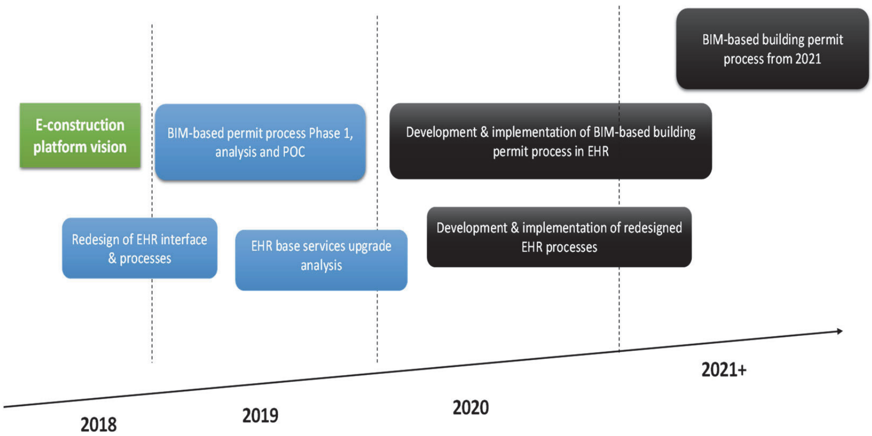


**Figure 3.** Roadmap for the BIM-based building permit process (source: Estonian Ministry of Economic Affairs and Communication).

The project is led by the MoEAC, as they "own" the Register of Buildings, which is used by all municipalities in Estonia for processing building permits. Thus, it is noteworthy to mention that the BIM-based building permit process will not be limited to TCG, but is also intended for all municipalities. However, TCG is the biggest municipality in the country, with high levels of construction activities, and it manages the most complex building permits. In 2020, the city planning department of TCG issued approximately 1149 building permits. TCG is the main partner with MoEAC in proof of concept, pilot projects, and training regarding the BIM-based building permit process. Hence, the BIM-based building permit process in TCG is considered as a case study in this paper. The chronological transition of the building permit process in TCG is shown in Figure 4.

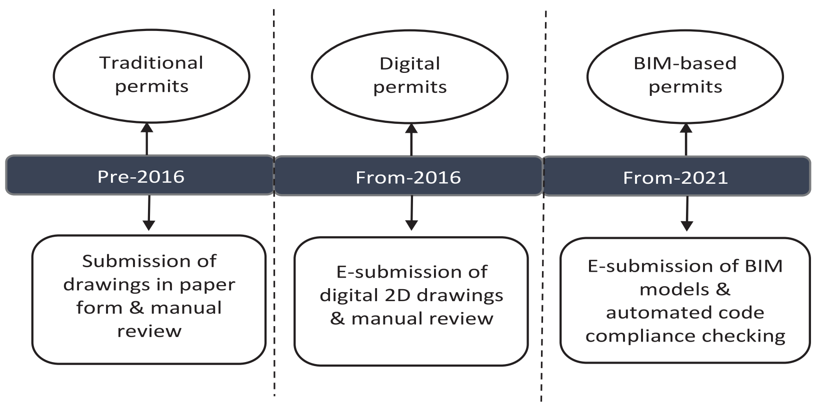


**Figure 4.** Building permit process transitions in the Tallinn City Government (TCG).

A proof of concept for the BIM-based building permit was developed by MoEAC with a private software firm. The proof of concept was intended to demonstrate the function of an automated BIM validation check. In the BIM-based building permit process, depending on the type of permit applied for, the applicant will upload a building information model in IFC format via the Register of Buildings platform. In the case of an invalid IFC dataset, the applicant will be notified to resubmit the BIM data in a valid format. The uploaded BIM data set will be saved to the server. The applicant can perform predefined checks depending on the type of permit to know in advance if the design meets the requirements, and then submit the application. The planning department receives the application, and automated BIM model checks are carried out. Based on the results, an official from the planning department then decides if the building permit application is to be approved or rejected. The workflow for the proof of concept is shown in Figure 5.

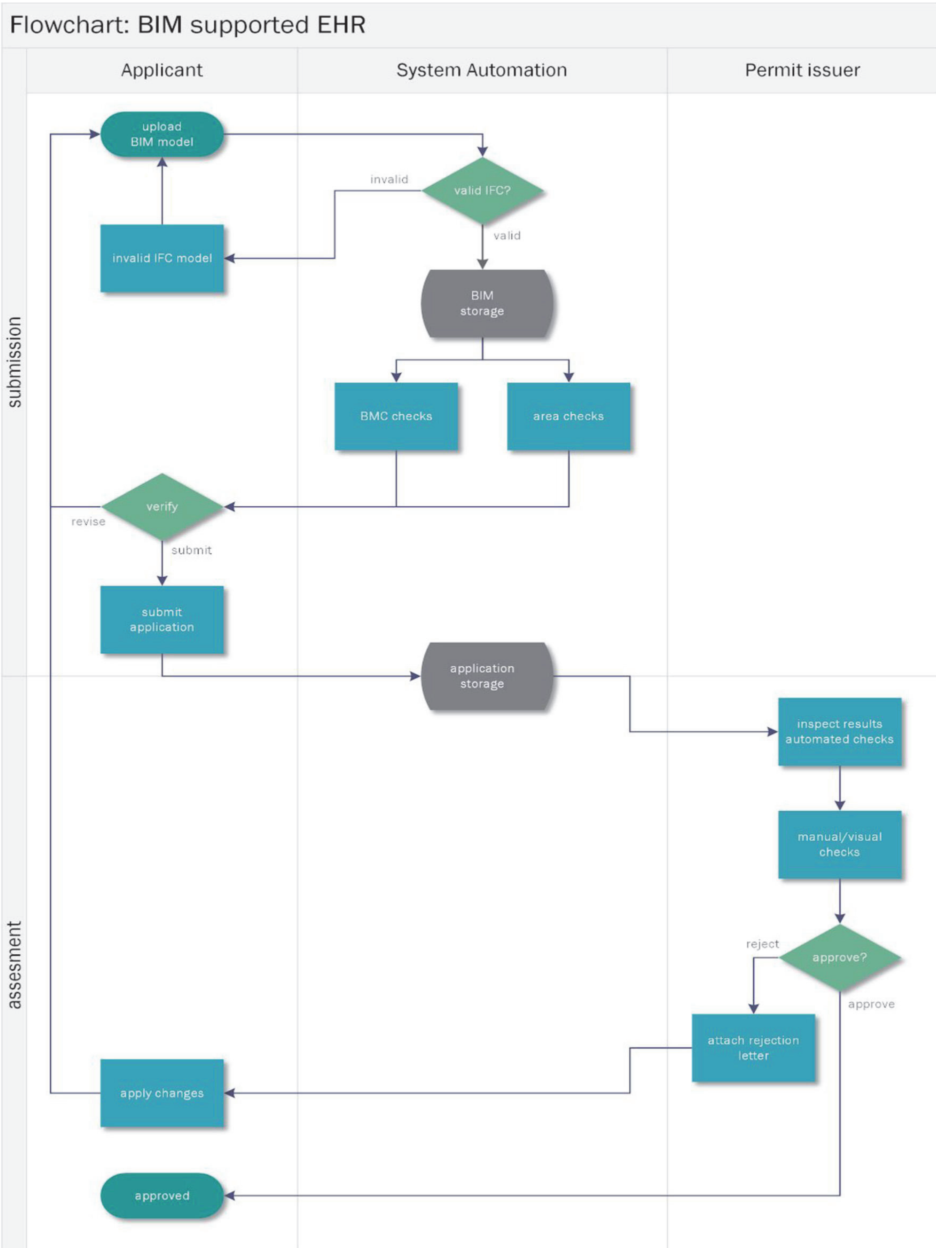


**Figure 5.** Proof of concept flowchart (source: Estonian Ministry of Economic Affairs and Communication (MoEAC), and Future Insight Group [49]).

The detailed BIM adoption process by the Tallinn City Government was analyzed in our initial study [35]. In this current study, the focus is to investigate the factors influencing BIM adoption for building permits.

## 5. Findings

The factors affecting adoption of a BIM-based building permit process were identified from the themes emerging in the data analysis related to the research aim. The prevalent responses from the interviewees in relation to emergent themes are summarized in Table 3.

**Table 3.** Summary of prevalent responses from thematic analysis.

| Themes | Nodes from Interviews | Number of Interviewees Referencing Nodes |
|---|---|---|
| Complexity (in both development and use) of BIM-based building permit systems | BIM-based building permit process is something new and different from BIM adoption in AEC organizations | 3 |
| | Translation of rules and regulations into machine-readable is a difficult task | 2 |
| | Little experience of employees in using BIM | 7 |
| Relative advantages/disadvantages of BIM for building permits | Stakeholders' perceptions of potential benefits act as enablers | 6 |
| The existing building permit system | Current e-permit system acts as motivation for further digitalization | 3 |
| Management support for BIM-based building permit process | Active involvement of management | 4 |
| Organizational culture | No resistance towards BIM adoption | 5 |
| | Learning new system might be difficult for some employees | 4 |
| BIM awareness | Aware of BIM potential benefits | 5 |
| Training and learning | Training and learning are key for BIM-based building permit process | 3 |
| Available expertise on a BIM-based process for building permit process | Very few experts | 6 |
| External pressure | No direct external pressure towards BIM adoption | 3 |
| | Existing few BIM-based permit processes in other countries acts as motivation | 2 |
| Legal context | Currently no legislation for BIM-based process for building permits | 3 |

### *5.1. Factors Affecting BIM Adoption for Building Permit Process*

#### 5.1.1. Complexity (In Both Development and Use) of BIM-Based Building Permit Systems

Five of the interviewees mentioned that one of the main factors affecting the BIM-based building permit process is the technical difficulty faced in developing the BIM-based building permit system. According to the interviewees, the BIM-based building permit process is something very new, and a desktop study was performed before developing proof of concept to look around the world for such systems to get ideas. Although a few municipalities use a BIM-based process for building permits up to some level, these were found too complex from the users' point of view. However, in the case of TCG, the focus was to keep the BIM-based building permit system user friendly, as mentioned by Interviewee 1:

*. . . The key for the BIM-based building permit process is that it has to be really simple, because on one side there are for example design firms having professionals dealing with BIM in their everyday work already but on other side in municipalities majority of the people dealing with building permit never used BIM as they just deal with 2D drawings.*

For developing a BIM-based building permit system capable of automated code compliance checking, the translation of the contents of codes and guidelines to a machine-readable language is one of the core tasks. On difficulties related to the translation of rules and regulations to a machine-readable form, Interviewee 4 mentioned that:

*. . . To make the auto checks the rules and regulations should be in machine-readable, some rules and regulations are not clear, it contains quite vague statements and occasional use of subjective expressions, making it difficult to convert them into machine-readable through programming.*

The complexity is not limited to the development phase, but also for the end users. In the municipality, there are people who have been working for a long time, and the majority are in the older age groups accustomed to the existing building permit system, so using a new system could be difficult for them, as mentioned by Interviewee 2:

*. . . . Learning the new system might be quite difficult and it cannot be developed as simple as like the current building registry, which is also not an easy thing to learn, when new people come, it actually takes a while to learn the current system.*

The accuracy of auto checks results depends on the correctness and availability of information in the submitted BIM model. Although many architectural firms are already using BIM, when it comes to a BIM-based building permit process, the models have to be presented in a highly standardized way, and must be saved in the required format with consequent interoperability issues. Currently, the MoEAC is developing BIM standards, initially for public clients, but these will later provide a form of general Estonian BIM standard. Interviewee 1 highlights this as:

*. . . . Another challenge is how to make sure that the BIM models that are uploaded to the system correspond to standards because the model needs to have certain elements and certain properties classified according to the standards.*

#### 5.1.2. Relative Advantages/Disadvantages of BIM for Building Permits

A BIM-based building permit process potentially offers various advantages, such as high efficiency, cost savings, time savings, high accuracy, and a transparent process. In the opinion of most of the interview participants, these potential advantages of BIM for building permits played a vital role in the decision to adopt it. According to the interviewees, the already established BIM applications in the AEC/FM industry in general, and the successful experiments on BIM-based model checking solutions from other countries, such as Norway, Netherlands, and Finland, were among the reasons to start efforts for leveraging BIM in the Estonian Register of Buildings for building permits. A selection of comments related to the relative advantages of a BIM-based building permit process by Interviewee 3 and Interviewee 1 are:

*. . . . The developed BIM-based building permit system gives the possibility to improve functionalities of municipalities particularity TCG, which deals with high number of permit applications comprised of complex buildings.*

*. . . . The BIM-based building permit process will not be limited to TCG, other municipalities in Estonia will also use it, so probably we are the first or among the first countries in the world implementing BIM for building permit at a national level.*

Interviewees argued that the Estonian construction sector productivity is currently low, and that low digitalization of the construction sector is one of the main reasons. The Estonian government aims to increase it by a factor of three by 2030 [50], partly through digitalization, as stated by Interviewee 6:

> . . . . *To increase construction productivity, e-construction platform vision has been started, and the BIM-based process for building permits is part of that bigger ambition.*

#### 5.1.3. The Existing Building Permit System

TCG has been using a basic e-permit system from 2016, so an element of digitalization on a small scale is already there. According to interviewees, the existing building permit system acted as an enabler towards a BIM-based building permit, as mentioned by Interviewee 1:

> . . . .. *We are somehow in good position as we have a digital building permit process already, which is mandatory, based on digital files such as pdf and signing the files through digital ID, so there is not a sudden shift from complete paper based to BIM-based built permit process.*

Interviewee 6 had a similar perception that if the transition was from a paper-based building permit procedure to a BIM-based permit process, TCG would have faced a lot more challenges both in terms of technology and people.

#### 5.1.4. Management Support for a BIM-Based Building Permit Process

According to the interviewees, one of the most important enablers in adopting BIM was the support from top management. Management support acts as a change agent in the BIM adoption process, as it also effects other drivers for BIM adoption i.e., providing resources, providing adequate BIM education, BIM awareness, and the selection of appropriate tools. Some of the interviews were carried out with top officials, and their commitment and support for BIM-based building permits was quite obvious. Comments by Interviewee 3 and Interviewee 5 highlighting management support are:

> . . . *there is huge role in transferring towards a BIM-based building permit process from the Ministry of Economic Affairs and Communication as well.*

> . . . *Management is motivating the employees towards BIM by explaining its benefits and trying to help them through organizing different training courses.*

#### 5.1.5. Organizational Culture

Organizational culture reflects the attitudes, values, norms, and behaviors of the organization members. When it comes to organizational culture regarding innovation adoption, some people show more interest based on its perceived usefulness and perceived ease of use compared to others. The participants of the interviews described the attitudes of people handling building permits as very positive towards BIM. A comment by Interviewee 3 reflecting end users' attitude towards a BIM-based building permit process is:

> . . . *The people working at TCG are welcoming BIM-based process for building permit. So far, I have not heard a single time if someone is saying, well this BIM-based building permit will be a waste of time or it will give us a lot of extra work, they are expecting it quite positively.*

Interviewee 2 highlighted the existing digital permit system's role in the positive attitudes of TCG employees towards BIM as:

> . . . *the current digital permit system saves time compared to traditional paper-based building permit, based on that TCG employees have already seen benefits of using technological tools, and now the BIM-based building permit capable of automatic checks will make the overall process highly efficient.*

Even though, in general, the organizational culture is positive towards BIM adoption, Interviewee 4 highted that:

> *...Some people are innovative so they will welcome such processes, while others accustomed with the already existing system might not be very enthusiastic, however, arranging training programmes is key to such issues.*

#### 5.1.6. BIM Awareness

Regarding familiarity of municipality employees with BIM utilization for building permits, Interviewee 1 commented that:

> *. . . BIM-based building permit process is different from BIM use in other organizations for example, design firms as they have professionals using BIM as a tool for their work but people working in the municipalities checking building permits, majority of them have not used BIM because it was always 2D drawings required for building permit.*

Interviewee 3 mentioned that, in the beginning, basic BIM training was given to TCG employees to create BIM awareness, and highlight its potential applications in the building permit process.

#### 5.1.7. Training and Learning for BIM-Based Building Permit Process

BIM, as an emerging technology, requires specialized learning and training for its utilization. There were comments regarding training and learning in almost all interviews, which shows their importance for BIM-based building permit processes. Regarding the significance of BIM training, Interviewee 5 stated that:

> *. . . . Once we have the knowledge and experience of BIM, then using BIM for building permits is not complex. However, it is also understandable that analysts at municipality are accustomed to existing system, so transfer to a BIM-based building permit process would require time for them.*

According to Interviewee 3, three types of BIM training have been provided so far to TCG employees working in the departments related to building permits. First, was basic BIM training: its purpose was to create BIM awareness, and explain its applications. The basic training was followed by advanced training. There was also BIM model checking training using Solibri model checker software. Solibri model checker was selected as, during that time, the system which is to be used by TCG was in the proof-of-concept phase, and the purpose of the Solibri model checker training was to demonstrate automated checking and the efficiency of such systems.

The interview participants highlighted that, for training and learning, the focus is not only on the TCG employees who are handling building permits, but also on training the applicants. A comment by Interviewee 1 relating to this is:

> *. . . In regard to requirements for BIM model submission, we do not want to set requirements something entirely new as there are companies already using BIM, so our base line is the already existing best practise for BIM models creation, further there will be templates for BIM submission, guidelines for BIM submission, and tutorial videos to assist the applicants.*

Though training and learning have highly positive impacts on BIM implementation, one of the issues with training and learning highlighted by Interviewee 2 was the age factor:

> *. . . .. The municipality is shattered in many departments and a lot of employees are physically old, already used to with the existing system, might not be interested to learn new technological things.*

#### 5.1.8. Lack of Experts on BIM-Based Building Permit Process

One of the challenges highlighted by the interviewees is that currently, in the municipalities, the number of people with BIM expertise or knowledge is quite small. Interviewees suggested that the existing building permit system could be a reason for this, as it is based on 2D drawings and manual checking, as stated by Interviewee 2:

> *...Regarding the BIM tools knowledge, for example in my department very few people are familiar with Solibri model check concept.*

The same interviewee mentioned that establishing new positions, such as BIM coordinator, and providing BIM knowledge to the existing employees are key to dealing with this issue.

#### 5.1.9. External Pressure

External pressure, such as government mandate, client pressure, and competitive pressure, influences BIM adoption decisions. In the case of TCG, there were no such direct pressures for BIM adoption; however, interviewees highlighted the motivation coming from some external sources. Interviewee 3 and Interviewee 1 comments related to this are:

> *. . . there are already many companies using BIM in their work process but when it comes to building permit, they require to submit 2D drawing and other information in pdf file costing them extra work, the overall process will be more productive if TCG starts to accept BIM datasets for building permit.*

> *...Earlier experiments and examples of BIM-based model checking solutions in Finland, Norway, Netherland and CORENET in Singapore indicated that a BIM-based building permit can be faster and cheaper than manual procedures.*

#### 5.1.10. Legal Context

There are always essential laws and regulations regarding building permit procedures. Though the BIM-based building permit is in the implementation phase, some possible legal obstacles were noted by Interviewee 1:

> *...There might be some legal questions as well but currently we are not making it mandatory, but as we go issues might occur and we have to solve them.*

Interviewee 5 also mentioned that:

> *...the current law is not saying anything about BIM-based building permit process, but we have to focus on that side as well.*

## 6. Discussion

The analysis of the interview data indicated the stakeholders' perceptions regarding factors influencing BIM adoption for building permits. In total, ten factors were identified from the analysis of the interview data. Using the Technology–Organization–Environment framework [51], factors from the findings are categorized into three groups: technology, organization, and environmental factors, as shown in Table 4.

**Table 4.** Factors affecting BIM adoption for the building permit process.

| **Factors Affecting BIM Adoption for the Building Permit Process** | |
|---|---|
| Technological factors | Complexity in developing and using BIM-based building permit system |
| | Relative advantages/disadvantages of BIM for building permits |
| | Existing building permit system |
| Organizational factors | Management support for BIM-based building permit process |
| | Organizational culture |
| | BIM awareness |
| | Training and learning for BIM-based building permit process |
| | Lack of experts on BIM-based building permit process |
| Environmental factors | External pressure |
| | Legal Context |

The findings reflect that adopting BIM in municipalities is different and relatively challenging in terms of technology (software) and users' experiences compared to BIM adoption in general AEC/FM organizations. In the technical context, in the case of AEC/FM organizations, the BIM tools are already there. For example, if an architecture firm decides to adopt BIM, multiple BIM software applications, such as Autodesk Revit, ArchiCAD, etc., are available to create model-based designs. This can also be observed in previous studies investigating factors affecting BIM adoption in the AEC/FM industry, e.g., Ma et al. [10] and Qin et al. [11], which highlight that the lack of BIM tools is not a major barrier or a commonly reported challenge. However, when municipalities decide to adopt BIM, the system which is capable of automatically checking submitted BIM models against set rules and regulations needs to be developed, as each country has their own rules and regulations. Sometimes, the rules and regulations also vary from municipality to municipality within the same country. In the current case study, initial challenges observed relate to developing their own system, which should be web-based, have a simple user interface, support open standards, and be based on the Estonian BIM standard. The issue of the lack of suitable software is also associated with GeoBIM integration for building permits, as highlighted in the study of Noardo et al. [14].

The high cost associated with software is often a barrier to BIM adoption [52]; however, the current study did not capture any financial difficulty faced by TCG towards adopting a BIM-based building permit process. The main reason for this appears to be that the technology for the BIM-based building permit process is provided by MoEAC, indicating that government support can play a key role in enabling a BIM-based building permit process in municipalities.

Previous studies on factors affecting BIM adoption reported complexity relating to the difficulty in using BIM tools as one of the main factors, for example, in the studies by Ahuja [53], and Gledson and Greenwood [33]. This can also be observed in the findings of the current case study. However, in order to minimize the complexity of this BIM-based building permit system, the developed proof of concept is web-based, with an easy-to-use interface, and is capable of automated checks according to respondents.

The findings of this study show that one of the most important enablers for adopting BIM for building permits is stakeholders' perceptions of the potential advantages associated with BIM technology. Relative advantages not only affect the decisions of top management to adopt BIM, but also act as motivators for the employees of the organization. As reported in the literature, for example, by Hong et al. [28], benefits associated with the implementation of BIM are a significant motivational factor.

The already existing norms and practices were found vital for successful BIM implementation, and the participants indicated that TCG is in a relatively good position due to the current capacity of the Register of Buildings to accept digital files. The role of the existing basic e-permit system (Level 1 in the framework of Shahi et al. [4]) in TCG's efforts towards a BIM-based building permit process shows that a step-by-step approach can be adopted, particularly in the municipalities of developing countries that may face greater financial difficulties.

A top-down approach was observed in the current case study: a decision from top management to adopt BIM, and then their direct involvement in the development phase of the system, and training of the employees. This shows the significance of top management support as a major driver in adopting BIM, which has also been highlighted in previous studies [31,53].

Challenges related to the lack of BIM experts were observed: for example, the interview participants stated that, currently, only a very small number of people working in TCG have a background of using BIM. Creating new positions related to BIM in TCG, and, in addition, training and learning programs are already underway to address this issue. It was observed that the purpose of training courses was not only related to skills development, but also created BIM awareness, and changed cultural resistance to BIM. This aligns with the studies of Liao and Teo [31] and Ma et al. [10] that emphasize the role of training and learning for successful BIM implementation.

As noted earlier, BIM adoption in municipalities differs compared to other organizations, and this is evident in the environmental factors that influence BIM adoption. In AEC/FM organizations, pressure from clients can play a vital role in decisions to adopt BIM. In addition, as it has become evident that BIM offers a better way of working, many large companies have already adopted BIM, and this forces others (competitors, as well as subcontracting and supplier organizations) to adopt BIM in order to maintain their market positions. In the case of TCG, there are no such external competitors imposing significant pressure to adopt a BIM-based building permit process. Though the interviewees did not reveal much information regarding legal obstacles, according to Shahi et al. [4], attention should be given to legal concerns, for example, in relation to the confidentiality and security of designs.

This research and other studies on BIM-based building permit processes show that BIM implementation is occurring in government agencies and municipalities, but BIM adoption by municipalities is particularly difficult, and comes with many challenges. However, as shown by the examples of successful BIM-based building permit processes by the Building and Construction Authority in Singapore; City of Vantaa, Finland; and various experiments in Nordic countries, municipalities facing inefficiencies in building permits should consider the potential benefits of a BIM-based permit process.

In comparison with previous studies which have mainly focused on prototypes/solutions for BIM-based building permit processes, translations of rules and regulations into machine-readable formats, etc., thus providing a technical perspective, the main contribution of this paper lies in its investigation of the BIM-based building permit process from an organizational perspective. The study reveals that adopting BIM for the building permit process in municipalities or public regulatory organizations is challenging, but management support, benefits associated with the BIM-based building permit system, early involvement of municipality employees through training programs, and BIM awareness can all act as catalysts towards successful BIM-based building permit process implementation. The single case study, qualitative approach employed has enabled the in-depth understanding of the phenomenon under investigation (BIM adoption for building permit processing) through the insights of interviewees who have considered this single (TCG) instantiation of the phenomenon from their own (unique) standpoints. This has unveiled a rich, multifaceted view of the organizational context, which is valuable in furthering our understanding in this relatively new area of research.

However, since this research is based on a single case study, which, on the one hand, allows greater depth than a comparative analysis of multiple case studies that would need to account for the (organizational) differences between cases, it may also limit the generalizability of its findings to other municipalities and countries. In addition, the number of interviews (7) was relatively low. Though a larger number of interviewees was initially anticipated, and may have revealed additional, specific insights, the authors are confident that the findings, in terms of nodes, themes, and factors, are robust and are unlikely to have been significantly affected by further interviews.

Whereas other existing studies on BIM adoption factors in the AEC/FM industry have mostly employed quantitative methods, this investigation has used a qualitative approach to enable an understanding of stakeholders' perceptions of the context of TCG's BIM-based process for building permits, and led to the derivation of a list of factors that affect it. Such an exploratory study reveals little about the relative importance or statistical analysis of each factor, and future studies will investigate this using quantitative or mixed method approaches to reveal more detailed information. Moreover, future studies are encouraged to help mitigate the challenges associated with BIM-based building permit processes, for example, through multiple criteria assessments, and the development of decision support systems for BIM-based building permit processes. In addition, the findings of this study can be used in future research with larger sample sizes focused on determining the critical success factors and strategies for effective implementation of BIM-based building permit procedures.

## 7. Conclusions

Recently, BIM has gained growing interest from public organizations, such as municipalities, for integrating BIM into their building permit procedures due to the potential benefits, i.e., faster, cheaper, more transparent, and easier tracking than manual processing. However, the implementation of a BIM-based building permit process is challenging due to various factors. This paper identified factors affecting BIM adoption for building permits through a case study. The responses from seven interviewees resulted in the identification of 10 factors affecting BIM adoption for building permit processes:

- Complexity (in both development and use) of BIM-based building permit systems;
- Relative advantages/disadvantages of BIM for building permits;
- The existing building permit system;
- Management support for a BIM-based building permit process;
- Organizational culture;
- BIM awareness;
- Training and learning;
- Available expertise on BIM-based building permit processes;
- External pressure;
- Legal context.

Some of the identified factors were found to be similar to factors affecting BIM adoption (generally) in the AEC/FM industry, whereas others were specific to the building permit process. Using the Technology–Environment–Organization framework, the identified factors were categorized into three groups. Factors such as the relative advantage of BIM, BIM training, and management support were found to be enablers of a BIM-based building permit process. Particular challenges were revealed in terms of the technical development of a BIM-based building permit process. The study found that special attention should be given to the development phase of systems for BIM-based building permit processes in order to decrease the effects of complexity of technology on end users. The findings of this study are expected to contribute to the small, but growing, body of research on BIM-based processing of building permits. The results are important for public authorities' understanding of both the enablers and challenges of BIM-based building permit processes, and have practical implications for professionals in public authorities in particular, and also in the AEC/FM industry in general, to guide their steps in adopting BIM.

**Author Contributions:** Conceptualization, K.U., E.W. and I.L.; methodology, K.U. and E.W.; investigation, K.U.; software, K.U.; formal analysis, K.U.; validation, E.W.; writing—original draft preparation, K.U.; writing—review and editing, E.W. and I.L.; supervision, I.L. and E.W.; project administration, I.L.; funding acquisition, E.W. and I.L. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was supported by the BIM-enabled Learning Environment for Digital Construction (BENEDICT) project (grant number: 2020-1-EE01-KA203-077993), Minimizing the influence of coronavirus in a built environment (MICROBE) project (grant number: 2020-1-LT01-KA203-078100), Strengthening University-Enterprise Collaboration for Resilient Communities in Asia (SECRA) project (grant number: 619022-EPP-1-2020-1-SE-EPPKA2-CBHE-JP) and the Integrating Education with Consumer Behaviour relevant to Energy Efficiency and Climate Change at the Universities of Russia, Sri Lanka, and Bangladesh (BECK) project (grant number: 598746-EPP-1-2018-1-LT-EPPKA2- CBHE-JP) all co-funded by the Erasmus+ Programme of the European Union. The European Commission support to produce this publication does not constitute an endorsement of the contents which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Conflicts of Interest:** The authors declare no conflict of interest.

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**Publication IV**

Ullah, K., Witt, E., Lill, I., Banaitienė, N., & Statulevičius, M. (2022). Readiness Assessment for BIM-Based Building Permit Processes using Fuzzy-COPRAS. *Journal of Civil Engineering and Management*. (**Journal paper: ETIS classification 1.1**)

Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2022 Volume 28 Issue 8: 620–633
https://doi.org/10.3846/jcem.2022.17274

# READINESS ASSESSMENT FOR BIM-BASED BUILDING PERMIT PROCESSES USING FUZZY-COPRAS

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Received 6 May 2022; accepted 27 June 2022

**Abstract.** With the recent technological advancement in the Architecture, Engineering, and Construction (AEC) industry, building control authorities in a number of countries are trying to integrate BIM into their building permit processes. Nevertheless, considering the involvement of multiple stakeholders and contexts, adopting BIM in any organization is challenging. The aim of this research is to assess readiness for BIM-based building permit processes using Fuzzy-COPRAS, a multiple criteria decision making (MCDM) method. In this research, three municipalities were selected as alternatives and twenty-five criteria (categorized into technology, people, process, and policies) related to BIM-based building permit processes were identified from a literature review. Then, as part of the COPRAS method, the weights of the criteria were determined based on their importance level through expert evaluation. The results of the study revealed the most important criteria for BIM-based building permit processes, i.e., supporting open standards, compatibility with existing building regulations and codes, willingness of employees, support from top management, and comprehensiveness of code compliance checks. Finally, the readiness assessment results demonstrated the most prepared alternative in the selected municipalities for the BIM-based building permit process based on the status of the considered criteria. The findings of this research have practical implications for municipalities considering and/or developing their BIM-based building permit processes in terms of where to focus their efforts with respect to the criteria associated with BIM-based building permits.

**Keywords:** building information modelling, building permits, e-permitting system, municipalities, readiness, fuzzy, MCDM, COPRAS.

## Introduction

A building permit is an official document which grants permission to construct a building once the design compliance with local building rules and regulations has been confirmed, and it is usually issued by a building control authority. In many countries, the building permit process is still based on a traditional approach which involves paper-based submission of applications including 2D drawings and a manual review of drawings by the local authority/municipality (Olsson et al., 2018). Traditional building permit procedures are considered to be laborious, subjective, prone to errors, time-consuming, costly, and unpredictable (Fauth & Soibelman, 2022; Malsane et al., 2015). In the last decade, municipalities have undergone a transition towards digital approaches in building permitting commonly referred to as "e-permitting systems" which enable the online submission of applications along with 2D drawings and other required documents in digital files. However, manual checks of 2D drawings are still carried out in the municipalities, thus the process remains time-consuming, and error prone (Shahi et al., 2019). In recent years, municipalities are incorporating the use of Building Information Modelling (BIM) in building permit processes in order to overcome these issues (Shahi et al., 2019; Noardo et al., 2020). BIM is "a digital representation of physical and functional characteristics of a facility, serving as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onwards" (American Institute of Architects, 2007). In the BIM-based building permit processes, the applicant submits an inclusive model

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of the proposed facility instead of 2D drawings, and then the submitted data can be reviewed automatically for code compliance in the municipality to generate reports and grant decisions (Shahi et al., 2019). BIM-based building permit processes are considered to be more efficient, transparent, and accurate compared to existing building permit procedures (Olsson et al., 2018). Though it is believed that BIM can be potentially utilized in building permitting, it is important to note that the adoption of BIM for a building permit processes is a complex task as, apart from the technology, BIM involves people, information, and process (Oesterreich & Teuberg, 2019). Further, the outcomes of the potential applications of BIM are dependent on the quality of its adoption process (Gurevich et al., 2017).

In recent years, municipalities in Singapore, Norway, Finland, Netherlands, Sweden, Estonia, Dubai (United Arab Emirates) etc., have been using (up to some level)/piloting/engaged with research related to BIM utilization in their building permit processes. Moreover, the potential benefits of BIM for building permits have also attracted academic researchers and many studies (Lee et al., 2016; Ciotta et al., 2021; Noardo et al., 2020, etc.) have been carried out mostly focused on the technical perspective, i.e., translations of laws into machine readable, code checking, etc. There is, however, a lack of studies on readiness assessment for BIM-based building permit processes in municipalities.

For effective implementation of BIM, organizational and industry readiness are critical (Juan et al., 2017). According to Holt et al. (2007) "Readiness collectively reflects the extent to which an individual or individuals cognitively and emotionally inclined to accept, embrace, and adopt a particular plan to purposefully alter the status quo". Liao et al. (2020) defined BIM implementation readiness of a project team as "the willingness or the state of being prepared for performing BIM implementation activities". Succar and Kassem (2015) defined "readiness" as "the level of preparation, the potential to participate or the capacity to innovate". In describing the BIM implementation concept, Succar and Kassem (2015) defined "BIM readiness" as the pre-implantation status indicating the tendency of an organization or organizational unit to adopt BIM technology, and "BIM capability" as the willful implementation of BIM tools, workflows, and protocols that is considered as the minimum ability of an organization or team to provide a measurable outcome. Based on the aforementioned readiness definitions, in this research BIM-based building permit process readiness is defined as: the state of an organization being prepared for using BIM in building permitting in terms of technology, people, process and policies. Thus, there is a significant need for readiness assessment of BIM-based building permit processes in municipalities and the aim of this paper is to do this.

In contrast to the scarcity of research on readiness assessment of BIM-based building permit processes in municipalities, there are many studies using different assessment models concerning BIM implementation in the AEC/FM industry generally such as BIM implementation readiness (BIMIR) (Liao et al., 2020), BIM maturity index (BIMMI) (Succar, 2009), BIMScore (BIMScore, 2013), and BIM quick scan (Sebastian & van Berlo, 2010). However, the application of these models to assessing BIM utilization in municipalities is limited as the BIM-based building permit processes in municipalities are primarily in their initial stages (e.g., pilot projects or currently in the process of adopting BIM for building permits) while the majority of these models are aimed to measure maturity levels. This study uses Complex Proportional Assessment (COPRAS), an MCDM method under fuzzy environment (Fuzzy-COPRAS) for readiness assessment. The COPRAS method is developed by Zavadskas et al. (1994) for determining the priority and the utility degree of alternatives. The COPRAS method considers the direct and proportional dependency of alternatives on the effect of values and weights of the criteria. In the current research, readiness assessment is carried out by taking the cases of City of Vantaa (Finland), Tallinn City Government (Estonia), and Dubai Municipality (United Arab Emirates). The readiness is measured in terms of technology, people, process, and policies.

The remaining sections of the paper are organized as follows: the methodology explaining criteria, alternatives and the COPRAS method under fuzzy environment is in the next section, which is followed by the results where criteria weights and readiness assessment results are presented. The results are then discussed before the research is summarized and conclusions are drawn.

## 1. Methodology

In this study, Fuzzy-COPRAS is used for readiness assessment of BIM-based building permit processes in selected municipalities. COPRAS is an MCDM method for establishing the priority and the utility degree of alternatives based on criteria weights and criteria rating with respect to alternatives. There are many MCDM methods such as Analytical Hierarchy Process (AHP), Evaluations of Mixed Data (EVAMIX), Analytical Network Process (ANP), Simple Additive Weighting Method (SAW), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), etc. However, according to Chatterjee et al. (2011), COPRAS is relatively simple and requires less calculation with very good transparency. In Fuzzy-COPRAS (Zavadskas & Antucheviciene, 2007), the weights of criteria and alternatives' criteria rating are stated in intervals. As the COPRAS method is about alternatives and criteria, firstly we describe the alternatives and criteria considered in this study, followed by the steps of the COPRAS method under fuzzy environment.

### 1.1. Describing alternatives and criteria

Recently, building control organizations in some countries have started initiatives regarding integrating BIM into their building permit processes. Based on access to the available data, this study selected three cases of BIM-based building permit processes as alternatives for readiness assessment, i.e., Dubai Municipality (Case 1), Tallinn City Government (Case 2), and City of Vantaa (Case 3).

*Dubai Municipality*, one of the major government organizations in the United Arab Emirates (UAE), established a committee for development in building permit procedures in 2017 and, in order to incorporate BIM in building permits, an E-checking BIM pilot project was initiated in 2019, and, in 2021, BIM e-submission service phase 1 (https://bim.geodubai.ae/) was launched (Ismail & Hamoud, 2021). With the Dubai Municipality BIM e-submission platform, it is aimed that the applicant will submit IFC models, and a permit engineer will carry out automated code compliance checking to grant the decision.

*Tallinn City Government* has been using an e-permitting system since 2016, through "Ehitisregister" (EHR)/ Register of Buildings which is an online platform: https://livekluster.ehr.ee/ui/ehr/v1/ that is owned and maintained by the Estonian Ministry of Economic Affairs and Communications (MoEAC). In 2018, MoEAC initiated a project "Introducing a BIM-based process for building permit for Estonia" (Estonian Ministry of Economic Affairs and Communication, 2020). The ongoing project is aimed so that a building permit applicant will upload BIM files through a web-based solution, an extension to the "Ehitisregister" while analysts in municipalities can automatically check code compliance of the submitted BIM files and grant decisions based on the results of these checks. This project will enable a BIM-based building permit process in Tallinn City Government along with other municipalities in the country (Ullah et al., 2022).

*City of Vantaa* started its e-permitting system called "Lupapiste" in 2014 and grants about 1500 permits per year (Virkamäki & Masjagutova, 2020). Based on the successful KIRI-digi project "BIMs in building control inspections" the building control department of City of Vantaa introduced a building permit process based on IFC model checking. In the process, an extension is added to https://www.lupapiste.fi/ which enables the submission of BIM files in IFC format and description of the BIM model in pdf format by the applicant. The building control officials use Solibri Model Checker for compliance checking (rule-based checking) in addition to visual examination.

To assess the readiness for BIM-based building permit processes, the main criteria are divided into four categories i.e., Technology, People, Process and Policies. As for BIM adoption in addition to technology itself, people, process and polices are considered as important contexts (Lee & Borrmann, 2020). These main criteria consist of further sub-criteria which are adapted from an earlier study (Ullah et al., 2022), a literature review of BIM implementation readiness, studies related to BIM-based building permit processes and MCDM studies related to innovate technologies. In total, 25 criteria were established to assess readiness for BIM-based building permit processes as listed in Table 1.

### 1.2. COPRAS

The steps of COPRAS method are summarized in the following stages (Zavadskas et al., 1994).

**Step 1.** Establish alternatives (in the current study, alternatives are the three municipalities dealing with BIM-based building processes) and criteria. Constructing an initial decision matrix as:

$$D = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}, \quad (1)$$

where $m$ – number of criteria, and $n$ – number of alternatives.

**Step 2.** Determining the weights ($q_i$) of criteria. The values of criteria weights $q_i$ are usually determined by the method of expert assessment, expressing the importance of criteria in relation to alternatives and are calculated with Eqn (2). The sum of criteria weights is always equal to 1.

$$q_i = \frac{S_i}{\sum_{i=1}^{m} S_i}, \quad S_i = 1, \dots, m, \quad (2)$$

where $Si$ is the sum of scores of the $i^{\text{th}}$ criterion by experts.

**Step 3.** Constructing the weighted normalized decision matrix $\hat{d}_{ij}$ using Eqn (2). The aim of this step is to get dimensionless weighted values of the criteria. All criteria, organically having different values can be compared once their dimensionless values are established.

$$\hat{d}_{ij} = \frac{x_{ij} \cdot q_i}{\sum_{i=1}^{n} x_{ij}}, \quad i = 1, 2, \dots, m, j = 1, \dots, n, \quad (3)$$

where $x_{ij}$ is the value of the $i^{\text{th}}$ criterion in the $j^{\text{th}}$ alternative, $q_i$ is weight of the $i^{\text{th}}$ criterion, $m$ is the number of criteria and $n$ is the number of compared alternatives.

**Step 4.** Calculating the sums of weighted normalized criteria describing the $j^{\text{th}}$ alternative. It is required to separate the maximizing criteria $S_{+j}$ and minimizing criteria $S_{-j}$. The sums are calculated using the following equations:

$$S_{+j} = \sum_{i=1}^{m} \hat{d}_{+ij}; \quad (4)$$

$$S_{-j} = \sum_{i=1}^{m} \hat{d}_{-ij}, \; i = 1, \dots, m, j = 1, \dots, n. \quad (5)$$

With greater value of $S_{+j}$ and lower value of $S_{-j}$, the more satisfied are the interested parties. The sum of "pluses" $S_{+j}$ and "minuses" $S_{-j}$ of all alternatives are always respectively equal to sums of significance of maximized and minimized criteria.

$$S_{+} = \sum_{j=1}^{n} s_{+j} = \sum_{i=1}^{m} \sum_{j=1}^{n} \hat{d}_{+ij}; \quad (6)$$

$$S_{-} = \sum_{j=1}^{n} s_{-j} = \sum_{i=1}^{m} \sum_{j=1}^{n} \hat{d}_{-ij}, \; i = 1, \dots, m, j = 1, \dots, n. \quad (7)$$

The results of calculations can be additionally checked in this way.

Table 1. Criteria for readiness assessment for BIM-based building permit processes

| Category | Criteria | References |
|---|---|---|
| Technology | C1: Simplicity of use (of the BIM-based building permit system) | Noardo et al. (2020), Plazza et al. (2019) |
| | C2: Compatibility with existing building regulations and codes | ByggNett (2013), Noardo et al. (2020) |
| | C3: Integration and interoperability with relevant systems and databases | Shahi et al. (2019), Kim et al. (2020) |
| | C4: Maintainability | ByggNett (2013) |
| | C5: Supporting open standards | Kim et al. (2020), Hjelseth (2015) |
| | C6: Cost (all costs e.g., capital, running, etc.) | Shahi et al. (2019) |
| | C7: BIM implementation in the local construction industry | Ullah et al. (2022), Hjelseth (2015) |
| People | C8: Top management support for the BIM-based building permit process | Shahi et al. (2019), Redacted Citation |
| | C9: Availability of employees with BIM skills | Ullah et al. (2022), Noardo et al. (2020) |
| | C10: Qualifications of the professionals dealing with building permit applications | World Bank (2020) |
| | C11: Availability of training programmes | Ullah et al. (2022), Guler and Yomralioglu (2021) |
| | C12: Willingness of employees to use a BIM-based building permit process | Ullah et al. (2022), Hjelseth (2015) |
| | C13: Building permit applicants' interest in using a BIM-based building permit process | Ullah et al. (2022) |
| Process | C14: Comprehensiveness of code compliance checks (number and types of checks, system ability to expand with new checks) | Hjelseth (2015), Noardo et al. (2020) |
| | C15: System allows pre-submission checks of BIM models by applicants | Ullah et al. (2022), Kim et al. (2020) |
| | C16: Efficiency of existing/previous (not BIM-based) building permit process | World Bank (2020) |
| | C17: Potential time saving | Shahi et al. (2019), Hjelseth (2015) |
| | C18: Potential cost saving | Shahi et al. (2019), Noardo et al. (2020) |
| Policies | C19: Level of information standardization (BIM standards, BIM protocol, classification systems, etc.) | Noardo et al. (2020) |
| | C20: BIM model submission guidelines for the BIM-based building permit process | Kim et al. (2020), Guler and Yomralioglu (2021) |
| | C21: BIM mandate in the local construction Industry | Shahi et al. (2019), Hjelseth (2015) |
| | C22: Support by government | Hjelseth (2015), Kim et al. (2020) |
| | C23: Clarity and easy access to building laws, regulations & building permit requirements | World Bank (2020), Noardo et al. (2020) |
| | C24: e-governance | Bellos et al. (2015), Guler and Yomralioglu (2021) |
| | C25: Legal framework for BIM-based building permit process | Hjelseth (2015), Shahi et al., 2019 |

**Step 5.** The relative significance $Q_j$ of each alternative is determined on the basis of "pluses" $S_{+j}$ and "minuses" $S_{-j}$ characteristics of the alternatives. Relative significance $Q_j$ of each alternative is determined using the equation:

$$Q_j = S_{+j} + \frac{s_{-\min} \cdot \sum_{j=1}^{n} S_{-j}}{s_{-j} \cdot \sum_{j=1}^{n} \left( \frac{s_{-\min}}{s_{-j}} \right)}, \; j = 1, \ldots, n. \quad (8)$$

**Step 6.** Establishing the priority order of alternatives based on the $Q_j$, the greater the $Q_j$ the higher is the alternative's efficiency.

Utility degree $N_j$ can be used for visually assessing the efficiency of the alternatives and is determined by equation (9). Utility degree for the analysed alternatives will range from 0 to 100%.

$$N_j = \frac{Q_j}{Q_{\max}} \times 100\%. \quad (9)$$

### 1.2.1. Criteria' weights and alternatives' ratings under fuzzy environment

In this research, weights of criteria and a number of criteria ratings for corresponding alternatives are determined through expert assessment based on fuzzy set theory. Firstly, linguistic terms are used in the questionnaire survey aimed to determine criteria weights and the rating of criteria for corresponding alternatives. A linguistic term is a variable with words or sentences as its values (Zadeh, 1975). According to Zadeh (1975), linguistic terms offer a means of approximate characterization of phenomena which are too complex or hard to define in conventional quantitative terms. Then, for the calculation, the linguistic terms are expressed as a fuzzy number. The relationships between linguistic terms and fuzzy numbers in this paper is given in Tables 2 and 3, adopted from Yazdani et al.

(2011). Some MCDM studies have used Likert scales for determining weights and rating of alternatives with respect to criteria. However, sometimes due to vagueness and uncertainty of human judgments, the crisp data are inadequate to measure real-life situations (Vahdani et al., 2014). Using linguistic terms instead of numeric values is a more realistic approach for determining criteria weights and ratings (Vahdani et al., 2014).

Table 2. Linguistic terms for weighting the criteria

| Linguistic Terms | Triangular Fuzzy Number (TFN) |
|---|---|
| Very low Importance | (0.0,0.0,0.25) |
| Low importance | (0.0,0.25,0.5) |
| Moderate importance | (0.25,0.5,0.75) |
| High importance | (0.5,0.75,1.0) |
| Very high importance | (0.75,1.0,1.0) |

Table 3. Linguistic terms for rating alternatives with respect to criteria

| Linguistic Terms | Triangular fuzzy number (TFN) |
|---|---|
| Very low (VL) | (0.0,0.0, 2.5) |
| Low (L) | (0.0,2.5,5.0) |
| Medium (M) | (2.5,5.0,7.5) |
| High (H) | (5.0,7.5,10.0) |
| Very High (VH) | (7.5,10.0,10.0) |

As stated earlier, in this research criteria weights are determined through expert survey. Using a purposeful sampling strategy, 12 experts participated in the survey. These expert participants were selected on the basis of their having adequate experience and in-depth knowledge of BIM and building permits. The minimum number of experts suggested for evaluating criteria weights is ten (Tupėnaitė et al., 2018; Saraji et al., 2022). Using linguistic terms, experts were asked to state the criteria importance in relation to the BIM-based building permit process. The experts' profiles are presented in Table 4.

Apart from the criteria weights, ratings of most of the criteria for corresponding alternatives were also determined through the same expert survey. Six of the experts (from within the group of 12 experts shown in Table 4) possessed knowledge of the BIM-based building permits situation in the 3 selected case municipalities. Thus, six experts rated the criteria status for the 3 corresponding alternatives (2 experts per municipality).

### 1.2.2. Fuzzy set theory

Fuzzy sets theory was introduced by Zadeh (1965) and it offers a precise mathematical framework to study vague phenomena (Zimmermann, 2010). There are several approaches to fuzzy sets in the literature. Klir and Folger (1988) defined a fuzzy set as follows: "Let X denote a universal set. Then, the membership function $\mu_A$ by which a fuzzy set A is usually defined has the form:

$$\mu_A: X \to [0,1], \tag{10}$$

where [0,1] donates the interval of real numbers from 0 to 1, inclusive". Such function is called a membership function and the set is defined by a fuzzy set.

According to Zavadskas and Antucheviciene (2007) these are fuzzy subsets of real numbers indicating the expansion of the idea of a confidence interval. Fuzzy numbers are fuzzy subsets with membership function between 0 and 1, with 1 meaning full membership and 0 non-membership (Yazdani et al., 2011).

The fuzzy number can be written as (Zavadskas & Antucheviciene, 2007):

$$u_{\tilde{f}}(x) = \begin{cases} L(x) & (f_1 \le x \le f_2), \\ R(x) & (f_2 \le x \le f_3), \end{cases} \tag{11}$$

where $L(x)$ is an increasing function of $x \in \{f_1, f_2\}$ and it is right continuous, $0 \le L(x) \le 1$; $R(x)$ is decreasing function of $x \in \{f_2, f_3\}$ and it is left continuous $0 \le R(x) \le 1$ (Zavadskas & Antucheviciene, 2007). $f_1$ and $f_3$ are lower and upper limits of $\tilde{f}$ and $f_2$ is called the mode of $\tilde{f}$.

Table 4. Profiles of experts

| # | Speciality | Work experience (Years) | Organization type |
|---|---|---|---|
| 1 | Expert in BIM & building permits | 40 | Municipality |
| 2 | Project management | 24 | Municipality |
| 3 | Product manager | 20 | Software Developer |
| 4 | BIM manager | 20 | Municipality |
| 5 | BIM manager | 15 | Municipality |
| 6 | BIM manager | 12 | Municipality |
| 7 | Analyst | 8 | Municipality |
| 8 | Researcher | 8 | Research Institute |
| 9 | Researcher | 6 | Research Institute |
| 10 | Researcher | 6 | Research Institute |
| 11 | BIM manager | 5 | Municipality |
| 12 | Researcher | 4 | Research Institute |

There are many fuzzy numbers such as Triangular Fuzzy Number (TFN), Trapezoidal Fuzzy Number (TrFN), and Gaussian Fuzzy Number (GFN), etc. In this study, TFNs are used for fuzzy numbers.

The membership function $u_{\tilde{f}}$ of a TFN $\tilde{f}$ is defined as (Chakraverty et al., 2019):

$$u_{\tilde{f}}(x)=\begin{cases} 0 & (x<f_1), \\ \dfrac{x-f_1}{f_2-f_1} & (f_1\le x\le f_2), \\ \dfrac{x-f_3}{f_2-f_3} & (f_2\le x\le f_3), \\ 0 & (x>f_3), \end{cases} \quad (12)$$

where $f_1$, $f_2$ and $f_3$ are real numbers and $f_1 \le f_2 \le f_3$.

The following operations will be used in this research:

Addition on TFNs:

$$\tilde{f}+\tilde{f}`=(f_1,f_2,f_3)+(f_1',f_2',f_3')=(f_1+f_1',f_2+f_2',f_3+f_3'). \quad (13)$$

Multiplication on TFNs:

$$\tilde{f}*\tilde{f}`=(f_1,f_2,f_3)*(f_1',f_2',f_3')=(f_1*f_1',f_2*f_2',f_3*f_3'). \quad (14)$$

After the expert survey, the linguistic variables were converted into triangular fuzzy numbers based on Tables 2 and 3. From triangular fuzzy numbers, crisp real values were obtained through defuzzification. Defuzzification is the process of conversion of fuzzy numbers into crisp real values. There are many defuzzification approaches such as Centroid of Area, Extended Centre of Area, Bisector of Area, Mean of Maximum, Smallest of Maximum, Largest of Maximum, Random Choice of Maximum techniques, etc. This research uses the Centroid of Area technique which is given by Best Non-fuzzy Performance (BNP) or crisp real values and can be calculated as (Yazdani et al., 2011):

$$\text{BNP} = [(f_3 - f_1) + (f_2 - f_1)]/3 + f_1. \quad (15)$$

Once the weights of the criteria and rating of alternatives with respect to criteria were determined, the readiness was assessed using the COPRAS method and the priority of alternatives was determined. The overall methodological flow chart followed in this study is given in Figure 1.

## 2. Results

### 2.1. Weights of criteria

To achieve the aim of the study, the weights of criteria were first determined. The criteria importance level for BIM-based building permit processes was asked from experts using linguistic terms. After the survey, the linguistic terms were converted into triangular fuzzy numbers based on Table 2 and then into crisp values using Eqn (15). The weights of the criteria for BIM-based building permit processes are calculated according to equation 1 and are listed in Table 5.

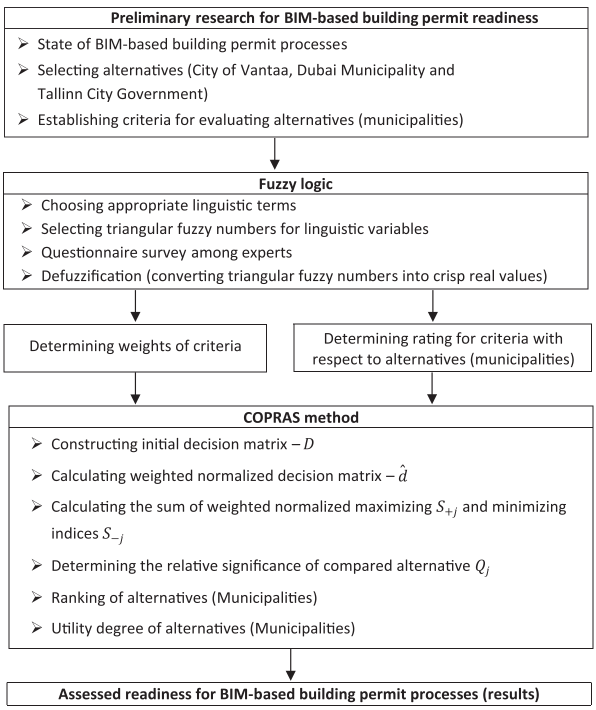


Figure 1. Methodology flow chart

Table 5. Criteria weights from experts' opinion

| Criteria | | Fuzzy aggregation | Crisp | Weights |
|---|---|---|---|---|
| Technology | C1: Simplicity of the BIM-based building permit system | (0.58, 0.83, 0.96) | 0.79 | 0.0411 |
| | C2: Compatibility with existing building regulations and codes | (0.67, 0.92, 1.00) | 0.86 | 0.0447 |
| | C3: Integration and interoperability with relevant systems and databases | (0.56, 0.81, 0.96) | 0.78 | 0.0404 |
| | C4: Maintainability | (0.50, 0.75, 0.94) | 0.73 | 0.0378 |
| | C5: Supporting open standards | (0.71, 0.96, 1.00) | 0.89 | 0.0461 |
| | C6: Cost (e.g., capital, running etc) | (0.35, 0.60, 0.85) | 0.60 | 0.0314 |
| | C7: BIM implementation in the local construction industry | (0.48, 0.73, 0.96) | 0.72 | 0.0375 |
| People | C8: Top management support for the BIM-based building permit process | (0.65, 0.90, 1.00) | 0.85 | 0.0440 |
| | C9: Availability of employees with BIM skills | (0.56, 0.81, 0.96) | 0.78 | 0.0404 |
| | C10: Qualifications of the professionals dealing with building permit applications | (0.48, 0.73, 0.92) | 0.71 | 0.0368 |
| | C11: Availability of training programmes | (0.54, 0.79, 0.98) | 0.77 | 0.0400 |
| | C12: Willingness of employees to use a BIM-based building permit process | (0.65, 0.90, 1.00) | 0.85 | 0.0440 |
| | C13: Building permit applicants' interest in using a BIM-based building permit process | (0.58, 0.83, 0.96) | 0.79 | 0.0411 |
| Process | C14: Comprehensiveness of code compliance checks (number and types of checks, system ability to expand with new checks) | (0.60, 0.85, 1.00) | 0.82 | 0.0425 |
| | C15: System allows pre-submission checks of BIM models by applicants | (0.50, 0.75, 0.94) | 0.73 | 0.0378 |
| | C16: Efficiency of existing/previous (not BIM-based) building permit process | (0.38, 0.60, 0.81) | 0.60 | 0.0310 |
| | C17: Potential time saving | (0.58, 0.83, 0.98) | 0.80 | 0.0414 |
| | C18: Potential cost saving | (0.48, 0.73, 0.92) | 0.71 | 0.0368 |
| Policies | C19: Level of information standardization (BIM standards, BIM protocol, classification systems, etc.) | (0.63, 0.88, 1.00) | 0.83 | 0.0432 |
| | C20: BIM model submission guidelines for the BIM-based building permit process | (0.58, 0.83, 0.96) | 0.79 | 0.0411 |
| | C21: BIM mandate in the local construction Industry | (0.56, 0.81, 0.96) | 0.78 | 0.0404 |
| | C22: Support by government | (0.63, 0.88, 0.98) | 0.83 | 0.0429 |
| | C23: Clarity and easy access to building laws, regulations & building permit requirements | (0.58, 0.83, 1.00) | 0.81 | 0.0418 |
| | C24: e-governance | (0.48, 0.73, 0.94) | 0.72 | 0.0371 |
| | C25: Legal framework of BIM-based building permit process | (0.52, 0.77, 0.96) | 0.75 | 0.0389 |

The weights of the criteria were determined on the basis of their importance level in relation to BIM-based building permit processes – Table 6 shows the ranking of the criteria based on their weights. Both the overall ranking and ranking in the specific category i.e., Technology, People, Process and Policies are presented.

### 2.2. Readiness assessment for BIM-based building permit processes

In order to perform multiple criteria assessment of readiness for BIM-based building permit processes in the selected alternatives (municipalities) i.e., Dubai Municipality (Case 1), Tallinn City Government (Case 2) and City of Vantaa (Case 3) by using the Fuzzy-COPRAS method, an initial decision matrix was developed. For the initial decision matrix, the statistics of criteria for the corresponding municipalities were determined through fuzzy rating and data from World Bank reports (World Bank, 2020). For the qualitative criteria the statistics were determined through linguistic terms – triangular fuzzy numbers and then converted into crisp values through the Centroid of Area technique shown in Eqn (15). A few of the quantitative criteria, i.e., cost (e.g., capital, running, etc.), and potential time saving of BIM-based building permit process rating were also determined through fuzzy rating, since the BIM-based building permit process is currently in development phase/pilot stages or in limited scale use in the selected municipalities, thus the statistics for these criteria were not available from databases. The fuzzy ratings for criteria were determined through 6 experts who rated the criteria status for their corresponding municipality. The qualitative and quantitative criteria information pertinent to the cases is provided in Table 7.

The initial decision matrix has been weighted and normalized through applying Eqn (3). The sum of weighted normalized maximizing values and sum of weighted normalized minimizing values for each case were determined through Eqns (4) and (5), respectively, and, finally, the significance values for the cases were evaluated using Eqn (8) and the cases were ranked based on the significance values. The results of the readiness assessment for BIM-based building permit processes in the selected municipalities i.e., Dubai Municipality (Case 1), Tallinn City Government (Case 2) and City of Vantaa (Case 3) are presented in Table 8.

Table 6. Ranking of criteria

| | Criteria | Weights | Ranking | |
|---|---|---|---|---|
| | | | Category wise | Overall |
| Technology | C1: Simplicity of the BIM-based building permit system | 0.0411 | 3 | 10 |
| | C2: Compatibility with existing building regulations and codes | 0.0447 | 2 | 2 |
| | C3: Integration and interoperability with relevant systems and databases | 0.0404 | 4 | 13 |
| | C4: Maintainability | 0.0378 | 5 | 18 |
| | C5: Supporting open standards | 0.0461 | 1 | 1 |
| | C6: Cost (e.g., capital, running etc) | 0.0314 | 7 | 24 |
| | C7: BIM implementation in the local construction industry | 0.0375 | 6 | 20 |
| People | C8: Top management support for the BIM-based building permit process | 0.0440 | 1 | 3 |
| | C9: Availability of employees with BIM skills | 0.0404 | 4 | 13 |
| | C10: Qualifications of the professionals dealing with building permit applications | 0.0368 | 6 | 22 |
| | C11: Availability of training programmes | 0.0400 | 5 | 16 |
| | C12: Willingness of employees to use a BIM-based building permit process | 0.0440 | 1 | 3 |
| | C13: Building permit applicants' interest in using a BIM-based building permit process | 0.0411 | 3 | 10 |
| Process | C14: Comprehensiveness of code compliance checks (number and types of checks, system ability to expand with new checks) | 0.0425 | 1 | 7 |
| | C15: System allows pre-submission checks of BIM models by applicants | 0.0378 | 3 | 18 |
| | C16: Efficiency of existing/previous (not BIM-based) building permit process | 0.0310 | 5 | 25 |
| | C17: Potential time saving | 0.0414 | 2 | 9 |
| | C18: Potential cost saving | 0.0368 | 4 | 22 |
| Policies | C19: Level of information standardization (BIM standards, BIM protocol, classification systems, etc.) | 0.0432 | 1 | 5 |
| | C20: BIM model submission guidelines for the BIM-based building permit process | 0.0411 | 4 | 10 |
| | C21: BIM mandate in the local construction Industry | 0.0404 | 5 | 13 |
| | C22: Support by government | 0.0429 | 2 | 6 |
| | C23: Clarity and easy access to building laws, regulations & building permit requirements | 0.0418 | 3 | 8 |
| | C24: e-governance | 0.0371 | 7 | 21 |
| | C25: Legal framework of BIM-based building permit process | 0.0389 | 6 | 17 |

Table 7. Initial data for readiness assessment

| | Criteria | * | Measuring units | Weights | Alternatives | | |
|---|---|---|---|---|---|---|---|
| | | | | | Case 1 | Case 2 | Case 3 |
| Technology | C1: Simplicity of the BIM-based building permit system | + | Rating | 0.0411 | 7.5000 | 9.1667 | 8.3333 |
| | C2: Compatibility with existing building regulations and codes | + | Rating | 0.0447 | 8.3333 | 8.3333 | 7.5000 |
| | C3: Integration and interoperability with relevant systems and databases | + | Rating | 0.0404 | 7.5000 | 8.3333 | 7.5000 |
| | C4: Maintainability | + | Rating | 0.0378 | 6.2500 | 6.2500 | 9.1667 |
| | C5: Supporting open standards | + | Rating | 0.0461 | 9.1667 | 9.1667 | 9.1667 |
| | C6: Cost (e.g., capital, running etc) | – | Rating | 0.0314 | 6.2500 | 3.7500 | 5.0000 |
| | C7: BIM implementation in the local construction industry | + | Rating | 0.0375 | 5.0000 | 7.5000 | 9.1667 |
| People | C8: Top management support for the BIM-based building permit process | + | Rating | 0.0440 | 9.1667 | 9.1667 | 9.1667 |
| | C9: Availability of employees with BIM skills | + | Rating | 0.0404 | 3.7500 | 3.7500 | 9.1667 |
| | C10: Qualifications of the professionals dealing with building permit applications | + | Index | 0.0368 | 4.0000 | 1.0000 | 2.0000 |
| | C11: Availability of training programmes | + | Rating | 0.0400 | 5.0000 | 7.5000 | 7.5000 |
| | C12: Willingness of employees to use a BIM-based building permit process | + | Rating | 0.0440 | 6.2500 | 8.3333 | 9.1667 |
| | C13: Building permit applicants' interest in using a BIM-based building permit process | + | Rating | 0.0411 | 5.0000 | 7.0833 | 9.1667 |

*End of Table 7*

| Criteria | | * | Measuring units | Weights | Alternatives | | |
|---|---|---|---|---|---|---|---|
| | | | | | Case 1 | Case 2 | Case 3 |
| Process | C14: Comprehensiveness of code compliance checks (number and types of checks, system ability to expand with new checks) | + | Rating | 0.0425 | 7.0833 | 7.5000 | 6.2500 |
| | C15: System allows pre-submission checks of BIM models by applicants | + | Rating | 0.0378 | 9.1667 | 9.1667 | 9.1667 |
| | C16: Efficiency of existing/previous (not BIM-based) building permit process | + | Score | 0.0310 | 89.8000 | 82.6000 | 75.9000 |
| | C17: Potential time saving | + | Rating | 0.0414 | 5.0000 | 8.3333 | 6.2500 |
| | C18: Potential cost saving | + | Rating | 0.0368 | 5.0000 | 7.0833 | 6.2500 |
| Policies | C19: Level of information standardization (BIM standards, BIM protocol, classification systems, etc.) | + | Rating | 0.0432 | 6.2500 | 8.3333 | 8.3333 |
| | C20: BIM model submission guidelines for the BIM-based building permit process | + | Rating | 0.0411 | 7.5000 | 7.0833 | 9.1667 |
| | C21: BIM mandate in the local construction Industry | + | Rating | 0.0404 | 6.2500 | 5.0000 | 7.5000 |
| | C22: Support by government | + | Rating | 0.0429 | 9.1667 | 9.1667 | 9.1667 |
| | C23: Clarity and easy access to building laws, regulations & building permit requirements | + | Index | 0.0418 | 2.0000 | 2.0000 | 2.0000 |
| | C24: e-governance | + | Index | 0.0371 | 0.8555 | 0.9473 | 0.9452 |
| | C25: Legal framework of BIM-based building permit process | + | Rating | 0.0389 | 3.7500 | 7.5000 | 7.0833 |

Table 8. Readiness assessment for BIM-based building permit processes

| Criteria | | * | Measuring units | Weights | Alternatives | | |
|---|---|---|---|---|---|---|---|
| | | | | | Case 1 | Case 2 | Case 3 |
| Technology | C1: Simplicity of the BIM-based building permit system | + | Rating | 0.0411 | 0.3000 | 0.3667 | 0.3333 |
| | C2: Compatibility with existing building regulations and codes | + | Rating | 0.0447 | 0.3448 | 0.3448 | 0.3103 |
| | C3: Integration and interoperability with relevant systems and databases | + | Rating | 0.0404 | 0.3214 | 0.3571 | 0.3214 |
| | C4: Maintainability | + | Rating | 0.0378 | 0.2885 | 0.2885 | 0.4230 |
| | C5: Supporting open standards | + | Rating | 0.0461 | 0.3333 | 0.3333 | 0.3333 |
| | C6: Cost (e.g., capital, running etc) | – | Rating | 0.0314 | 0.4167 | 0.2500 | 0.3333 |
| | C7: BIM implementation in the local construction industry | + | Rating | 0.0375 | 0.2308 | 0.3462 | 0.4230 |
| People | C8: Top management support for the BIM-based building permit process | + | Rating | 0.0440 | 0.3333 | 0.3333 | 0.3333 |
| | C9: Availability of employees with BIM skills | + | Rating | 0.0404 | 0.2250 | 0.2250 | 0.5500 |
| | C10: Qualifications of the professionals dealing with building permit applications | + | Index | 0.0368 | 0.5714 | 0.1429 | 0.2857 |
| | C11: Availability of training programmes | + | Rating | 0.0400 | 0.2500 | 0.3750 | 0.375 |
| | C12: Willingness of employees to use a BIM-based building permit process | + | Rating | 0.0440 | 0.2632 | 0.3509 | 0.3859 |
| | C13: Building permit applicants' interest in using a BIM-based building permit process | + | Rating | 0.0411 | 0.2353 | 0.3333 | 0.4313 |
| Process | C14: Comprehensiveness of code compliance checks (number and types of checks, system ability to expand with new checks) | + | Rating | 0.0425 | 0.3400 | 0.3600 | 0.3000 |
| | C15: System allows pre-submission checks of BIM models by applicants | + | Rating | 0.0378 | 0.3333 | 0.3333 | 0.3333 |
| | C16: Efficiency of existing/previous (not BIM-based) building permit process | + | Score | 0.0310 | 0.3617 | 0.3327 | 0.3056 |
| | C17: Potential time saving | + | Rating | 0.0414 | 0.2553 | 0.4255 | 0.3191 |
| | C18: Potential cost saving | + | Rating | 0.0368 | 0.2727 | 0.3864 | 0.3409 |

*End of Table 8*

| | Criteria | * | Measuring units | Weights | Alternatives | | |
|---|---|---|---|---|---|---|---|
| | | | | | Case 1 | Case 2 | Case 3 |
| Policies | C19: Level of information standardization (BIM standards, BIM protocol, classification systems, etc.) | + | Rating | 0.0432 | 0.2727 | 0.3636 | 0.3636 |
| | C20: BIM model submission guidelines for the BIM-based building permit process | + | Rating | 0.0411 | 0.3158 | 0.2982 | 0.3859 |
| | C21: BIM mandate in the local construction Industry | + | Rating | 0.0404 | 0.3333 | 0.2667 | 0.4000 |
| | C22: Support by government | + | Rating | 0.0429 | 0.3333 | 0.3333 | 0.3333 |
| | C23: Clarity and easy access to building laws, regulations & building permit requirements | + | Index | 0.0418 | 0.3333 | 0.3333 | 0.3333 |
| | C24: e-governance | + | Index | 0.0371 | 0.3113 | 0.3447 | 0.3439 |
| | C25: Legal framework of BIM-based building permit process | + | Rating | 0.0389 | 0.2045 | 0.4091 | 0.3863 |
| The sum of weighted normalised maximining $S_{+j}$ | | | | | 0.2959 | 0.3220 | 0.3485 |
| The sum of weighted normalised minimizing $S_{-j}$ | | | | | 0.0130 | 0.0078 | 0.0104 |
| Significance of the alternatives $Q_j$ | | | | | 0.3045 | 0.3361 | 0.3594 |
| Priority of Alternatives | | | | | 3 | 2 | 1 |
| Utility degree of alternatives $N_j$ | | | | | 84.76 | 93.55 | 100 |

## 3. Discussion

The multiple criteria decision-making method, COPRAS under fuzzy environment applied in this research assessed the readiness of BIM-based building permit processes in selected municipalities. BIM itself is a complex innovative technology and its adoption in municipalities for building permit processes considers a number of criteria. In this study, first 25 criteria were identified from a literature review and then categorized into *Technology*, *People*, *Process*, and *Policies*. As an important part of the COPRAS steps, the weights of the criteria were determined through expert survey. This research identifies the municipality most ready for BIM-based building permit processing, and, in addition, the weights of criteria establish the most significant criteria for BIM-based building permit processes. The criteria weights explain what criteria are important in comparison to other criteria for implementing BIM-based building permit processes.

In the *Technology* category, supporting open standards, i.e., openBIM is the most important criterion as shown in Table 6. This also reflects the findings of the study by Ciotta et al. (2021) that exchanging information in openBIM standards like IFC, Model View Definitions (MVDs), are essential for permitting systems to read the content and perform automatic code checking of rules. In the *Technology* category, the second most important criterion is that the BIM-based building permit system should be compatible with the building regulations and codes. In the building permit process, many departments are involved such as planning, fire, and public works. It is thus essential for BIM-based building permit systems to be integrated with other relevant databases. Among the six criteria in *People* category, the panel of experts gave importance to top management support (0.044), willingness of employees to use a BIM-based building permit process (0.044) and building permit applicants' interest in using a BIM-based building permit process (0.0411) as listed in Table 6. The top management support significance for successful BIM implementation is highlighted extensively in the literature on BIM implementation as well (e.g., Ahuja et al., 2016). In the *Process* category, the comprehensiveness of code compliance checks (number and types of checks, system ability to expand with new checks) was ranked the most important criterion, followed by potential time saving. This finding also reflects the recommendations of Future Insight Group (2019) that efficient BIM-based building permit processes should have the maximum number of checks. Initially they can be set up with a number of basic checks and then the number of checks can be increased based on technology advancement and user experience. Increasing the number of checks step by step also maintains the simplicity of the BIM-based building permit system from the users' point of view and thus can lead to higher interest from building permit applicants. Based on the weights in the *Polices* category, Level of information standardization (BIM standards, BIM protocol, classification systems, etc.) is the most significant criterion as listed in Table 6. Another important criterion in the *Polices* category is government support. The vital role of government in the form of BIM funds, mandate and other legal perspectives is not only essential for BIM-based building permits but also for BIM implementation in AEC/FM industry as highlighted in previous studies (Yang & Chou, 2018; Song et al., 2017).

As mentioned earlier, the primary aim of this research was to assess readiness for BIM-based building permits in the selected three municipalities, Table 9 concludes the final results based on Fuzzy-COPRAS. Since the established criteria for assessing readiness went further than *Technology*, it is important to note that the intention of this study was not to compare or identify the best software solution from the municipalities using/developed for BIM-based building permit process.

Table 9. Results of the readiness assessment based on Fuzzy-COPRAS

| Alternatives | Significance | Rank | Utility degree (%) |
|---|---|---|---|
| Case 1: Dubai BIM-based building permit process | 0.3045 | 3 | 84.75 |
| Case 2: Tallinn BIM-based building permit process | 0.3361 | 2 | 93.55 |
| Case 3: Vantaa BIM-based building permit process | 0.3594 | 1 | 100 |

Based on the 25 weighted decision criteria, the *City of Vantaa* is ranked first followed by *Tallinn City Government* and then *Dubai Municipality* for readiness towards a BIM-based building permit process. Finland is among the earliest national adopters of BIM in the AEC industry (Borrmann et al., 2018), and Solibri Model checker, developed in Finland, allows up to 70% automated, rule-based checking of building designs (Virkamäki & Masjagutova, 2020). The Common BIM (CoBIM) Requirements 2012 directly add to high readiness for BIM-based building permit process in the case of the City of Vantaa. Since 2007 Senate properties, Finland has mandated the use of BIM in public projects depending on their size (Borrmann et al., 2018) and very high levels of implementation of BIM in the AEC industry explain the high ranking of the City of Vantaa case. These high levels of BIM implementation translate into the availability of employees with BIM skills and building permit applicants' interest in using a BIM-based building permit process which were observed as high.

In Tallinn City Government, the web solution for BIM-based building permit process owned by the Estonian Ministry of Economic affairs and Communications is a BIM server, where the analyst from the municipality will not require any additional software for checks as these will be carried out in the server environment (Estonian Ministry of Economic Affairs and Communication, 2020). This makes the BIM-based building permit system user-friendly and thus the ratings are high for simplicity of BIM-based building permit process system in the Tallinn City Government case. Further, availability of training programmes and comprehensiveness of code compliance checking were observed to be high. Estonia being ranked second in e-governance in the world (United Nations, 2020) is considered among the enablers towards digital construction in the country and this includes the BIM-based building permit process.

Though Dubai Municipality is ranked 3rd in the readiness assessment of BIM-based building permit processes in the current study, the Dubai BIM e-submission service has the functionality of integration with GIS apart from performing automatic code compliance checking (Ismail & Hamoud, 2021) and thus aims at Level 3 of e-permitting with integration of BIM and GIS (Shahi et al., 2019). Similarities are observed in all the three cases in terms of accepting openBIM standards (IFC, BCF, etc.) and enabling the applicant to perform pre-checks on the models in order to check whether they fulfil the requirements or not. The readiness assessment also showed support from organizational top management and government in all cases.

Based on comparatively low ratings of criteria with respect to alternatives in Table 8, the readiness assessments highlight potential areas of focus for the selected municipalities. For *City of Vantaa*, the area of focus should be comprehensiveness of code compliance checks (number and types of checks, system ability to expand with new checks). For *Tallinn City Government*, BIM implementation in the industry, employees with BIM skills, and BIM mandate are all areas requiring attention. For *Dubai Municipality* the areas of focus should include BIM implementation in the industry, employees with BIM skills, and the legal framework for the BIM-based building permit process.

The readiness assessment reflects that municipalities aiming for BIM-based building permit processes should pay attention to software solutions capable of exchanging data in open standards, that are easy to operate, and, ideally, having a single-window approach in allowing one submission and then linking that to all relevant systems. Training programs are vital to increase the interest towards the BIM-based building permit process among municipality personnel. Lastly, from the policies point of view, legislation regarding BIM e-submission is essential once the process has been adequately established and has reached a certain maturity level.

In comparison with previous studies on BIM and building permitting which were mainly focused on the technical context of the subject, this study, to the best of the authors' knowledge, is the first to use MCDM methods in relation to BIM-based building permit processes, and that has enabled the investigation from a multifaceted perspective i.e., technical, people, process, and policies. The limitations of this research include that it was based on a limited number of criteria and some relevant criteria related to BIM and building permitting may have been omitted. Another limitation of this study is that some quantitative criteria were assessed on the basis of ratings given by BIM experts, due to a lack of statistics from databases or any other sources. The number of alternatives considered in this study and the number of experts for rating the criteria with respect to those alternatives were comparatively low. However, the experts who did participate in this study were well-informed about the corresponding municipalities and the authors are confident that the findings are therefore robust. The developed model of criteria for BIM-based building permit processes can be used in future studies for readiness assessment in other municipalities.

## Conclusions

Inspired by the rich information of BIM models, building control authorities are seeking to utilize BIM in the building permit process. This study aimed to assess the readiness for BIM-based building permit processes in three municipalities of different countries by applying Fuzzy-COPRAS – a multiple criteria decision-making method. In order to achieve the aim of the study, 25 criteria were identified from a literature review and categorised into technology, people, process, and policies. The weights of the criteria were then determined based on their importance level through expert evaluation.

The results of the study revealed the most important criteria for BIM-based building permitting from all four categories: supporting open standards, compatibility with existing building regulations and codes, willingness of employees to use a BIM-based building permit process, top management support for the BIM-based building permit process, comprehensiveness of code compliance checks, system allows pre-submission checks of BIM models by applicants, level of information standardization and government support. The readiness assessment for BIM-based building permit processes revealed that the *City of Vantaa* ranked first, and this can be explained by the high ratings for BIM implementation in the local construction industry, building permit applicants' interest in using a BIM-based building permit process, and the existence of a BIM mandate. The study results revealed similar rating trends for the technical criteria in all three municipalities. We can conclude that, for full utilization of BIM-based building permit processes in municipalities, attention to the organizational and policy contexts are essential alongside technical considerations. These results are expected to contribute to the body of knowledge with respect to BIM-based building permit processes and to have practical implications for municipalities seeking to use BIM in their building permit processes. Meanwhile, the applied methodology and identified criteria can be used to rank any municipality and can assist decision-making in relation to BIM adoption for building permitting and for prioritizing improvement efforts.

## Funding

This research was supported by the BIM-enabled Learning Environment for Digital Construction (BENEDICT) project (grant number: 2020-1-EE01-KA203-077993), Minimizing the influence of coronavirus in a built environment (MICROBE) project (grant number: 2020-1-LT01-KA203-078100), Strengthening University-Enterprise Collaboration for Resilient Communities in Asia (SECRA) project (grant number: 619022-EPP-1-2020-1-SE-EPP-KA2-CBHE-JP) and the Integrating Education with Consumer Behaviour relevant to Energy Efficiency and Climate Change at the Universities of Russia, Sri Lanka, and Bangladesh (BECK) project (grant number: 598746-EPP-1-2018-1-LT-EPPKA2- CBHE-JP) all co-funded by the Erasmus+ Programme of the European Union. The European Commission support to produce this publication does not constitute an endorsement of the contents which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained there-in.

## Author contributions

K. U. and E. W. conceived the study and were responsible for the design, data collection and analysis. N. B. and M. S. contributed to the methodological design by the study. The study was supervised by I. L. and E. W. K. U. wrote the first draft and E. W., I. L., N. B., and M. S. reviewed and edited the article.

## Disclosure statement

Authors of this article declare no competing financial, professional, or personal interests from other parties.

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**Publication V**

Ullah, K., Witt, E., & Lill, I. (2022). BIM adoption processes: findings from a systematic literature review. In 11th Nordic Conference on Construction Economics and Organization. Springer Proceedings in Business and Economics (**Conference paper: ETIS classification 3.1**)

# BIM adoption processes: findings from a systematic literature review

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*Significant improvements in the performance of the construction industry have been expected from Building Information Modelling (BIM) and this has led to widespread attempts at its adoption. In parallel, there has been growing interest among researchers to examine BIM adoption processes together with the constraints they face, and this suggests that there is now a need for an up-to-date, state-of-the-art overview of BIM adoption research. The purpose of this study is to review and analyse existing BIM adoption research in order to synthesise their findings and derive an overall understanding of BIM adoption processes. To achieve this purpose a systematic review methodology was followed. The scope of the review is limited to academic articles written in English that are focused on BIM adoption processes and the factors affecting BIM adoption. A total of 410 relevant articles comprising mainly exploratory surveys and case studies on BIM adoption were identified and reviewed. Content analysis of the articles resulted in the classification of BIM adoption literature into project, organization, and industry levels and classification of factors affecting BIM adoption process. This research has implications for practice and research that the classification of factors that affect BIM adoption process can be used to help analyse BIM adoption in different organizations.*

KEYWORDS: Building Information Modelling, BIM adoption, Construction Industry, Literature review, Content analysis

## Introduction

BIM as an innovative technology offers various potential benefits, and as a result BIM adoption in the AEC/FM industry is on the rise, particularly in recent years (Ullah et al., 2019). It is believed that BIM implementation can also assist in achieving UN's Sustainable Development Goals (Umar, 2021) particularly: SGG9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities & Communities) though its applications in visualization, energy simulations, life cycle assessments and collaboration working environment.

The term adoption is often used interchangeably with implementation and is defined by Roger (1983) as "a decision to make full use of an innovation as the best course of action available". Based on Roger's Diffusion of Innovation theory, Hochscheid, & Halin, (2018) described BIM

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adoption process as a five-stage process i.e., awareness about BIM followed up by possible intention toward it, decision to adopt BIM, implementation, and confirmation to continue use of BIM. In recent years academic research in the area of BIM has increased, including studies investigating BIM adoption process. Research related to BIM adoption has mainly focused on motivation or readiness towards BIM (Juan et al., 2017), practical case studies of BIM implementation (Shibeika & Harty, 2015), implementation frameworks (Kouch, 2018), maturity models and adoption rate (Succar & Kassem, 2015), and factors affecting BIM adoption (Ahuja et al., 2020). These studies provides useful insights about various aspects of BIM adoption; however, there is still scarcity of research that holistically review BIM adoption processes in project, organization, and industry wise and factors (drivers and impediments) affecting it since given scattered in these studies. Recently, many review studies have been carried out on BIM research for instance, Gao & Pishdad-Bozorgi (2019); however, most of reviews were concentrated on certain BIM applications such energy analysis, knowledge management, BIM for facility management, BIM for sustainable construction, and BIM for existing buildings. Consequently, this research is aimed to systematically review studies which were performed particularly on BIM adoption to state current state of the BIM adoption research and factors affecting it.

The remainder of the paper is structured as follows: the methodology used for the systematic literature review is described in section 2. The findings of the study are reported in section 3, and this is followed by a discussion and conclusion.

## 2. Methodology

Systematic literature review is a widely used methodology in academic research aimed at generating robust knowledge from already existing or published literature (Kraus et al., 2020). This study adopted a systematic literature review methodology following the guidelines recommended by Bearman et al., (2012).

### *2.1 Review question:*

What is the current state of the research of BIM adoption process and what are the factors (drivers and impediments) influencing the BIM adoption process?

### *2.2 Inclusion and exclusion criteria*

As BIM is a wide topic, papers from peer-reviewed journals and conference proceedings of high quality focused on the BIM adoption process and factors affecting it were considered relevant. Only papers published in English language were included. No restriction on the years of publications was imposed.

### *2.3 Search strategy*

A desktop study was performed using the search engines provided by ASCE Library, EBSCOhost, Emerald Insight, Science Direct, Scopus, and Web of Science. The main search strings and key words were (("Building Information Mode?l*" OR "BIM") AND ("Adoption" OR "Implementation"). The keywords (Process) or (Diffusion) or (Factors) or (Drivers) or (Challenges) Or (Impediments) were also tried alongside main search strings and key words. This, however, did not result in any additional articles being found compared to the initial main search strings and key words.

### *2.4 Screening and search results*

Papers relevant to the review question were screened from the database search results, looking into their titles and abstracts if necessary. The relevant papers were exported through Mendeley reference manager and duplicates were removed.  Search results are given in findings section.

### *2.5 Data extraction and quality evaluation*

The data relevant to the review question was extracted using NVivo (V.12) software by qualitative content analysis of reviewed papers returned from the selected databases.

### *2.6 Synthesis and reporting findings*

Each article was read, and all content related to the review question was coded using NVivo (V12). The findings of the systematic literature review are given below.

## 3 Findings

### *3.1 Current state of the research on BIM adoption process*

#### *3.1.1 Database search results*

From the databases search, a total of 410 papers were found relevant to the review question. Out of 410 papers only a few papers were practical cases of BIM implementation. However, the rest of the papers were found relevant because of their focus on themes directly relating to BIM adoption, e.g., awareness, readiness, frameworks/models, strategies. Table 1 and Table 2 show results from data searches and main sources of articles respectively.

| **Databases** | **ASCE Library** | **EBSCOhost** | **Emerald Insight** | **Science Direct** | **Scopus** | **Web of Science** | **Overall, after removing duplicates** |
|---|---|---|---|---|---|---|---|
| Number of relevant articles after screening | 62 | 119 | 57 | 40 | 218 | 185 | 410 |

*Table. 1 Database research results*

| **Publication Source** | **Number of articles** |
|---|---|
| Automation in Construction | 21 |
| Journal of Management in Engineering | 19 |
| Engineering, Construction and Architectural Management | 18 |
| Journal of Construction Engineering and Management | 15 |
| Construction Innovation | 13 |
| Architectural Engineering and Design Management | 9 |
| Journal of Information Technology in Construction | 9 |
| International Journal of construction management | 7 |
| Sustainability | 7 |
| Journal of Civil Engineering & Management | 6 |

Table 2. Top sources of relevant articles

#### *3.1.2 Theme of the reviewed papers*

A number of themes related to BIM adoption process were found and these include:

- BIM awareness and readiness (Juan et al., 2017), (Eadie et al., 2015)

- BIM acceptance models (Kim et al., 2016), (Acquah et al., 2018)
- BIM implementation frameworks (Almuntaser et al., 2018), (Kouch, 2018)
- Factors affecting BIM adoption (Ahuja et al., 2020), (Hong et al., 2016)
- Drivers/Motivations for BIM adoption (Liao & Teo, 2019),
- Challenges to BIM adoption (Vass & Gustavsson, 2017)
- BIM maturity model (Succar & Kassem, 2015)

### *3.1.3 Theoretical lenses*

From the literature review, it was observed that themes related to BIM adoption were studied using different theoretical lenses as shown the Table 3. These theoretical lenses, particularly innovation diffusion theories are based on well-established bodies of knowledge from sociology, psychology, and communication (Kale and Arditi, 2005) and are useful for understanding all aspects of innovation adoption or diffusion (Hosseini et al., 2015). A large number of papers did not use any theoretical lens, however, an increasing trend of using theories to explain aspects of BIM adoption can be observed in the recent papers.

| **Type of Theory** | **Explanation** | **Used by studies** |
|---|---|---|
| Diffusion of innovation theory (DOI) (Rogers, 1983) | DOI explains "innovation diffusion" is a process through which innovation is communicated through certain channels over time among the member of social system. | (Geldson & Greenwood, 2017), (Shibeika & Harty, 2015) |
| Technology Acceptance Model (TAM) (Davis, 1989) | TAM based on two attributes "perceived usefulness" and "perceived ease of use" aims to predict information technology acceptance by users and explains the behaviour of users in acceptance of information technology. | Hong et al., 2016, (Kim et al., 2016), |
| Technology, Organizational & Environment (TEO) framework (Tornatzkly et al., 1990) | TEO framework describes the influences of Technological, the organizational, and the environmental context on innovation adoption. | (Ahuja et al., 2020) |
| Theory of Reasoned action (TRA) (Fishbein and Ajzen, 1995) | To explain acceptance or action behaviour, TRA proposed that the behavioural intention (BI) of a person is influenced by his/her attitude and subjective norms. | (Ding et al., 2015) |
| Theory of Planned Behaviour (TPB) Ajzen (1991) | TRA adds Perceived Behavioural Control (refers to people's perception of the ease or difficulty of performing the behaviour of interest) to the exist theory of TRA | (Nnaji et al., 2019) |
| Institutional Theory (DiMaggio and Powell (1983), | Institutional Theory suggest that isomorphic pressures (coercive, mimetic, and normative) motivates structural and behavioural changes in organisations while gaining social legitimacy | (Cao et al., 2017) |
| Task-Technology Fit Theory (TTF) (Goodhue and Thompson, 1995) | TTF describes that degree of suitability of technology to the user's task affects the use of information technology. | (Gurevich et al., 2017) |

*Table 3. Theorical lenses*

### *3.1.4 Overview of reviewed papers on BIM adoption*

The papers covered in the systematic literature review on the various aspects of BIM adoption are categorised into three types of studies: studies focused on BIM adoption at the level of industry, organization and project are shown in table 4, table 5, and table 6 respectively.

| Highlight of focus | Methodology | Lens | Country | Studies |
|---|---|---|---|---|
| BIM implementation challenges | Quantitative | (none) | Poland | (Lesniak et al., 2021) |
| Key actors' perspective on BIM adoption | Qualitative | (none) | New Zealand | (Doan et al., 2021) |
| BIM adoption in SMEs in UK AEC sector | Mixed method | (none) | UK | (Vidalakis et al., 2020) |
| Factors affecting BIM adoption in AEC industry | Quantitative | (none) | China | (Ma et al., 2019) |
| Organizational change framework for BIM adoption | Quantitative | (none) | Singapore | (Liao & Teo, 2019) |
| Management strategies for BIM adoption | Quantitative | Psychological climate theory | Hong Kong | (Chan et al., 2018) |
| Level of BIM acceptance | Quantitative | TAM | Ghana | (Acquah et al., 2018) |
| BIM in UK construction industry | Quantitative | DOI | UK | (Gledson & Greenwood, 2017) |
| Factors influencing BIM adoption | Quantitative | TAM | Australia | (Hong et al., 2016) |
| Factors affecting BIM acceptance | Quantitative | TAM | Korea | (Kim et al., 2016) |
| Conceptual structure on Macro BIM adoption | Literature review | (none) | Australia | (Succar & Kassem, 2015) |
| BIM adoption process on basis of hierarchy of needs | Mixed methods | Maslow's motivational theory & DOI | Australia & Finland | (Singh & Holmstrom, 2015) |
| BIM readiness and changes required for BIM adoption | Quantitative | (none) | UK | (Eadie et al., 2015) |
| BIM acceptance in construction industry | Quantitative | TAM | Korea & USA | (Lee et al., 2015) |
| Roadmap for BIM implementation | Mix method | (none) | Finland & UK | (Khosrowshahi & Arayici, 2012) |
| Collaborative BIM Decision Framework for BIM adoption | Qualitative | (none) | Australia | (Gu & London, 2010) |

*Table 4. BIM adoption studies at Industry level*

| **Highlights/focus** | **Methodology** | **Lens** | **Organization type** | **Country** | **Reference** |
|---|---|---|---|---|---|
| Readiness framework for BIM implementation | Qualitative | (none) | Design firms | Vietnam | (Tong & Phung, 2021) |
| Clients' role in BIM implementation | Case study | (none) | Public client | Sweden | (Lindblad, H., 2020) |
| BIM implementation framework | Case study | PMI framework | Architecture | KSA | (Almuntaser et al., 2018) |
| BIM adoption for asset management. | Quantitative | (none) | Public organization | Canada | (Brunet et al., 2019) |
| BIM implementation framework for SME | Literature review | (none) | Contractors | Finland | (Kouch, 2018) |
| BIM adoption actions of public facility agencies | Case study | TAM, TTF, BAM | Public facility agencies | UK | (Gurevich et al., 2017) |
| Motivations for BIM implementation | Quantitative | Institutional Theory | Design & contractor | China | (Cao et al., 2017) |

| | | | | | |
|---|---|---|---|---|---|
| Organizational challenges to BIM implementation | Case study | IT business Value model | public client | Sweden | (Vass & Gustavsson , 2017) |
| BIM acceptance and readiness | Quantitative | TAM & Artificial Neural Network | Architecture | Taiwan | (Juan et al., 2017) |
| Factors affecting BIM adoption behaviours | Quantitative | (none) | Architecture & Engineering firms | Thailand | (Ngowtana sawan, 2017) |
| Factors influencing BIM adoption | Quantitative | TOE frame-work | Architecture | India | (Ahuja et al., 2020) |
| BIM implementation in FM | Case study | (none) | Public client | Canda | (Burak et al., 2015) |
| Factors affecting BIM adoption | Quantitative | TRA | Architecture | China | (Ding et al., 2015) |
| Contractors' transformation strategies for BIM adoption | Case study | (none) | Contractor | USA | (Ahn et al., 2015) |
| Perceptions, challenges, drivers for BIM adoption | Mixed method | (none) | Engineering firms | Malaysia | (Rogers et al., 2015) |
| Diffusion process of BIM | Case study | DOI | Engineering firms | UK | (Shibeika & Harty, 2015) |
| Factors affecting Behavioural intentions to adopt BIM | Quantitative | TAM | Architecture | Korea | (Son et al., 2015) |
| Factors affecting BIM adoption | quantitative | (none) | Constructer | Nigeria | (Abubakar et al., 2014) |
| BIM implementation planning procedures | Case study | (none) | Facility owners | USA | (Chunduri et al., 2013). |
| BIM adoption process | Case study | (none) | Architecture | UK | Arayici et al 2011 |

*Table 5. BIM adoption studies at organization level*

| # | Description | Methodology | References | Country |
|---|---|---|---|---|
| 1 | BIM adoption process in a residential project | Case study | (Whitlock & Abanda, 2020) | UK |
| 2 | BIM implementation in the design processes | Case study | (Pruskova & Kaiser, 2019) | Czech Republic |
| 3 | BIM implementation in a renovation building project | Case study | (Roodra & Liu, 2019) | Canada |
| 4 | BIM Adoption process in a real time refurbishment project | Case study | (Okakpu et al., 2019) | New Zealand |
| 5 | BIM adoption process in building project | Case study | (Qie, 2011) | China |
| 6 | BIM adoption process and its impacts in the design and construction phase | Case study | Rowlinson et al 2010 | Hong Kong |
| 7 | BIM implementation process of a building project | Case study | Harty & Throssell, 2010 | UK |

*Table 6. BIM adoption studies at project level*

The above tables show that the studies covered in the systematic literature review were mainly focused on examining the BIM adoption process and the factors affecting it. Table 5 indicates that BIM adoption studies on an organizational level were mostly concentrated on architecture firms. It shows that architecture firms are some of the most active organizations in BIM adoption. The studies focused on investigating BIM adoption on project level were practical cases of BIM adoption.

Considering BIM adoption process as a social phenomenon, various authors have tried to explain it rationally. To understand the BIM adoption process, Roger's Diffusion of Innovation (DOI) Theory is one of the widely used theoretical lenses. Based on the DOI theory, Hochscheid & Halin, (2018) developed a model showing the BIM adoption process, which starts from *awareness* (expose to BIM), intention (evaluate the possibility of using BIM), *decision* (decision of adopting/ Rejecting BIM), if the decision is made to adopt BIM then *Implementation (*the actual start of using BIM) and confirmation (BIM already in use, reached some level of mastery and willingness to continue).

In the literature review, Gu & London, (2010), Cao et al., (2017) Singh & Holmstrom, (2015) studies were found related to the early stages of the BIM adoption process. Gu & London, (2010) developed a collaborative BIM decision framework for industry stakeholders who are likely to adopt BIM. Based on institutional theory, Cao et al., (2017) studied motivations of contraction professionals to implement BIM and found that image motives and cross project economic motives were the main reasons to adopt BIM. Similarly, Singh & Holmstrom, (2015) explored the motivation of actors in BIM adoption decision using Maslow's motivational theory & DOI. Studies by Almuntaser et al., (2018) and Arayici et al., (2011) were practical cases of BIM adoption, reporting various actions/techniques undertaken by organizations to implement BIM.

## 3.2 Factors influencing BIM adoption process

### *3.2.1 Drivers for BIM adoption*

The literature review reveals various drivers motivating stakeholders towards BIM adoption. According to Khosrowshahi & Arayici, (2012) the main driver for full BIM implementation is the project participants' understanding of its potential benefits over the traditional project delivery. External forces (BIM mandate, client demands etc.) can also lead to organizations taking the BIM adoption decision. Table 7. shows the drivers for BIM adoption in the technology, organization, and environment contexts.

| Context | Drivers | References |
|---|---|---|
| Technology | 1) Perceived usefulness of BIM<br>2) Perceived ease of use<br>3) Observability of BIM benefits | (Gurevich et al., 2017)<br>(Acquah et al., 2018)<br>(Ding et al., 2015) |
| Organization | 1) Top Management support<br>2) Organizational readiness<br>3) Finical resources<br>4) Supportive organization culture<br>5) Leadership leading the adoption process | (Liao & TEO, 2019)<br>(Jaun et al., 2016)<br>(Chan et al., 2018)<br>(Gu & London, 2010)<br>(Liao & Teo, 2019) |
| Environment | 1) Client demands<br>2) BIM Mandate<br>3) Partner`s influence<br>4) Competitor's pressure | (Chen at al., 2019)<br>(Rogers et al., 2015)<br>(Ahuja et al., 2016)<br>(Eadie et al 2015) |

*Table 7. Drivers for BIM adoption*

### *3.2.2 Impediments to the BIM adoption process*

BIM adoption is a complex process and can face a number of impediments. The impediments to the BIM adoption process identified from the literature review are listed in Table 8.

| Context | Impediments | References |
|---|---|---|
| Technology | 1) Complexity of BIM tools<br>2) Interoperability issues<br>3) Large size of BIM files | (Ahuja et al., 2016)<br>(Ma et al., 2019)<br>(Ngowtanasawan, 2017) |
| Organization | 1) Insufficient senior management support<br>2) Less capability of BIM Team<br>3) Cost constraints<br>4) Inadequate BIM training system<br>5) Lack of collaboration among project participants | Siebelink et al., 2020)<br>(Siebelink et al., 2020)<br>(Chan et al., 2018)<br>(Ahn et al., 2016)<br>(Ahuja et al., 2016) |
| Environment | 1) Insufficient Government support<br>2) Legal issues<br>3) No BIM use from the other/partners organizations | (Ngowtanasawan, 2017)<br>(Gu & London, 2010)<br>(Chan et al., 2018) |

*Table 8. Impediments to BIM adoption process*

## 4. Discussion

With the potential BIM applications throughout the building life cycle enabling sustainable developments, the topic of BIM has attracted the attention of researchers particularly in the last decade and a number of studies have been carried out. This current paper reviewed the research on the BIM adoption processes. The results found that a limited number of studies were carried through theoretical lenses, which reflects the findings of Akintola et al., (2019) stating that only 64 out of 1040 reviewed papers on BIM published from 2005 to 2016 were found to have used a theoretical lens.

The classification of papers into industry, organization and project levels showed that many studies were centred on architecture firms, this can be related to Ahjua, et al., (2016) reporting architecture firms among early adopters of BIM. Similarly, the results revealed that a majority of the publications were from developed countries, arguably due to high BIM adoption and BIM mandates in these countries compared to developing countries. Further, quantitative approaches were observed in the majority of the reviewed papers which were mostly focused on factors affecting BIM adoption and BIM acceptance models. While studies on real-time BIM implementation in AEC organizations dominantly used qualitative methods.

The findings also revealed the drivers and impediments to the BIM adoption process, which were grouped into technology, organization, and environment contexts. This shows that apart from technology, other contexts (organization and environment) are also important for successful BIM adoption and these too require due attention.

## 5. **Conclusion**

This research has systematically reviewed existing literature on BIM adoption processes, classified the studies concentrating BIM adoption into industry, organization, and project levels. Theoretical lenses used to understand the BIM adoption phenomenon in the construction industry have also been identified and summarised. Most of the current BIM adoption research has focused on themes such as readiness and acceptance models, BIM adoption frameworks, factors affecting adoption, drives and barriers to adoption. However, there are limited studies on actual cases of BIM implementation in AEC organizations describing the whole adoption process. Real-time cases studies on BIM implementation are useful for successful BIM implementation as these provide lessons and detailed information on strategies and techniques followed during the BIM adoption process in a specific organization.

In the systematic literature review, a scarcity of studies on BIM adoption in public organizations or agencies was observed, future research could focus on this area. Further, future works can be carried out to minimize the impediments to BIM adoption in AEC/FM industry. One limitation of this paper is that some relevant studies may have been missed due to the keyword search strategy selected. Lasty, this study contributes to the existing body of knowledge on BIM adoption and offers useful insights for researchers and industry practitioners. The results of this study can be useful for successful BIM implementation, which provides an opportunity to achieve sustainable construction and thus towards the fulfilment of SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities).

## Acknowledgements

This research was supported by the BIM-enabled Learning Environment for Digital Construction (BENEDICT) project (grant number: 2020-1-EE01-KA203-077993), Minimizing the influence of coronavirus in a built environment (MICROBE) project (grant number: 2020-1-LT01-KA203-078100), Strengthening University-Enterprise Collaboration for Resilient Communities in Asia (SECRA) project (grant number: 619022-EPP-1-2020-1-SE-EPPKA2-CBHE-JP) and the Integrating Education with Consumer Behaviour relevant to Energy Efficiency and Climate Change at the Universities of Russia, Sri Lanka, and Bangladesh (BECK) project (grant number: 598746-EPP-1-2018-1-LT-EPPKA2- CBHE-JP) all co-funded by the Erasmus+ Programme of the European Union. The European Commission support to produce this publication does not constitute an endorsement of the contents which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained there-in.

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ISSN 2585-6901 (PDF)
ISBN 978-9949-83-905-6 (PDF)