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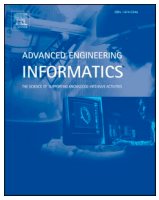

Full length article

The unbalanced research on digitalization and automation of the building permitting process

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ABSTRACT

The building permitting process is characterized by enormous complexity and multidisciplinarity. It consists of multiple steps, and many involved stakeholders with various responsibilities and personal goals. This, together with the fact that in common practice issuance of a building permit is mostly manual, makes the process long, inefficient and subjective. Digitalization of the building permitting process has been a subject of interest for many researchers. In this work, by implementing a systematic literature review, we map the existing knowledge gaps in the domain that hinder further development and facilitation of technological solutions within the building permitting process. This work demonstrates that the lack of fundamental research and the lack of detailed investigation of each individual sub-process within the entire permitting process, hinder further development of digital or automated solutions for building permitting. Furthermore, we provide a detailed mapping of the sub-processes that building permitting comprises of, as identified in the existing research. As much of the existing research efforts are focused on digitalization and automation aspects, we also provide a clear definition of the different levels of digitalization and automation of the permitting process.

1. Introduction

The issuance of a building permit is a crucial step for every construction project as it is the official permission to begin construction work. The building permit ensures the compliance of the design with the applicable law and provides the local administrations with control over the development of the city. Through the process of issuing a building permit, all relevant laws and regulations that ensure construction quality, user safety, environmental safety etc. are enforced. Although the building permit is only a small part of the building life cycle, it carries impact on both schedule and cost of a construction project. The phase of obtaining a construction permit is often the cause of delays and cost overruns [28].

With the recent technological development and its impact on the construction sector, the interest in streamlining the permitting process through digitalization grows [19,42]. Looking at building permitting from a construction management and process management perspective is an important approach to address efficiency improvement.

Interestingly, many sub-processes which collectively comprise the entire permitting process [13], are investigated individually, independent of the overall process. For example, there is much research on Automated Code Checking (ACC) [2] aiming to automate the process of checking and approving a permit. The basic assumption is that the submission process will rely on Building Information Models (BIM), as it enables implementation of technologies such as ACC [10]. Integration of BIM and Geographic Information Systems (GIS) is a topic that raises much research attention as an opportunity to provide support for decision making [32]. Any developments in that direction can be leveraged both for the area check and for ownership and development control. However, the existing research is fragmented, looking into individual challenges usually outside the context of the entire permitting process. Therefore, the main goal of this work is to explore the existing efforts aiming to digitalize or automate the permitting process, and provide a holistic view on the state-of-the-art research on the subject. This will help identify the knowledge gaps and required research directions to further develop the field.

1.1. The digital transformation in building permitting

According to the McKinsey Global Institute report [3], the

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construction industry suffers from a productivity problem. Construction productivity can be improved using digital tools, technology, automation and innovation. Three automation directions are recognized in the report as opportunities to increase the productivity in construction; one is robotic support for manual activities on site, the second is implementing modular construction and off-site manufacturing including 3D printing. The third recognized opportunity is the digitalization of design, planning and management procedures that can be followed by automation. The building permitting process is one such procedure, where unfortunately digitalization and automation are still very poorly adopted. In fact, we still lack an accepted definition of what is digitalization in building permitting. While some consider paperless permits as fully digital processes, others refer to higher level digital information management and even decision support tools as the goal for digital permitting [12]. Some of the existing research even present the potential of advanced technologies such as Augmented Reality (AR) to support different stakeholders involved in the permitting process [51]. In addition, Ammar et al [1] dealt with the Digital Twin approach and its connection with the building authority in the building life cycle.

In a survey performed by Riggs et al. [50] the state of the art in Internet Technology employed by planning departments of over 500 cities in the US found that only 21% of the cities offered an online application system for building permitting. We can expect that the number has grown since, not only in the US, however the capabilities of such online permit submission systems remain limited [4]. For example, checking the submitted requests is still performed manually either on 2D or 3D plans [39]. Important to mentioning is the BRISE Vienna project, which aims at digitally supporting the entire building permit process - from submission to issuance of the notice- in the city of Vienna. To this purpose, various methods such as artificial intelligence, augmented reality, and BIM are implemented to map a complete digital and partially automated building permit process [30].

In the systematic literature review performed by Papadonikolaki et al. [46], digitalization of the permitting process is recognized as a subject of future research in most of the existing work in the field. Furthermore, it was recognized that the idea of digitalization in construction is mostly explored on the level of individual projects, while processes such as permitting require research on an organizational level as they involve governmental agencies and local authorities. Many stakeholders play a role in the permitting process, both from the applicant side (e.g., developers, designers, owners), and from the approving side (e.g., local authorities, government agencies, city planners, regulators), making the process into a bureaucratic procedure that is often full of ambiguity and subjectivity. Implementation of new technologies in such complex environment is difficult, hence not surprisingly, the effect of the digital transformation that the construction industry is experiencing has been limited for permitting so far.

Given the situation described above, one of the aims of this work is to investigate the existing literature focusing on digitalization aspects of the permitting process in order to gain understanding of further required research to promote digitalization and automation of the building permitting process.

2. Aims and methodology

The objective of this work is to map the existing research efforts on digitalization or automation of the building permitting process. We assume the current research is fragmented, focused on specific sub-processes, and that in fact the research about the permitting process as a whole (the “big picture”) is mostly lacking. Therefore, we aim to synthesize the most substantial research that is directly focused on the building permitting process, to form a coherent view on the fields that have been to some extent correlated into the “big picture”, thus forming an understanding of the current state of the art and the existing knowledge gaps in the domain.

We aim to lay the foundations for a holistic view of digitalization of the permitting process. As a first step, we explore the building permit process as considered in research so far, in a very detailed way. We then examine the existing research in the direction of digitalization of the permitting process and identify the sub-processes that have been examined for potential digitalization, and those that have not. Reviewing the current state of the art in research about building permitting, allows us to identify the existing knowledge gaps and required directions for further research in order to advance the field.

2.1. Review method

As explained above, we are looking to map sub-processes within building permitting, and examine the existing digitalization efforts within these sub-processes. Unlike the existing work on the subject [42], we implement a very narrow and specific search strategy where the idea is to identify the contributions that are directly focused on the building permitting process (in its various aspects), and not the papers that focus on other procedures and only mention building permitting as related. The review process is performed in four stages as illustrated in Fig. 1. First, we search for relevant papers both on the Scopus and on the Web of Science data bases which are two of the largest databases for academic work. We use a variety of key words to search within titles, abstracts and key-words in order to identify as many contributions as possible which describe the process of building permitting. Eliminating work that is not in English, overall 468 papers were found on Web of Science and 337 papers on Scopus, including 65 papers that appeared in both databases. We then begin our filtering process by classifying the results into four classes: Relevant, Possibly relevant, Not relevant and Not available. This initial classification is based on a brief review of the abstracts. To improve robustness and to ensure that relevant contributions are not filtered out by mistake, the classification process was performed by three people individually. Every disagreement between the three opinions led to the paper being classified “Possibly relevant” so that it is examined again.

After another round of examination and elimination of “Not relevant” publications, we were left with 76 publications which were the subject of content analysis. First, 25 additional papers were filtered out as they are not considering the permitting process as the main theme, but rather mention it (usually in the abstract) in the context of the described work. The remaining publications were divided into two main groups: one group contains publications that focus on different views on the permitting process and the other contains papers focusing on digitalization or automation of procedures within the process. The first group was then examined in detail to produce a mapping of the procedures to consider within the permitting workflow. This mapping was further analyzed to gain understanding as to why some of the processes are investigated more than others. The content of the publications in the second group was also examined in detail, mainly to understand which efforts have been made to digitalize the different aspects within the permitting process.

2.2. Final papers for review

The final list of analyzed publications is presented in Table 1 for papers describing building permitting processes, and Table 2 for papers focusing on the digitalization and automation aspects of permitting.

While some of the identified papers are concerned with the permitting process as a whole, or with specific sub-processes within the permitting process, others are more focused on automation aspects. To identify the underlying topics of the papers we examined the authors’ keywords for each publication. The keywords should express the basic ideas described in the publications. To find the common interests in the collection of documents, we analyzed the keywords considering only those that repeat at least twice in the whole set. Fig. 3 illustrates the result of keyword analysis. We can clearly see that implementation of BIM and integration of GIS into the permitting process are two

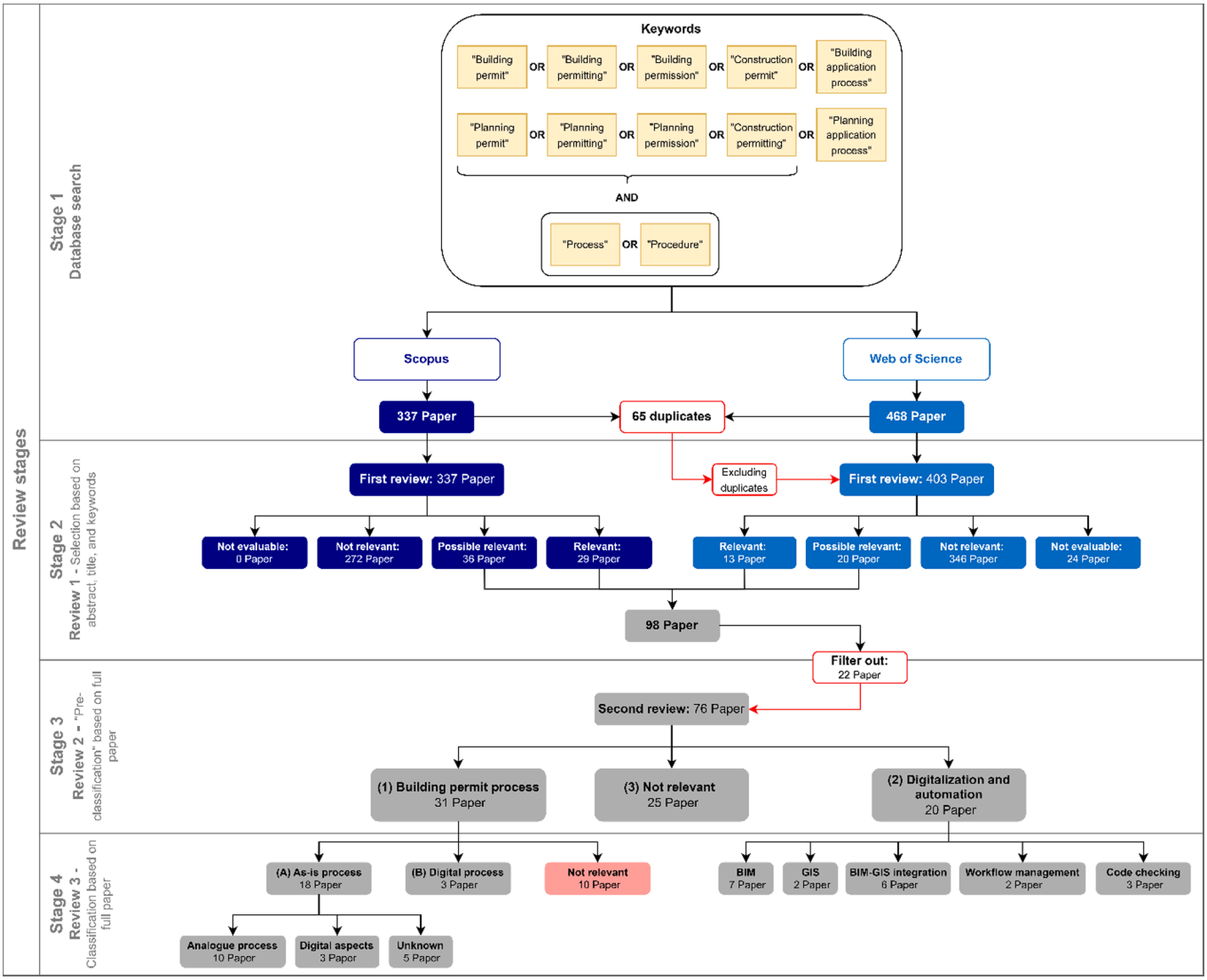

Fig. 1. Review method.

Table 1
Classification of publications focused on the process aspect of building permitting based on main topics.

Topic	Citation	Topic	Citation
As is process	[34]	**As is process (continue)**	[59]
	[31]		[47]
	[9]		[48]
	[11]		[49]
	[14]		[53]
	[15]		[54]
	[18]		[57]
	[22]	**Digital/Automated (future) process**	[19]
	[23]		[42]
	[24]		[27]
	[28]		

Table 2
Classification of publications focused on digitalization or automation of building permitting based on main topics.

Topic	Citation	Topic	Citation
BIM	[55]	**BIM-GIS Integration**	[7]
	[56]		[45]
	[39]		[20]
	[38]		[29]
	[8]	**Code checking**	[37]
	[43]		[26]
	[40]		[25]
GIS	[6]	**Workflow management**	[16]
	[58]		[4]
	[44]		
	[21]		

prominent underlying research topics. Another prominent topic is information flow and management. This is evident from the keyword e-government that expresses the aspect of technological communication opportunities with the authorities.

Looking at construction permitting from a global perspective, we can see that although the interest in the topic is rising in some parts of the world, in other parts there is no research on the subject (illustrated in Fig. 4).

3. Review of process related contributions

Most of the reviewed publications that are focused on the process aspect of building permitting, describe the building permitting process as it is implemented in different countries of the world (depending on the origin of the research). Nevertheless, half of these publications (nine out of 18) also discuss some aspects of digitalization and the need for future technological advances within the process. Three of the reviewed

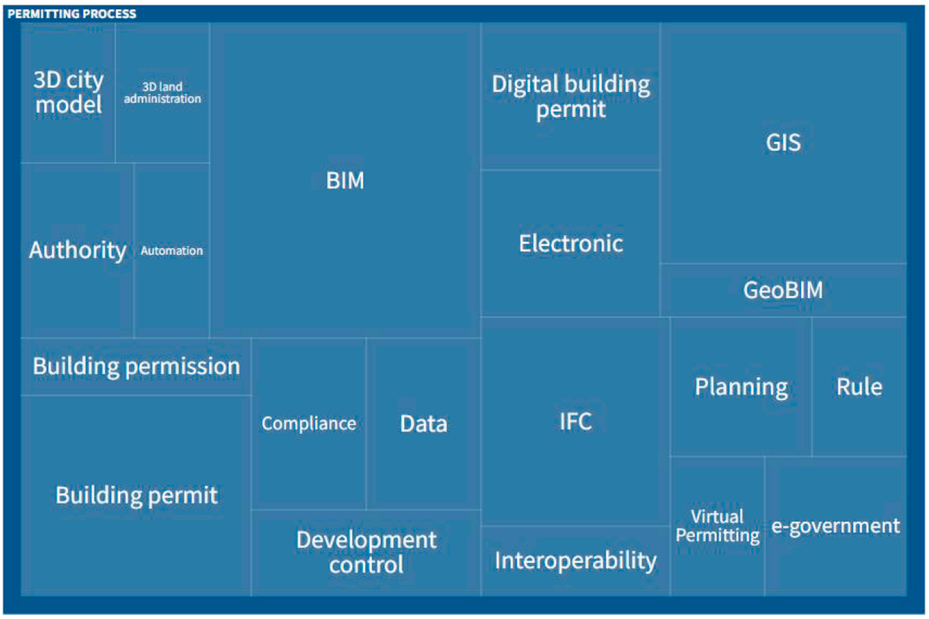

Fig. 3. Result of key words analysis for all relevant publications.

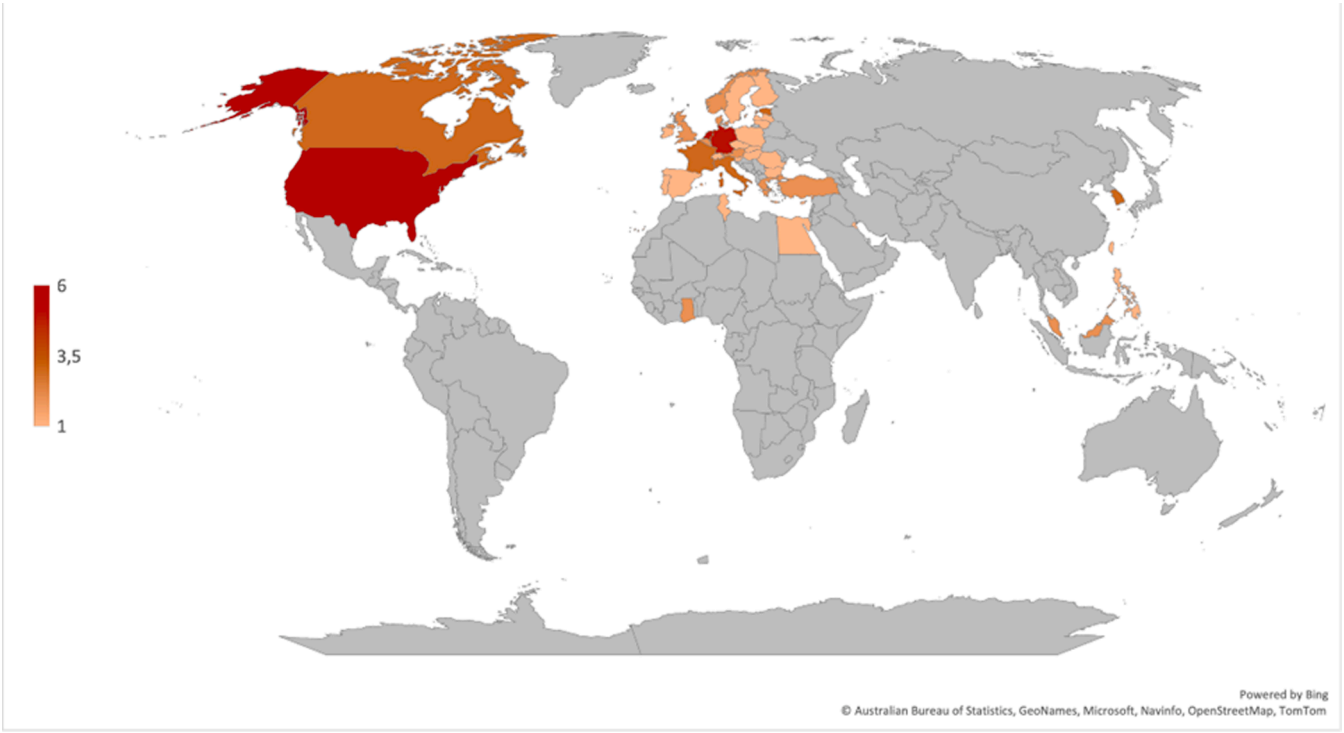

Fig. 4. Distribution of relevant publications based on the source country.

papers are focused on a suggested 'future' process for building permitting that heavily relies on technology such as BIM. A detailed analysis of the described processes and identified sub-processes (for both cases), is provided below.

3.1. Mapping the permitting process across the world

Table 3 and Table 4 illustrate all the sub-processes that were identified in the set of relevant publications. A total of 59 sub-processes were identified, which in turn are divided into different levels of detail: main sub-processes (in bold), and their associated lower-level sub-processes. The tables also show how often certain sub-processes were mentioned in the respective papers that were analyzed in this literature review. Sub-processes are assigned to 18 papers in total while two papers are listed twice since each of them refers to the building permitting process in two different countries. The work of Fauth and Soibelman [14] investigates Germany (column e) and the USA (column a), and the work of Guler and Yomraliogue (2021) includes details about the permitting process in Turkey and in the EU. Note that the article in column j is not focused specifically on the process, but rather mentions it mostly in the literature review while referring to the work of Meijer et al. [36], Meijer and Visscher [35] and Noardo et al. [41].

Table 3
Detailed mapping of the sub-processes and research efforts referring to each of the sub- processes (Part A).

	Process steps / Countries / Articles	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	Summary
		North America				Europe									Africa				Asia			
		[14] Fauth & Soibelman, 2022 (USA)	[11] Eirinaki et al., 2016 (USA)	[57] Whitell et al., 2020 (Canada)	[22] Shahi et al., 2017 (Canada)	[14] Fauth & Soibelman, 2022 (Germany)	[49] Ponnewitz & Bargstaedt, 2019 (Germany)	[24] Kettner & Diaz, 2000 (Germany)	[53] Sonntag & Wimmer, 2003 (Austria)	[48] Plazza et al., 2019 (Italy)	[18] Guler and Yomralioglu, 2021 (EU)	[47] Pedro et al., 2011 (EU)	[34] Meijer & Visscher, 2006 (EU)	[18] Guler and Yomralioglu, 2021 (Turkey)	[15] Fawzy et al., 2020 (Egypt)	[23] Karoui et al., 2016 (Tunisia)	[54] Tengan et al., 2018 (Ghana)	[28] Kpamma & Adjei-Kumi, 2013 (Ghana)	[9] Omorog et al., 2018 (Philippines)	[59] Yaakup et al., 2007 (Malaysia)	[31] Lee & Chiang, 2017 (Taiwan)	
1	**Application preparation**	**X**		**X**	**X**	**X**						**X**	**X**			**X**	**X**			**X**		**9**
2	• Pre-consultation				X						X									X		**3**
3	• Compile application requests requirement list																		X			**1**
4	• Obtaining site validity certificates														X							**1**
5	• Obtaining construction conformity certificate from construction														X							**1**
6	• Participation (by applicant)	X		X													X					**3**
7	• Collect statements	X																				**1**
8	• Assess statements	X																				**1**
9	• Zoning review process (by applicant)				X																	**1**
10	**Submission**	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**		**X**		**X**	**X**	**X**	**X**	**X**	**X**			**15**
11	• Initial check of the application during in-person meeting with applicant			X																		**1**
12	• Zoning Amendment Application (optional)				X																	**1**
13	**Formal review (planning department)**	**X**																				**1**
14	**Content review (planning department)**	**X**															**X**					**2**
15	• Hearing	X																				**1**
16	• Meeting with supervisor	X																				**1**
17	• Property condition check							X														**1**
18	**Formal review (building department)**	**X**		**X**	**X**		**X**	**X**											**X**			**6**
19	• Completeness check							X														**1**
20	**Registration**			X																X		**2**
21	• Import application into a Public Administration Software			X																		**1**
22	Assignment among plan reviewers		X	X			X	X														**4**
23	Payment		X	X					X	X		X					X	X	X			**8**
24	Applicant presents building application																		X			**1**
25	Land title confirmation																	X				**1**
26	Site inspection								X						X		X	X		X		**5**
27	Building committee meeting									X						X						**2**
28	Security commission															X						**1**

It is also important to note that the order of the sub-processes shown in Table 3 and Table Table 4 is not consistent and cannot be projected to reality in every case. Examples are that sometimes the participation of other agencies to obtain comments is done by the applicant before submitting the building application and sometimes the participation is done by the authorities. Another example is formal review which, in most cases, takes place directly after the submission of the application. But in some countries, formal review is repeated at the end as a final completeness check. Payment is also a sub-process that can take place either at the very beginning or at the end of the review.

A detailed analysis of the reviewed papers reveals that not all the identified sub-processes were mentioned in all the publications concerning the building permitting process, even if the same country is investigated. As illustrated in Table 3 and Table 4, only four of the identified sub-processes were mentioned between 11 and 19 times within the set of relevant publications. This concerns content review by the building department (mentioned 18 times), submission (mentioned 15 times), issuance of the building permit (mentioned 13 times), and participation (mentioned 12 times). Nine of the sub-processes were mentioned between 5 and 10 times. This concerns application preparation (mentioned 8 times), payment (mentioned 8 times), review of building regulation (mentioned 7 times), formal review by the building department (mentioned 6 times), inspection during construction (mentioned 6 times), review zoning regulations (mentioned 5 times), decision (mentioned 5 times), start of construction (mentioned 5 times), and issuance of completion certificate or occupancy permit (mentioned 5 times). However, a total of 39 sub-processes were mentioned only 1 or 2 times, which underlines the high diversity of the process but most importantly the variance and incompleteness of the existing research. While it is clear that some of the sub-processes are receiving much more attention than others, we can also see inconsistencies within the existing research efforts, even when the process of the same country is investigated.

The articles in Table 3 and 4 are sorted relative to their regional affiliations (continents) to see the regional differences and similarities. It is interesting to see that there are not many obvious similarities (besides the main process steps). For instance, for the German cases (columns e, f, and g) there are similarities in line 22 or 35, but there are also mismatches. We would expect that investigating the permitting process in a specific country, although by different researchers, would lead to identification of the same sub-processes. However, as shown in Table 3 and 4, in some cases different sub-processes were identified. Same is true for Ghana (columns p and q) where there are matches for example in lines 23 and 26, but mismatches in lines 25 and 46. Both the implemented methodology and the level of detail in each of the research efforts is different which may be the reason for these mismatches. We can

Table 4
Detailed mapping of the sub-processes and research efforts referring to each of the sub- processes (Part B).

	Process steps / Countries / Articles	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	
		North America				Europe									Africa				Asia			
		[14] Fauth & Soibelman, 2022 (USA)	[11] Eirinaki et al., 2016 (USA)	[57] Whitell et al., 2020 (Canada)	[22] Shahi et al., 2017 (Canada)	[14] Fauth & Soibelman, 2022 (Germany)	[49] Ponnewitz & Bargstaedt, 2019 (Germany)	[24] Kettner & Diaz, 2000 (Germany)	[53] Sonntag & Wimmer, 2003 (Austria)	[48] Plazza et al., 2019 (Italy)	[18] Guler and Yomralioglu, 2021 (EU)	[47] Pedro et al., 2011 (EU)	[34] Meijer & Visscher, 2006 (EU)	[18] Guler and Yomralioglu, 2021 (Turkey)	[15] Fawzy et al., 2020 (Egypt)	[23] Karoui et al., 2016 (Tunisia)	[54] Tengan et al., 2018 (Ghana)	[28] Kpamma & Adjei-Kumi, 2013 (Ghana)	[9] Omorog et al., 2018 (Philippines)	[59] Yaakup et al., 2007 (Malaysia)	[31] Lee & Chiang, 2017 (Taiwan)	**Summary**
29	**Participation**		**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**				**X**		**X**		**X**	**X**	**13**
30	• Hearing of involved parties								X													**1**
31	• Collect statements					X																**1**
32	• Assess statements					X																**1**
33	**Content review (building department)**	**X**	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**19**
34	• Review zoning regulation	X			X	X	X														X	**5**
35	• Review building regulation	X		X	X	X	X	X												X	X	**8**
36	• Review construction law																				X	**1**
37	• Mechanical plan examination				X																	**1**
38	• Fire revision examination				X																	**1**
39	• Prepare technical report																			X		**1**
40	• Consultation with applicant	X				X														X		**3**
41	• Meeting with supervisor	X				X																**2**
42	• Recommendation to statutory planning committee (SPC)																X	X				**2**
43	• Review planning policies (by town planning committee)																			X		**1**
44	**(Final) Formal review**			**X**																		**1**
45	• Check stamps			X																		**1**
46	• Check payment			X													X					**2**
47	• Check participation statements			X																		**1**
48	Decision				X			X			X					X			X	X		**6**
49	**Issuance of the building permit**	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**		**X**			**X**		**X**	**X**	**X**			**13**
50	• Forwarding to District Assembly's Works Department																X					**1**
51	• Issuance notification letter for construction start											X					X					**2**
52	Start of construction										X	X	X	X	X							**5**
53	Obtain approval of the construction conformity														X							**1**
54	Inspection during construction		X								X	X	X	X	X							**6**
55	Construction completion (notification)										X	X	X	X								**4**
56	Submit construction conformity certificate														X							**1**
57	Final inspection										X	X			X							**3**
58	Issuance of completion certificate (Occupancy permit)		X								X	X	X	X								**5**
59	Archiving							X		X												**2**

assume that in some cases the interviewees or participants just missed telling sub-processes assuming they are obvious.

Some sub-processes are very specific and unique. This depends, for example, on specific regulations in the respective countries. Other articles refer to a specific type of building (e.g., high-rise buildings). There is a great diversity in the examination of the regulations. The regulations in each country are structured differently and refer to different contents that have to be checked by the building authorities (mechanical plan examination is not approved by authorities in every country). Thus, the different planning and building codes affect the building permit processes. Another example that the tables clearly illustrate is that there are several commissions and committees (e.g., lines 27, 28, and 42) in different countries, and this is also described in the publications. In some countries, there are several commissions, which supplement or replace the statements obtained from other agencies or authorities. In other countries, however, there are no commissions and committees at all.

In conclusion, we can clearly see that some sub-processes are investigated more than others. This may be due to the fact that the process has not been studied and documented in sufficient detail. For example, Lee and Chiang [31] focus on participation and content review only. Furthermore, some studies are limited to a certain area (e.g., sub-processes within an authority), or the sub-processes do not play a role for a certain discipline (e.g., geospatial science does not look into interior engineering regulations).

With the analysis it becomes clear that a great deal of tacit knowledge is associated with the building permit process. This makes it difficult to fully document the processes, since seemingly obvious processes (e.g., payment) are not investigated and documented, or only insufficiently. An additional difficulty is the terminology used in the domain of building permitting. Some terms appear to be specific to the respective country, or face an issue in terms of translation into English. This means that it cannot always be safely assumed that an exact definition is involved. For example, the concept of building permitting means generally "building submission" in Austria which is actually just a subprocess on an international perspective. We also encountered synonyms used for describing the same subprocess such as for content review: technical review, final review, application check, and inspection of design.

The relevant publications can be classified into four levels of detail as suggested by Fauth [13]:

- Level 0 represents a general overview level where usually a view on the phases performed by different stakeholders is provided. For example, design stage by applicants, review stage by authorities, or construction stage.
- Level 1 represents major sub-process steps such as the steps denoted in bold in Table 3 and 4.
- Level 2 considers content-wise sub-processes. For example, the lower-level sub-processes within each of the major process steps.
- Level 3 represents sub-processes related to conformity issues, for example a deep investigation into the specific requirements within a specific content-wise sub-process.

Fig. 5 illustrates how often each level of detail was implemented in the set of reviewed publications. Three of 18 articles represent research efforts on level 0, six articles for level 1, which means a low detail representation. Level 2 is implemented in nine publications. However, level 3 was not found at all. The question arises what level of detail would be needed for digital transformation of the building permitting process. We can assume that the level of detail in the existing efforts is the aftermath of the selected research methodologies. Fig. 6 shows the methodologies used for the investigation of the process. Although all methods seem reasonable, we do not see an indication to the most suitable method or combination of methods.

3.2. The future of permitting process

Three of the identified relevant articles [42,27]and [19] introduce a future or a 'to-be' building permit process. The identified sub-processes within these publications are illustrated in Table 5. Note that the work of [19](in column a) relies on the process as it is described in [52]. The level of detail described in the articles is very different (either level 0 for column a or level 2 for columns b and c). While Shahi et al. [52] roughly shows the whole process in submission, review, construction, and operation with the respective BIM and GIS usage, Kim et al. [27] describes the process in detail by including different developed country-specific software applications in South Korea. In contrast, Noardo et al. [42] shows a summarized flow (split between applicant and authority), which mainly considers the provision and preparation of BIM and GIS information.

It can be seen that the basic processes (see Table 3 and 4) remain largely the same, but they are supported by technological systems. The change in the processes lies, among other things, in the preparation of BIM models and their integration into GIS systems and verification of the BIM models created. As a result, we see much more sub-processes in the responsibility of the applicant. The shift of sub-processes to the applicant plays an important role here. Compared to the as-is processes, a numerous number of sub-processes before or along with the submission is provided. Some manual sub-processes, such as the verification of regulations, is performed or supported by software applications. Subsequently, only the output reports are checked manually. It shows that the innovation grade is different, too.

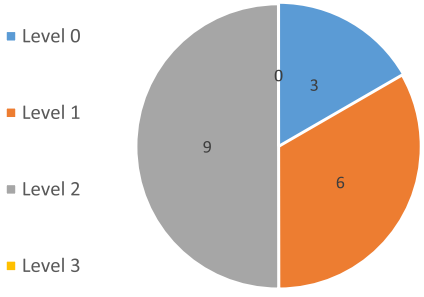

Fig. 5. Classification of publications describing "as-is" permitting processes based on the level of detail.

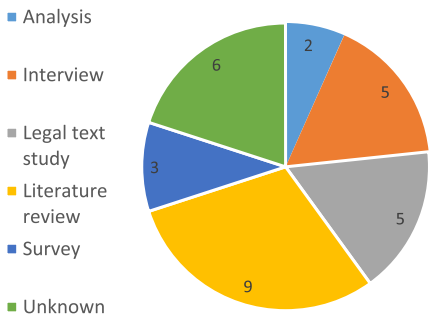

Fig. 6. The different methodologies implemented in the reviewed publications focused on building permit process.

Table 5
Mapping the reviewed articles based on suggested future building permitting process.

	Process steps	Articles			
		a	b	c	Summary
		[19] (Canada)	[42] (n.a.)	[27] (South Korea)	
1	**Application preparation**		**X**	**X**	**2**
2	Rule interpretation and digitalization		X		**1**
3	Rule-based BIM model pre-checks			X	**1**
4	Preparation of 3D city model and geodata		X		**1**
5	Pre-consultation and preliminary analysis		X		**1**
6	BIM modeling and IFC export		X		**1**
8	**BIM model quality check**			**X**	**1**
9	Submit IFC files to Quality Center			X	**1**
10	Select checking purposes			X	**1**
11	Check			X	**1**
12	Get checking result			X	**1**
13	**Submission**	**X**		**X**	**2**
14	Electronic submission (using BIM and GIS)	X			**1**
15	Extract necessary information (BIM model and external data)			X	**1**
16	Generate XML file			X	**1**
17	Submit to SEUMTER system			X	**1**
20	**Formal review**		**X**	**X**	**2**
21	Conversion 3D city model / geodata		X		**1**
22	Quality check of the BIM model			X	**1**
24	**Content review**	**X**	**X**	**X**	**3**
25	Automatic regulation and planning check (using BIM and GIS)	X		X	**2**
32	Issuance of the building permit		X	X	**2**
33	**Construction**	**X**			**1**
34	Inspections (using BIM and GIS)	X			**1**
35	**Operation**	**X**			**1**
36	BIM and GIS based asset management	X			**1**

4. Review of automation opportunities

In many countries, government agencies are searching for solutions to increase productivity in all stages of construction projects, including permitting. As part of their efforts, more countries are now implementing a digital online application system as part of their e-government services to replace the paper-based permitting process. In most cases this is an online sophisticated document management platform integrated with the ability to manage and control a predefined workflow [17]. Based on Meijer [33] an online electronic system has positive effects on the process as it improves communication between the different agencies involved in reviewing and approval of the requests, and increases transparency. Despite the many research efforts to reach higher levels of digitalization and even some automation, the common practice remains of digital platforms for document management. Document management is very different from information management and certainly from any sophisticated tools for decision support that are being developed in hopes to improve the permitting process.

In most countries, there are two parts within the permitting process that deal with plan checking. The first part is the area check, or zoning check to make sure that the planned building conforms to the city plans in terms of land use, design requirements, facility planning, etc. This requires integration of both GIS data as well as BIM data. The second part is the detailed engineering check, assuring conformance to the building codes and regulations. While this does not require GIS data, it relies on both the digital representation of the design as well as a digital representation of the regulations. Much of the benefits that the use of BIM brings to the process is the ability to check the plans automatically. Integrating between BIM and GIS provides the opportunity not only for an engineering perspective design check (code compliance), but also for inspection of various visual criterions. In the work of Olsson et al. [44], BIM and geospatial data was utilized to automatically check the planned building's height, footprint and general maintenance aspects considering the building on the built up area. Furthermore, they classified the property criteria to be checked based on the requirements in Sweden into three groups: quantitative, visual and qualitative. Based on their analysis, 30% of the quantitative requirements can benefit from the integration of BIM and geospatial data for reviewing a permit request. Although the presented plan checking results are accurate based on a comparison with manual calculations, the used BIM models had to be extensively pre-processed for obtaining a checking result. For example, specific *IfcSlab* and *IfcWall* entities that do not correctly represent the building area had to be filtered out. This is in fact a well-known problem within the automated code compliance checking domain. Any regulations that we would like to automatically check, require specific information to be explicitly presented in the BIM models [5]. This has a direct impact on the information flow within the permitting process. Namely, it is not enough to allow applicants to submit a BIM model, it is also necessary to clearly define the information types that must be represented within BIM models. The development of an initial Model View Definition (MVD) for integrating the specific information related to structural assessment to be delivered as an IFC file in the permitting process was the focus of study of Ciotta et al. [8]. However, they focused on formal definition of the concepts to be represented in the MVD and point to the lack of computer-readable regulations as a drawback to implementing ACC in the permitting process.

GIS integration within the planning process is crucial not only to review permit applications, but also for planning on the strategic level. Such a system can allow a good and accurate information flow both from the authorities to the applicant as well as from the applicant to the authorities. As described in [58], the information flow from the applicants to the local authority in Malaysia is provided in a form of a development proposal report that includes description of status of the land, land use analysis, the potential of the site, surrounding development etc. That information is then kept internally within the authorities. Their work demonstrates how GIS can facilitate this information flow for development control for the authority as well as for planning authorization (submission and approval of applications). However, as stated in [58]implementing such a system requires to change the way of thinking among the various participants, especially in terms of cooperation and information sharing within the city hall departments. In fact, the complementarity of BIM and GIS has been acknowledged by many researchers. In the work of Chognard et al. [7], the authors focused on exploring the possibility to transform GIS data into a BIM compatible format to be used as reference in the project development stage in a BIM environment. The goal is to later update the GIS system with the new developed design ("As built" data). The focus is on the data exchange perspective through the use of IFC which proved to be feasible and beneficial to both the designers and the municipalities in a digital permitting environment.

The IFC format proved to be suitable for facilitating information that is relevant to building permitting in several other research projects as well [45]. The use of open BIM for building permitting has also been investigated in the work of [43]which is focused on establishing the readiness level of the practitioners to implement permitting procedures relying on IFC data as it is produced in common practice by the authoring tools. However, given that most modelers are not very concerned with the IFC output but rather with the native information represented in the authoring tool, the quality of the information required in the process cannot be assured. Therefore, the work of [43]focused mainly on the geometric aspects with the minimum associated semantics. Based on their initial investigation into extracting required information to enable an automated check of the building's height and the required parking spaces, they propose several guidelines to the modelers such as providing a proper georeference to specific building elements, assigning required attributes to zones, etc. However, they only cover a small portion of requirements that are relevant to a specific procedure within the permitting process which is the zoning check.

A more thorough investigation into the data requirements to facilitate an automated building permitting process is necessary. Although the BIM-GIS integration attracted much researcher's attention [29], there have been very limited efforts towards automation of checking zoning regulations in the context of building permitting. As found in a recent review by İlal and İlal [21], most papers on the subject of BIM-GIS integration are focused on various interoperability aspects and information exchange between the platforms, but only five papers were found in their review focusing on automated zoning checks.

In that field, Brasebin et al. [6] propose a model for representing urban regulations and formulizing rules using Object Constraints Language (OCL) that can be implemented for checking if suggested building complies to the urban restrictions. In the work of Hobeika et al. [20] three sets of requirements relying on BIM and GIS information were implemented and checked. One is the requirement for the proposed building's footprint to fit within the limits set for the plot based on the municipality's guidelines. Another check is focused on the height of the proposed building, and the last is concerned with detecting neighbouring roads and assessing the admissible overhang over these roads. Although facing some technical difficulties like long run time and poor visualization, they demonstrated the benefit of integrating BIM and geospatial data to achieve not only digitalization, but also automation within the permitting process.

We observe a similar pattern in research of code compliance checking (ACC). Despite being a widely researched subject [2]that can greatly enhance the permitting process, only a handful of papers on ACC were discovered during our search. Most research efforts keep the connection to the permitting process very loose and ideological but do not deal with the practical integration of such procedures within the building permitting. This is evident when comparing the analysed data sets in previous reviews on code checking to the data set in this work. In a review by Amor and Dimyadi [2], extensive history of research in the domain is presented. Their work includes an overview of 17 systems for ACC (some of which are designed specifically for permitting like the

CORENET [17], different approaches to code checking, and existing challenges. This forms an extensive knowledge base on the subject which is focused on the digital representation of the design and the regulations, but lacks the fundamental knowledge on how such systems should be integrated within permitting. Other reviews on the subject of code checking exist as well, for example [60]which is focused on challenges in rule representation, but they as well do not address the issue of code checking within permitting.

The challenges of adopting and implementing advanced technologies, BIM in particular, in the AEC industry and specifically in the public sector has been extensively investigated. Furthermore, the challenges of implementing BIM for permitting tasks have been mapped out using the Tallinn municipality test case [55]. This includes a variety of technological factors, organizational factors and environmental factors. But of course, in different countries the major challenge could be a much more basic, such as the lack of knowledge. A survey in the state of Florida [38] found that 58% of building officials and 60% contractors and design professionals who participated in the survey are not familiar with BIM technology. Although majority of design professionals were supportive of implementing BIM in the permitting process, when building officials were asked of their opinion, only 50% of the survey participants expressed support for integrating BIM for permitting [38]. Using interviews to map the stakeholder's perception of the factors that influence BIM adoption in the permitting process,[56]concluded that the factors affecting BIM adoption in the permitting process are different than those affecting the BIM adoption in the entire AEC industry. One of the influencing factors is that there are no BIM-based platforms that are tailored to the requirements of the permitting process through its stages. This includes not only the information exchange aspects but also design review capabilities as well as integration with geospatial information of the city. The need to represent the required information in an agreed upon manner within the BIM models in order to enable automation of checking according to the permitting process, has been pointed out in the context of permitting for prefabricated buildings in [37]. However, the exact requirements for BIM-based exchange model to enable automation and streamline the permitting process have not been defined yet. It is also not clear if the requirements will be scalable to different local authorities and to different building types, for example will the same tools be applicable to on-site construction and as well as to prefabricated buildings. As concluded in [16]an efficient design review process can greatly contribute to reduce requirements for corrections, and therefore rework, and streamline the whole permitting process. This aligns with the findings of [39]who used survey questions for design examiners and showed that the number of corrections is the most significant factor for delays in the permitting process.

5. Discussion

As demonstrated in this work, although some digital solutions for permitting have been conceptualized before, they usually do not consider all the sub-processes involved. Furthermore, while some sub-processes gain much research attention others are completely ignored. Specifically, sub-processes that may appear trivial such as submission, assignment, payment, etc. are usually overlooked. Each such sub-process relies on decisions intuitively made by different stakeholders based on their policies, business plans, knowledge etc. A digital permitting system can provide an automated decision-making support engine for these sub-processes as well. Taking assignment for example, every time a new application gets to the department manager at a municipality, that manager has to decide to which plan checker the application should be assigned to. This decision is usually not random, it relies heavily on the department's policy and considerations such as work load distribution, expertise, etc. This implicit decision-making workflow can be supported by automation, thereby relieving the decision makers to the difficult engineering tasks which require human interpretation and understanding. This brings out the ultimate question of how much automation should we really strive for within the permitting process, and what are the exact sub-processes that should (and can) be automated? While some sub-processes are composed of prescriptive, repetitive and time-consuming tasks which can be supported by automation, permitting also involves tasks that require human expertise and creativity which cannot be automated.

Based on the findings of this work we can see four distinct levels of digitalization\ automation to be considered as depicted in Fig. 7. In common practice, many municipalities around the world abandon the paper-based manual permitting, and implement an online digital system for submission and issuing of building permits. However, that system remains completely manual as it only provides a sophisticated tool for document and process management. The next level of digitalization is focused on information management, including information about the integration of the individual building within the view of the build environment. This includes two major challenges, one is adopting a BIM-based permit submission system, and the other is integration between BIM and GIS. At the highest level, the digital process is integrated with decision making support tools such as automated plan checking tool and automated code checking tool. Existing research on the subject is compartmentalized, focused on very specific niches within the permitting process and usually does not investigate the information flow between the stakeholders and between the systems (administrative information, BIM, GIS, and automated tools) within the process as a whole. This is one of the main challenges in moving towards the next level of digitalization in the permitting process.

Moving towards automation has many implications on the process itself but also on the stakeholders and the shared responsibilities between them. Automation usually reduces subjectivity as the decisions are made based on strictly defined rules and policies and not affected by the human factor. However, relying on the machine, legal liability considerations need to be addressed.

Currently, sub-processes are mostly investigated on a very coarse scale. When classifying the papers dealing with digitalization or automation efforts (group 2), based on the same classification system as described in section 3.1, we see that 30% of the analysed papers are classified as level 3 (see Table 6). This should be expected since development of automated solutions should rely on very detailed analysis of the sub-processes that we are aiming to automate, which is clearly missing in the literature as demonstrated in Fig. 5. In an attempt to compensate for this gap, much of the existing work focuses on very small specific test cases and investigates them individually i.e. dealing with specific zoning rules like regulations on building height.

To conclude, in order to advance in the field, it is crucial to investigate the permitting process on a much higher level of detail to enable development of complete and comprehensive digital or automated tools. However, it is also crucial to investigate these tools in an integrated way, in the context of the 'big picture', considering how these tools tie together to provide one comprehensive solution. This work demonstrates that while the research on process investigation tends to be 'Top down', it fails to reach the required level of detail to enable digitalization/automation. On the other hand, research that includes development of solutions tends to be 'Bottom up', however it is focused on the very specific tasks and mostly fails to generalize.

5.1. Limitations

This work relies on a literature review to identify and present the state of the art in research about building permitting. Since much of the terminology on the subject originates from direct translations from different languages, we assume that not all existing research efforts were identified. From the analyzed work we can also see inconsistencies in the used terminology between the papers which strengthens the aforementioned concern. Although diverse terms were used at the search phase (as described in the methodology section), some relevant publication may not have been found due to the terminological differences. In

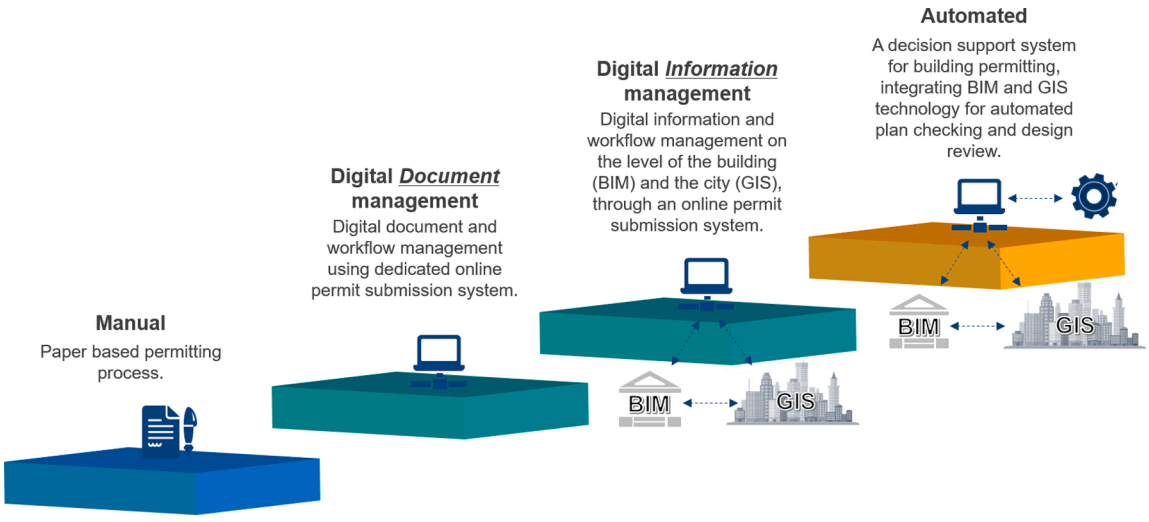

Fig. 7. The levels of digitalization and automation in the building permitting process.

Table 6
Classification of all reviewd publications based on the level of detail.

Level of Detail	Process Investigation	Digitalization\ Automation
Level 0	3	2
Level 1	6	6
Level 2	9	6
Level 3	0	6

addition, some countries may not have published relevant research in English, while there are publications on the subject in other languages which are missed in this review. Nevertheless, the examined papers provide an overview of the topics of interest within the domain of permitting, and make it possible to define future directions and existing knowledge gaps.

6. Conclusions

The process of obtaining a building permit is complex and time-consuming and has an effect on the workflow of any construction project. Not surprisingly, many researchers developed hope for improving the process through digitalization. However, as shown in this work, digitalization is a wide concept that can be divided into several levels that eventually should lead to automation. As illustrated in this work, the distinction between the existing levels is not well defined and not uniformly comprehended amongst the researchers in the field. One of the contributions of this work is the distinction between the different levels of digitalization in the building permitting process. As described above, digitalization can have two very different levels; one of process management and one of information management. The final level of 'Automation' builds upon the digital information management system and enhances it with decision support tools. One issue that has not been addressed so far, and is crucial for further advancing the field, is a clear definition of which sub-processes can benefit from such tools, or what level of automation should we even strive for in the overall process and in each sub-process individually.

It is evident that the existing research efforts towards digitalization are mostly too shallow in the context of process investigation, but on the other hand too specific in the context of automation. It is interesting to see that although the importance of data sharing and information flow within the process is clearly recognized, there is very little research that demonstrates such information flow for digital permit processes *as a whole*, while considering all the sub-processes together. Although the existing permitting process is investigated in different parts of the world, the research methodologies and the achieved level of detail differ greatly, which makes the results of existing work not comparable. Understanding the common practice is a crucial knowledge base required for further development of comprehensive solutions. Meaningful research on the subject has to present higher levels of detail than usually considered in existing research.

To sum up, there is a great mismatch between the work focused on permitting process investigation and the efforts towards digitalization. While process investigation efforts mainly adopt the 'Top down' approach, they fail to actually drill down to the required level of detail to support digitalization and automation. On the other hand, efforts towards automated tools tend to (understandably) adopt the 'Bottom up' approach, but fail to generalize and to connect the individual efforts into a holistic solution. In addition, much fundamental research is still lacking in order to facilitate further development of digital or automated solutions. This includes first and foremost the definition of possible, required and acceptable levels of automation in each sub-process and in the overall permitting process.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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