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

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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:

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

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.

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

where Si is the sum of scores of the i^{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.

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

where x_{ij} is the value of the i^{th} criterion in the j^{th} alternative, q_i is weight of the i^{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^{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:

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

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

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.

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

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

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 μ_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.

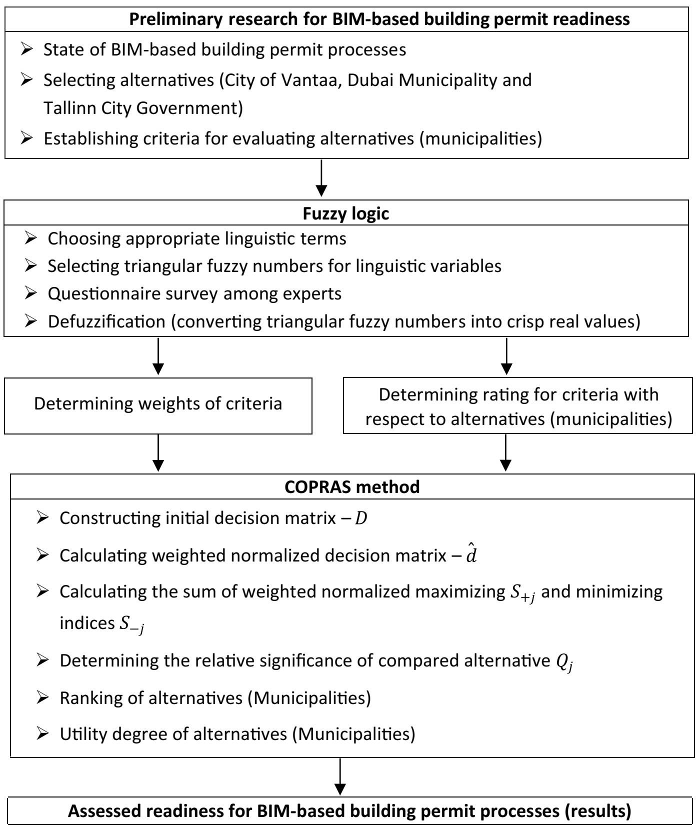

Figure 1. Methodology flow chart

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

Category	Criteria	Weights	Ranking: Category wise	Ranking: 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

Category	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.

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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

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