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GLOBAL ADVANCEMENTS IN BIM-BASED BUILDING E-PERMIT SYSTEM ADOPTION: A REVIEW

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Abstract. Globally, several countries have begun to promote the application of building information modeling (BIM) technology and implement BIM-based building e-Permit systems. Despite the relatively rapid updates in the field of BIM-based building e-Permit systems, currently a lack of systematic sorting and summarization exists. This review evaluates the situation of seven representative countries from three aspects: the current adoption status of the BIM-based building e-Permit system, adoption background (BIM-related policy, roadmap, standards, and guidelines), and a future development plan for digital construction. These three aspects are analyzed, common measures across these countries are summarized. Four viewpoints are extracted for promoting BIM-based building e-Permit system adoption, which are mandatory policy orientation, standardization, internationalization, and intelligence. Finally, as the integration of AI into BIM-based building e-Permit systems is a recent research trend, this study also investigates existing research, highlights bottlenecks and points out future directions for AI integration.

Keywords: building information modeling (BIM), Industry Foundation Classes (IFC), BIM-based building e-Permit system, automated code compliance checking, artificial intelligence (AI).

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1. Introduction

With the development of information technology (IT) and maturing of technologies such as artificial intelligence (AI) and big data, various industries are undergoing digital transformation. The construction industry conventionally employs paper-based drawings, with a relatively low level of digitization. Building information modeling (BIM) technology incorporates features such as visualization, coordination, and information completeness, which can better serve engineering construction and provide data foundation for digitizing the construction industry. Various countries have begun emphasizing the application of BIM technology in the construction field and mandate the submission of BIM models for building permit (Eastman et al., 2011; Pan & Zhang, 2023).

Many countries have established their building e-Permit systems, typically consisting of an online platform and document workspace that connects municipal authorities and other government agencies with AEC professionals to complete the submission, review, and approval process for building permits. Despite the mandatory submission of BIM models, the submitted models has no significant impact on the permitting process, the building approval is still based on traditional 2D drawings. Since automated code compliance checking technology can check BIM models against building codes, numerous countries have begun integrating this automated code compliance checking technology into their existing building e-Permit systems, known as the BIM-based building e-Permit system. The system typically comprises three parts: submission of BIM models, automated code compliance checking, and generation of checking reports (Kim et al., 2020; Noardo et al., 2022; Shahi et al., 2019; Sing & Zhong, 2001).

In several countries, significant efforts have been invested in the promotion of the application of BIM technology and implementation of BIM-based building e-Permit systems, including formulating BIM-related policies, establishing BIM standards and guidelines, and developing automated code checking systems and future digital building development plans.

For example, by 2015, Singapore required public projects that exceed 5000 m^2 to be submitted using BIM and developed the world's first online electronic submission system (CORENET) for building administrative approval. Recently, the Singaporean government incorporated various disciplines by integrating seven government departments related to the approval process and developed a comprehensive approval system called CORENET X (Kim et al., 2020). South Korea launched an eight-year large-scale Korea BIM (K-BIM) research and development project from November 2013 to December 2021 and has made considerable efforts in the development of a BIM-based building e-Permit system (OpenBIM Research Group [ORG], 2024). The United Kingdom (UK) has established a network called "D-COM" to integrate the forces of academia and industry and jointly promote the digitization of compliance checking processes in building environments (D-COM Network, 2024). The Center for Digital Built Britain [CDBB] in the UK also provided a comprehensive summary and analysis of achievements in the field of automated code checking in academia and industry in the final report of D-COM in 2019 (CDBB, 2019). In 2017, the buildingSMART International [bSI] established a separate regulatory domain to promote the application of automated compliance checking systems in government building approval processes (bSI, 2024). In 2013, Norway conducted a comprehensive survey of automated digital solutions related to global building permit applications and approvals to develop a building e-Permit system (Holte Consulting, 2014). Recently, the European Network for Digital Building Permits [EUnet4DBP] was established to accelerate the digital transformation of the building permit process (EUnet4DBP, 2024).

Recently, an increasing number of studies have investigated the current status of application of BIM Technology, BIM-based building e-Permit system, and related automated code checking technology, presenting comprehensive summaries. Several relevant articles, books, and reports on this topic have been published.

Cheng and Lu (2015) presented a systematic summary of the application of BIM in various countries, including its development goals, implementation status, and relevant BIM standards. Amor and Dimyadi (2021) summarized compliance checking from a technical perspective, and they highlighted the challenges of sharing digital architectural and engineering design information. Muto (2020) sorted the permit approval processes in various countries and developed common e-submission guidelines for incorporating BIM technology into the building approval process. In 2013, Norway conducted a comprehensive survey of automated digital solutions related to global building permit applications and approvals to develop a building e-Permit system (Holte Consulting, 2014). The Center for Digital Built Britain (CDBB) in the UK also provided a comprehensive summary and analysis of achievements in the field of automated code checking in academia and industry in the final report of D-COM in 2019 (CDBB, 2019).

Currently, various countries are actively exploring the implementation of BIM-based building e-Permit systems and taking different measures. In order to summarize the experiences and practices of these countries and provide directional guidance for the development of this field, the authors refer to the above summary reports and papers to summarize the latest BIM policies and BIM-based building e-Permit system adoption in various countries. However, this article differs from the previous research. The review sorts out the situation in several representative countries from three aspects: the current adoption status of the BIM-based building e-Permit system, adoption background, and future development plan for digital construction. The investigation is summarized and analyzed, and viewpoints are obtained as a reference for the industry and relevant institutions to promote BIM-based building e-Permit systems. This review focuses on the current adoption status of BIM-based building e-Permit systems in seven representative countries from Asia, North America, Oceania and Europe. However, it is acknowledged that further analysis of South America, Africa, and other parts of Europe could provide a more comprehensive global perspective. Despite this limitation, the analysis of selected countries provides valuable insights into global trends and challenges in this field. Meanwhile, AI integration in BIM-based building e-permit systems is the latest research trend, the authors will also investigate existing research and interpret the research trends.

2. Research methodology

2.1. Research scope selection

Recently, BIM-based building e-Permit system has become a hot topic, and scholars worldwide are actively exploring this field. Noardo et al. (2022) conducted a review from 2001 to 2021. Studies related to the actual progress of digital building permits have been primarily conducted in 26 countries, including the USA, South Korea, the Netherlands, Sweden, Canada, and the UK.

Owing to the limited space of this article, it is not possible to conduct an in-depth analysis and research for each country. Therefore, we selected several major countries for our review.

First, Singapore, Norway, Australia, and the USA have made the earliest attempts to develop automated code checking. Eastman et al. (2009) summarized the situation of these four countries in the classic paper "Automatic rule-based checking of building designs". Therefore, we believe that it is meaningful to investigate and summarize the latest situation in the four aforementioned countries.

Meanwhile, the UK and South Korea have two large research groups to implement the BIM-based building e-Permit system. They have contributed substantial investments and practices in the field of BIM. The two groups are KBIM and D-COM in the UK and South Korea, respectively. China has the largest construction market in the world. Recently, the Chinese government has taken effective measures, including a large number of practical actions and corresponding policies to support the BIM-based building e-Permit system to cope with the era of digital buildings.

In addition to the attempts of these seven countries, many other countries, such as United Arab Emirates (UAE), Ireland, and Finland, also have very good practices. However, owing to a lack of sufficient corresponding English material, the authors could not conduct a complete investigation of these countries. Therefore, the scope of this study is limited to the investigation and research of Singapore, Norway, UK, South Korea, USA, China and Australia.

2.2. Methodology

(1) Investigation methods

The literature review of this paper is divided into two parts. First, this study conducts a review on the current situation of the adoption status of the BIM-based building e-Permit system, adoption background (BIM-related policy, roadmap, and guidelines), and future digital construction development plan of the aforementioned seven countries. Second, this study investigates the current research on the integration of AI into BIM-based building e-Permit systems to sort out and summarize the cutting-edge trends in this field.

For the first review of the current situation in the seven countries, it differs from a typical pure literature review by primarily accessing official websites related to BIM and BIM-based building e-Permit of government agencies and non-profit organizations in various countries to obtain the latest updates on BIM based building e-Permit systems, including BIM policy information, related standards, guidelines, etc.

For the second review on current research related to the integration of AI into BIM-based building e-Permit Systems, the authors conduct a literature review and comprehensively analyze the current research trends. The specific methods are described in Section 5.1.

(2) Framework of this study

First, the authors investigate the current situation of BIM-based building e-Permit system in different countries, including BIM-based building e-Permit system adoption status, adoption background (BIM policy, roadmap, standards, and guidelines), and future digital construction development plans.

Second, based on above investigation, the authors analyze and summarize the common measures of promoting BIM-based building e-Permit system adoption.

Third, the authors investigate the integration of AI into the BIM-based building e-Permit system to sort out the relevant research trends.

Finally, discussions are presented, which include four viewpoints and some common issues that the industry needs to address to promote the BIM-based building e-Permit system adoption.

Figure 1 shows the framework of this study.

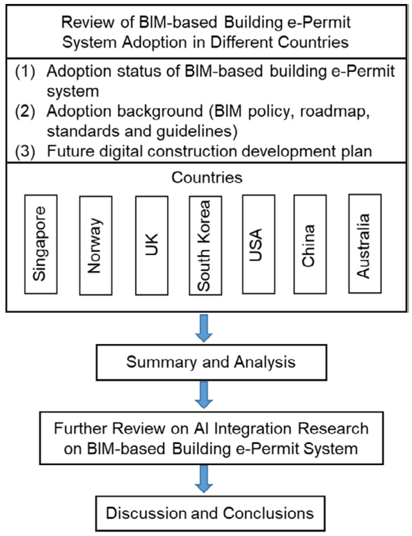

Figure 1. Framework of this study

3. Review of BIM-based building e-Permit system adoption in different countries

A review was conducted to examine the BIM-based building e-Permit system adoption in Singapore, Norway, UK, South Korea, the USA, China, and Australia from three aspects: the adoption status of the BIM-based building e-Permit system, adoption background (BIM-related policy, roadmap, and guidelines), and future digital construction development plan.

3.1. BIM-based building e-Permit ystem adoption in Singapore

3.1.1. Adoption status of BIM-based building e-Permit system

Singapore, a representative country in terms of permission and delivery through BIM, developed the Construction and Real Estate Network (CORENET) service in 1995 and has used it in the permission process. CORENET comprises e-submission, e-plancheck, and CORENET e-Info. CORENET e-submission is an Internet-based system that lets Architecture, Engineering and Construction (AEC) professionals to submit project-related construction documents to the regulatory authorities for different types of approval. E-plancheck is a FORNAX-based checking system that began as a two-dimensional (2D)-based review system (Kim et al., 2018, 2020). In January 2010, nine agencies began to accept architectural BIM models submitted using CORENET for approval. Subsequently, mechanical, electrical, and plumbing (MEP) and structural BIM models were accepted in 2011 (Building and Construction Authority [BCA], 2011a; Shahi et al., 2019). The currently acceptable file formats include native and lightweight file formats (BCA, 2016d). However, automated code checking systems have not yet been fully utilized in practice (Amor & Dimyadi, 2021). In July 2018, the Singapore government implemented a BIM-based e-submission project called CORENET-X,

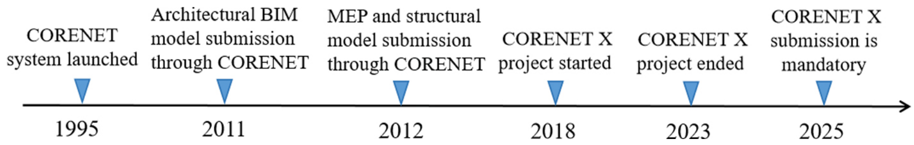

Figure 2. Timeline of BIM-based building e-Permit system development in Singapore

which intends to combine different regulatory agencies to form an integrated BIM-based building e-submission platform. The project was expected to end by 2023. By April 1, 2025, it will be mandatory to submit new projects through CORENET X (BCA, 2024). Figure 2 illustrates the timeline of BIM-based building e-permit system development in Singapore.

3.1.2. Adoption background

In 2010, the Building and Construction Authority launched the Singapore BIM roadmap, which specified that 80% of buildings would adopt BIM by 2015 (BCA, 2011b). The BCA also developed a phased plan for submission using BIM for planning permission. In 2013, the architectural BIM e-submission system was mandated for new buildings with a gross floor area of more than 20000 m^2, and the engineering BIM e-submission was mandated in 2014. By 2015, all new buildings with an area of more than 5000 m^2 were submitted using BIM (BCA, 2015).

The BCA also introduced a series of BIM guidelines to facilitate the implementation of BIM. First, the Singapore BIM guide outlines the roles and responsibilities of project members when implementing BIM in a project, including BIM specifications, BIM modeling, and collaboration procedures (BCA, 2016a).

Combined with "the Singapore BIM guideline", BCA issued various "BIM essential guides" for providing good BIM practices as a reference in an easily understandable manner. It provides guidance on how to implement BIM in an organization, such as BIM essential guides for adoption in organizations and execution plans. It also provides a BIM guide for different roles in the project, such as essential BIM guides for architectural consultants, civil and structural (C&S) consultants, MEP consultants, contractors, and land surveyors. Moreover, it provides a BIM guide for different usage purposes, such as collaborative virtual design and construction, building performance analysis, asset information delivery, and BIM for design, manufacturing, and assembly (BCA, 2016b).

To coordinate with BIM-based e-submission, Singapore implemented a series of codes of practice for BIM e-submission, which includes four parts: general requirements, architectural requirements, C&S requirements, and MEP requirements (BCA, 2016c).

3.1.3. Future digital construction development plan

In Singapore, virtual design and construction (VDC) is the future direction of BIM usage in construction. VDC entails the management of BIM models, personnel, and processes to achieve clear project or organizational goals and improve performance. VDC can help reduce problems and resolve delays (BCA, 2017, 2022a).

In November 2018, BCA launched an integrated digital delivery (IDD) implementation plan to encourage the digitization of more enterprises in the building environment industry (BCA, 2022b). Based on BIM and VDC, IDD integrates the workflow and connects stakeholders involved in the same project using digital technology throughout the construction and building lifecycle with the aim of integrating and digitalizing the building environment value chain (BCA, 2022a, 2022c).

The construction industry transformation map (ITM) was released in October 2017 to advance and integrate the industry. IDD is one of the three key transformation areas (BCA, 2018).

Currently, the Infocomm Media Development Authority [IMDA], in cooperation with BCA and the industry, has jointly formulated the construction and facilities management industry digital plan (CFMIDP), which is consistent with ITM. The plan includes three stages: Stage 1, uplifting digital capabilities and optimized operations; Stage 2, integrating ecosystems and streamlining processes; and Stage 3, intelligent business and autonomous operations. Coordinated regulatory approvals and rule-based model checkers, aimed at improving the design and BIM quality and streamlining the regulatory submission and approval processes (IMDA, 2022), are mentioned in Stage 2.

3.2. BIM-based building e-Permit system adoption in Norway

3.2.1. Adoption status of BIM-based building e-Permit system

The ByggSøk system is a public system in Norway that provides electronic services for zoning and building matters. The ByggSøk system includes three modules: an information system, a building application submission system, and zoning proposal system (Choi & Kim, 2015). The ByggSøk system allows applications for permission by Norwegian local governments (Kim et al., 2018). Twenty-seven forms were integrated into web-based services. IFC files are allowed, but drawings in the PDF format must be included. The database covers approximately 70 building applications (Hjelseth, 2021). In 2013, the Bygglett project was conducted as a pilot project to enable users to visually identify a construction project in an online environment through the link between GIS information and the BIM model (Kim et al., 2018). The ByggSøk system was first launched in 2003 and closed for new applications in October 2020 (Hjelseth, 2021; Dibk, 2024a). Currently, the new digital solutions that replaced the ByggSøk system

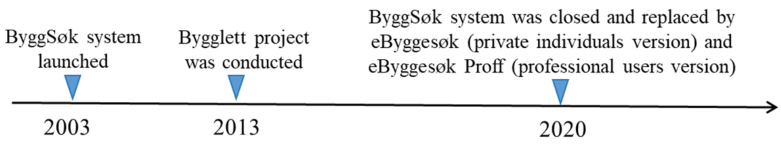

Figure 3. Timeline of BIM-based building e-Permit system development in Norway

are divided into two versions: eByggesøk for private individuals and eByggesøk Proff is project-oriented for professional users (Dibk, 2024b). Figure 3 illustrates the timeline of BIM-based building e-permit system development in Norway.

3.2.2. Adoption background

In 2010, the Norwegian government announced that it would begin adopting BIM. Many public sector institutions in Norway launched BIM programs to follow the government (Cheng & Lu, 2015).

Statsbygg is the Norwegian government's building commissioner, property manager, and developer, and is one of the main public sector bodies that promotes BIM. It has mandated BIM for all public construction projects since 2010 (Fatt, 2012; Kassem et al., 2015).

Statsbygg developed a separate set of BIM delivery requirements. Currently, the latest version is SIMBA 2.1 and SIMBA X. SIMBA 2.1 applies to all new projects from July 2022. It contains detailed Statsbygg delivery requirements for BIM, including interior design, water and drainage, prerequisite subject environment and safety, and detailed descriptions of geometry. SIMBA X is a standardized set of BIM requirements for existing buildings that has been applied to new agreements for modeling existing projects since March 2022 (Statsbygg, 2024).

In October 2017, The Norwegian Construction Industry Federation [BNL] published Digital roadmap 1.0. The roadmap mentions the "Maturity ladder for digitization", mainly focusing on different maturity levels related to digitization. Level 0 is unstructured information – "manual drawing board", Level 1 is structured information – "standalone BIM", Level 2 is File based, compiled Information Models (federated models) – "proprietary interaction BIM", Level 3 is Database based information models – "integrated BIM" (BNL, 2017).

3.2.3. Future digital construction development plan

In October 2020, BNL published an updated digital strategy for the Norwegian construction industry – Digital roadmap 2.0. The roadmap highlights the importance of building a common framework for information management. The Norwegian framework should comply as far as possible with international standards, such as the two new international standards ISO 23386:2020 (ISO, 2020a) and EN ISO 23387 (ISO, 2020b), to ensure that the Norwegian industry becomes part of the European and international market through digitalization.

To support the information framework, some necessary common specifications and components, such as a library of generic 3D objects at the component and construction element levels, a national catalog for product properties, access to information of as-built buildings, etc. (Cobuilder, 2022; BNL, 2020), have been suggested.

3.3. BIM-based building e-Permit system adoption in United Kingdom

3.3.1. Adoption status of BIM-based building e-Permit system

In the UK, most planning and building control applications can be submitted online and applied to any local authority in England through the Planning Portal, which was established in 2002 (Planning Portal, 2024). In collaboration with Solibri and Buter & Young, the National Building Specification [NBS] completed a pilot project to demonstrate how currently available tools can be used to perform automated code compliance checking for building code approval documents in a BIM model (NBS, 2014).

However, there has been no meaningful adoption of automated compliance checking; therefore, the digitization of requirements, regulations, and compliance checking processes in the built environment (D-COM) network was formed (D-COM Network, 2024; Kim et al., 2020). It is planned that by 2025, the UK will reach the brink of large-scale industrialization of automated compliance checking. This will be achieved through the following four stages: research, pilot or proof-of-concept, industrialization, and commercial adoption (CDBB, 2019).

The development of a new digital compliance ecosystem was jointly undertaken by the D-COM Network and the Construction Innovation Hub, which was planned to be completed by August 2022 (Construction Innovation Hub, 2024). The ecosystem is a set of software services that uses publicly defined Application Programming Interfaces (APIs) to integrate new and existing compliance-checking tools to digitize and automate the compliance process from design and construction to the entire asset lifecycle (Construction Innovation Hub, 2021). Figure 4 shows the timeline of BIM-based building e-permit system development in the UK.

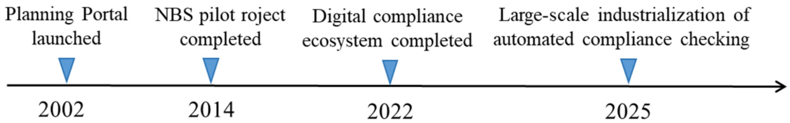

Figure 4. Timeline of BIM-based building e-Permit system development in the UK

3.3.2. Adoption background

Bew and Richards (2008) presented a BIM maturity model for use in the UK construction field. Since its development, the BIM maturity model has become a major component of the BIM implementation strategy adopted by the UK. The maturity model has four levels: 0–3. It classifies the types of technology and collaborative work to concisely describe the processes, tools, and technologies to be used. Level 0 refers to the stage in which paper is the main data exchange mechanism using unmanaged CAD. Level 1 refers to the transition from 2D to 3D using a collaboration tool that provides a common data environment. Level 2 refers to moving from modeling to collaboration and interoperability, by using managed 3D environment in separate discipline "BIM" tools with attached data. Level 3 refers to the transition from collaboration to a fully open process and data integration, which conforms to ISO BIM standards (Bew & Richards, 2008; Dakhil et al., 2015; Khosrowshahi & Arayici, 2012). In 2011, the government mandated the use of level 2 BIM in all public sectors by 2016 in full collaboration with 3D BIM (Cabinet Office, 2011; HM Government, 2015).

A series of standards and protocols have been developed to support Level 2 BIM in the UK construction industry. The processes required to implement Level 2 BIM defined in PAS 1192-2:2013 (British Standards Institution [BSI], 2013) and PAS 1192-3:2014 (BSI, 2014). PAS 1192-2:2013 (BSI, 2013) specifies an information management process to support Level 2 BIM during the capital/delivery phase of projects. PAS 1192-3:2014 (BSI, 2014) focuses on the operational stages of assets. Both are based on the existing code of practice for the collaborative production of architectural, engineering, and construction information, as defined in BS 1192:2007+A2:2016 (BSI, 2016).

Currently, the UK has requested that the International Organization for Standardization [ISO] develop a series of ISO BIM standards based on existing and emerging UK BIM methods to help industries in the UK domestic and international markets. The British Standards Institution (BSI), Center for Digital Built Britain (CDBB), and UK BIM alliance jointly established the UK BIM Framework to formulate standards and guidelines for implementing BIM in the UK using the information management framework provided by the ISO 19650 series. ISO 19650-1:2018 (ISO, 2018a) and ISO 19650-2:2018 (ISO, 2018b) describe the evolution of UK information management standards using BIM, in accordance with BS 1192:2007+A2:2016 (BSI, 2016) and PAS 1192-2:2013 (BSI, 2013). Meanwhile, PAS 1192-3:2014 (BSI, 2014) is in the process of transitioning to ISO (UK BIM Framework, 2024a, 2024b).

3.3.3. Future digital construction development plan

In February 2015, the HM Government published the Digital Built Britain Level 3 Strategic Plan. The plan describes how Level 3 BIM will change the operation of the global construction industry. It incorporates Industrial strategy – Construction 2025, Business and Professional Services Strategy, Smart Cities Strategy, and Information Economy Strategy to provide a consistent vision to create an efficient and transparent economy and provide efficient services for all citizens (HM Government, 2015).

3.4. BIM-based building e-Permit system adoption in South Korea

3.4.1. Adoption status of BIM-based building e-Permit system

Since 2008, building submissions in South Korea have been improved by non-visit submissions and real-time aggregation via the Internet. In 2009, SEUMTER was developed through an intelligent architecture administration system project and expanded to the entire country in 2011. Currently, the permission process is primarily based on checking 2D drawings and is expanding toward BIM-based checking (Kim et al., 2018, 2020). Since 2013, a KBIM e-submission process has been developed to connect with existing building administration systems to promote the use of BIM technology in national R&D projects. The KBIM e-submission system is primarily divided into two stages. A basic prototype was formed during the first stage (2013.11–2016.11), and a test server system was established in a virtual system that is similar to the building approval environment. The second stage (2017.3–2021.12) further expanded the system developed in the first stage, and the government planned to put the system into practical use.

Since April 2021, Ministry of Land, Infrastructure, and Transport of Korea [MOLIT] has launched another "Technology development of AI-based architecture design automation" project, which will conclude by the end of 2025. The project aims to enhance design productivity and support administrative services using AI technology (AIBIM, 2024). Figure 5 shows the timeline of BIM-based building e-permit system development in South Korea.

3.4.2. Adoption background

When MOLIT announced its first master plan for architectural policies in 2009, it promoted the adoption of BIM as a strategy to strengthen construction and urban industries. According to the BIM adoption roadmap of the Public Procurement Service (PPS), from 2012, BIM was applied to

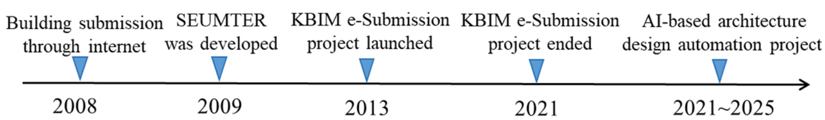

Figure 5. Timeline of BIM-based building e-Permit system development in South Korea

all public building projects worth more than KRW 50 billion. By 2016, all public facility projects had to adopt BIM. In 2017, MOLIT announced that by 2020, more than 20% of civil engineering projects would require the use of BIM (Lee, 2014, 2018).

In December 2020, MOLIT released the Roadmap for Building (Architectural) BIM Activation (2021–2030). It is specified to promote the step-by-step expansion of BIM application to public housing projects, achieving 20% by 2020, 50% by 2022, and 100% by 2024. All buildings over 500 m^2 must use BIM by 2030 (MOLIT, 2020a).

South Korea has issued several BIM related guidelines. In 2009, MOLIT launched a national architectural BIM guide as a national domain-specific BIM guide. Subsequently, other public organizations issued corresponding BIM guidelines, including the BIM Guide by PPS, BIM Guide for Modeling FM Information by Korea Institute of Construction Technology (KICT), BIM design guide by Land and Housing (LH), and the BIM guideline released by the Ministry of National Defense (MND).

In 2020, MOLIT released the "Basic Guidelines for BIM in the Construction Industry" and the "Execution Guidelines for BIM in the Construction Industry" in 2022, which primarily includes specific details, standards, methods, and procedures for the production, delivery, and use of BIM deliverables (MOLIT, 2020b, 2022).

3.4.3. Future digital construction development plan

In October 2020, MOLIT published the Roadmap for Building (architectural) BIM Activation (2021~2030). It highlights the importance of developing common data standard codes, data utilization guidelines, product standard guidelines, and data management systems. It is necessary to develop BIM element technology in preparation for the 4th Industrial Revolution, such as BIM design and construction automation technology, and AI-based maintenance technology (digital twin technology). It is necessary to discover new architectural industries that use digital technologies, such as big data, artificial intelligence, and the Internet of Things. Accordingly, it is important to establish a policy and roadmap to develop architectural digital industries (MOLIT, 2020a).

3.5. BIM-based building e-Permit system adoption in USA

3.5.1. Adoption status of BIM-based building e-Permit system

Many cities in the United States have developed their own building e-Permit systems. In 2011, the City of New York launched the Development Hub, which allows the online submission of permit application forms and project documents (NYC Buildings, 2024a; Shahi et al., 2019). Similar systems exist in several other cities, such as Arlington (Permit Arlington, 2024), Boston (City of Boston, 2024), and Reno (City of Reno, 2024). However, most require only 2D drawings to be submitted without the requirements for BIM models. New York City has BIM-based submissions for site safety plans and provides BIM site safety submission guidelines and standards. However, automated code checking has not been applied to the submitted BIM files (NYC Buildings, 2024b).

In 2006, the International Code Council introduced the SMART code project, which aimed to establish a platform to support automated code checking for building planning to comply with international codes and federal, state, and local revisions of these codes. In 2007 and 2008, a proof-of-concept system was developed and demonstrated at several venues. Owing to the lack of funds, the project ended in 2010 (Conover & Lee, 2008; Holte Consulting, 2014). Meanwhile, General Services Administration [GSA] and US courts supported the development of a code checking system for spatial validation based on the Solibri model checker (SMC) platform (Eastman et al., 2009).

Another automated code checking project, AutoCodes, was led by FIATECH. The study was divided into two phases. Phase 1 started in 2011 and aimed to verify the application of automated code checking in real-work compliance assessments and promote the building permit process. Phase 2 started in 2013, and it aimed to expand the rule set development for other occupancy categories and building code rand and develop training materials to help jurisdictions transition from traditional 2D-based plan review to automated code checking (Soliman-Junior et al., 2020; Holte Consulting, 2014; Fiatech, 2012, 2015).

In 2022, the National Institute of Building Sciences [NIBS] launched the National Building Information Management Program (NBP). According to the research plan, model-based permitting approaches will be studied in the fourth and fifth years (NIBS, 2022c). Figure 6 illustrates the timeline of BIM-based building e-permit system development in USA.

3.5.2. Adoption background

The United States is a pioneering country in BIM technology, and both public and private sectors are actively promoting BIM technology (Cheng & Lu, 2015). The GSA required that all projects funded in the fiscal year 2007 and beyond to use BIM and submit them to the office for final approval (GSA, 2007; Jiang et al., 2022).

Starting from July 1, 2009, Wisconsin became the first state to mandate the use of BIM in all public projects with budgets exceeding $5 million and new building projects worth over $2.5 million (Department of Administration of

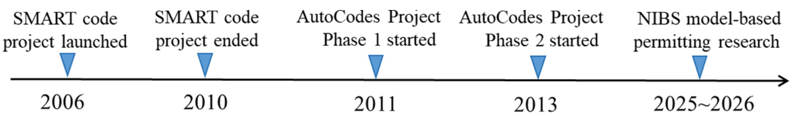

Figure 6. Timeline of BIM-based building e-Permit system development in the USA

Wisconsin [DOAWI], 2018; Jiang et al., 2022). The United States Department of Veterans Affairs [VA] also adopted BIM for designing major construction projects in 2009 and issued BIM guide requirements for use in all VA constructions in 2010 (Cheng & Lu, 2015; VA, 2023). The Indiana University [IU] requires all construction projects with a total funding of $5 million or more to use BIM (IU, 2015).

Meanwhile, as early as 2006, the US Army Corps of Engineers [USACE] released a BIM roadmap. The roadmap specifies that preliminary BIM operational capabilities should be achieved by 2008. By 2010, it should have established lifecycle interoperability and achieved 90% compliance with national BIM standards (NBIMS). By 2012, with full operational capabilities, the NBIMS would be used as part of contract advertising, awards, and submissions for all projects. Automating lifecycle tasks and utilizing NBIMS data will greatly reduce the cost and time of facility construction by 2020 (Brucker et al., 2006).

In 2012, USACE published a new version of the BIM roadmap with five objectives: achieving, maintaining, and expanding BIM competencies through education, establishing policies and procedures for measuring process improvement by integration, promoting effective data transfer among automated systems and business lines by collaboration, achieving full operational capability using BIM by automation, and identifying downstream technologies and processes to leverage investment in BIM through innovation (USACE, 2012; Cheng & Lu, 2015).

Different public sectors, such as the NIBS, GSA, and American Institute of America (AIA), have issued BIM standards and guidelines to promote the implementation of BIM. The NIBS has developed a national BIM standard (1st version in 2009, 2nd version in 2012, and 3rd version in 2015), and the new version is version 4.0, which is currently a pre-released version. It includes core BIM requirements, BIM execution planning, BIM use, and COBie (Construction to Operations Building Information Exchange) (NIBS, 2024a).

GSA released eight series of BIM guidelines until 2017 (Jiang et al., 2022), which included BIM guide overview, spatial program validation, 3D laser scanning, 4D phasing, energy performance, circulation and security validation, building elements, and facility management (Jiang et al., 2022).

3.5.3. Future digital construction development plan

The National Building Information Management Program (NBP) aims to bring industry stakeholders together to achieve critical digital transformation throughout the lifecycle of the design, construction, and operation of building environments (NIBS, 2024b).

The program contains six key workflows, including owner leadership, project delivery implementation, standards and guidelines, stakeholder engagement, education and training, and legal and insurance.

Within the NBP implementation plan, the standards and guidelines highlight collaborating with the ISO to review and participate in ISO/TC 59/SC13, organization and digitization of building and civil engineering information, including BIM, integrating ISO 19650 into the U.S. Market, and coordinating with other organizations to ensure comprehensive standards for implementing BIM (NIBS, 2022a).

Currently, NIBS is leading an alliance of industry representatives from design, construction, manufacturing, technology, and asset operations departments to develop a standard that reflects both current best practices in the U.S and international process standards, as well as the evolution of future digital practices (NIBS, 2022b).

3.6. BIM-based building e-Permit system adoption in China

3.6.1. Adoption status of BIM-based building e-Permit system

In May 2018, the State Council issued a notice on launching the pilot program of the reform of the approval system for construction projects. The main objective was to reform and cover the entire process of construction project approval and promote the optimization and standardization of the approval process for construction projects. Sixteen provinces and cities, including Beijing, Shanghai, Guangzhou, and Shenzhen, were selected for pilot reforms for the approval of construction projects. The goal was to reduce the approval time from the current average of 200 working days to 120 working days by 2018 (General Office of the State Council of the People's Republic of China [GOSCPRC], 2018). Meanwhile, the Ministry of Housing and Urban Rural Development [MOHURD] launched pilot projects on the use of BIM systems for engineering construction project reporting and integration with the "Multi-regulatory Integration" management platform, as well as the use of BIM systems for construction project review and approval, and the construction of the City Information Modeling (CIM) platform. The use of BIM information technology to promote the transformation of construction project approval procedures and management methods should be investigated to develop a scientific, convenient, and efficient engineering construction project approval and management system (Wang, 2019).

Since 2018, government departments in cities and regions such as Xiong'an New Area, Xiamen, Guangzhou, and Nanjing, as well as provinces and cities such as Hunan and Shanghai, have issued notices encouraging or selecting pilot projects for BIM-based building approval (Wang, 2023).

In August 2020, Hunan Province implemented a BIM digital review system, which was the first province-level implementation of BIM reviews in China. The review format was based on the XDB (The People's Government of Hunan Province [PGHP], 2020).

Since June 2022, a trial operation for a BIM project application system was conducted in Shenzhen. The review format was based on the SZ-IFC data format, which localizes the IFC data format in Shenzhen (Housing and Construction Bureau of Shenzhen Municipality [HCBSM], 2022).

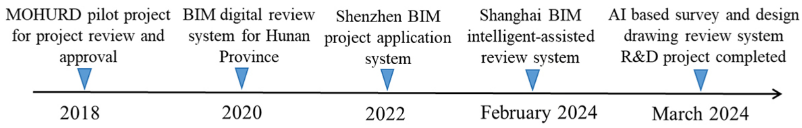

Figure 7. Timeline of BIM-based building e-Permit system development in China

Shanghai began implementing a BIM intelligent-assisted review in February 2024. This review is based on the model files in the "EDM" format. For structural specialties, the design institute must provide files in the "SDM" format. Moreover, it is evident that the review system should continue to be optimized and upgraded, gradually exploring the use of the internationally recognized Building Information Modeling standard (IFC) in BIM intelligent-assisted reviews (Shanghai Municipal People's Government [SMPG], 2024).

In March 2024, the MOHURD completed the "Research and Development of AI based Survey and Design Drawing Review System" project, which primarily focuses on AI drawing recognition in the field of architecture and structure (China Academy of Building Research [CABR], 2024). Figure 7 illustrates the timeline of BIM-based building e-permit system development in China.

3.6.2. Adoption background

Since MOHURD released the "2011–2015 Outline for the Informatization Development of the Construction Industry" in 2011, BIM has been included in the construction of information technology standards for the first time, which mentions accelerating the promotion of new technologies, such as BIM and 4D project management in survey and design, construction, and engineering project management (MOHURD, 2011).

In 2015, MOHURD issued the "Guiding Opinions on Promoting the Application of BIM", which highlighted that by the end of 2020, Class A surveys and design companies in the construction industry, as well as special and first-class housing construction enterprises, should master and achieve the integrated application of BIM with enterprise management systems and other information technologies. By the end of 2020, the proportion of integrated BIM application projects in the survey, design, construction, operation, and maintenance of the following new projects should reach 90%: large and medium-sized buildings largely funded by state-owned funds, public buildings that apply for recognition as green buildings, and green ecological demonstration communities (MOHURD, 2015).

In 2016, the MOHURD issued the "2016–2020 Outline for the Informatization Development of the Construction Industry", which proposed accelerating the popularization and application of BIM technology and upgrading the survey and design technology (MOHURD, 2016).

In May 2022, the MOHRUD distributed a development plan for the engineering survey and design industry of the 14th five-year plan (2021–2025). The plan outlines the need to accelerate forward collaborative design based on BIM, promote the delivery of BIM for engineering project design schemes, promote the digitization and intellectualization of construction drawing reviews, expand the pilot scope of artificial intelligence drawing reviews, and gradually promote BIM-based drawing review (MOHURD, 2022).

To date, five BIM-related national standards have been released: the Unified standard for BIM, Standard for BIM in construction, Standard for classification and coding of building information models, the standard for the design and delivery of BIM, and the standard for storing BIM.

3.6.3. Future digital construction development plan

In July 2020, 13 Chinese government departments, including MOHURD, jointly issued the "Guiding Opinions on Promoting the Coordinated Development of Intelligent Building and Building Industrialization", which proposed that by 2025, the policy system and industrial system for the coordinated development of China's intelligent building and building industrialization should be basically established, the level of building industrialization, digitization, and intelligence should be significantly improved, and the Internet platform for the construction industry should be initially established. By 2035, significant progress will be made in the coordinated development of intelligent construction and industrialization, with a significant improvement in enterprise innovation capabilities and a significant enhancement in overall industrial advantages (MOHURD, 2020a).

In August 2020, nine Chinese government departments, including the MOHURD, jointly issued a document titled "Several Opinions on Accelerating the Development of New Building Industrialization", which proposed the acceleration of the integrated application of BIM technology throughout the lifecycle of new building industrialization. Accordingly, it is crucial to fully utilize social resources, jointly establish and maintain a standardized component library based on BIM technology, and achieve information interconnection and interactive sharing in stages such as design, procurement, production, construction, delivery, operation, and maintenance. Pilot promotion of BIM construction approval and drawing BIM review models, promoting integration and linkage with City Information Modeling (CIM) platforms, enhancing information supervision capabilities, and improving the efficiency of resource allocation throughout the entire construction industry chain (MOHURD, 2020b).

3.7. BIM-based building e-Permit system adoption in Australia

3.7.1. Adoption status of BIM-based building e-Permit system

In Australia, many cities, such as Geraldton (City of Greater Geraldton [CGG], 2024) and Nillumbik (Nillumbik Shire Council [NSC], 2024), have developed their own e-Permit systems. However, the requirements for submitting BIM files are not mentioned.

In the late 1990s, the Commonwealth Scientific and Industrial Research Organization (CSIRO) developed a classic knowledge-based system that could help check whether building designs complied with the Building Code of Australia, which was not based on BIM (Drogemuller et al., 2000).

In 2006, the Australian Cooperative Research Centre for Construction Innovation launched the DesignCheck project, which is divided into two stages. The first stage examines the basic functions required for automatic code checking using Express Data Manager (EDM) and Solibri Model Checker. Australian Standard 14280.1 "Design for Access and Mobility" are used for preliminary feasibility evaluation. The results of the evaluation phase indicate that the EDM is relatively more flexible in editing and writing new rules. The EDM platform is subsequently used for the second phase of the project for developing DesignCheck system (Eastman et al., 2009).

Currently, Digital Twin Victoria (DTV) is collaborating with the Victorian construction industry and startup community to introduce digital assessment technologies. The project is called eComply and supports the development of 3D building compliance technology for checking building designs against selected plans and building specifications. The concept was validated in 2021. Since 2023, the first commercial solution, Archistar Apply, has become publicly available to check development projects in Victoria against the Small Lot Housing Code (State Government of Victoria [SGV], 2024a, 2024b).

Meanwhile, in a planning project November 2023, the New South Wales [NSW] government launched an AI-based solution, which aimed to simplify the development application process using AI technology and contribute to increasing housing supply and affordability (NSW, 2024). Figure 8 illustrates the timeline of BIM-based building e-permit system development in Australia.

3.7.2. Adoption background

In Australia, the mandatory use of BIM at the federal government level has not yet been implemented, with limited government recommendations (Illankoon et al., 2021; Shi, 2023). The Australian Department of Defense is a leading force in BIM and has used BIM in infrastructure projects for many years (Australasian BIM Advisory Board [ABAB], 2021b).

Most states and territories have begun to adopt BIM on a project-by-project basis, resulting in a customized approach that benefits suppliers rather than a consistent government approach (ABAB, 2021b). In certain states, mandatory measures have been implemented. For example, since July 2019, all government infrastructure projects in Queensland worth A$50 million or more have been required to use BIM from an early planning stage. Since the end of 2023, the application of BIM will be gradually expanded to include all government built assets (Queensland Government [QG], 2018).

Since 2013, the New South Wales Health Infrastructure mandated the use of BIM in all projects that exceeded $30 million (NATSPEC, 2017).

Meanwhile, the Australia Institute of Architects (AIA) released a BIM roadmap. The roadmap divides the BIM development process into four stages: 2D, modeling, collaboration, and integration. Six detailed work programs were specified: procurement, BIM guidelines, training, product data and BIM libraries, processes and data exchange, and regulatory frameworks. These six work programs began in 2012–2013 and ended in the first half of 2016. The goal of the roadmap was to reach the final stage by the second half of 2016 (Lee, 2018).

The first version of the NATSPEC national BIM guide was released in 2011 and was adapted from The VA BIM Guide v1.0, released by the United States Department of Veteran Affairs. The current version was published in October 2022 and defines the overall requirements of a BIM project, including its use in projects, BIM management plan content, roles and responsibilities, collaborative procedures, modeling requirements, document standards, and digital deliverables. This version contains many concepts and principles described in AS ISO 19650 (NATSPEC, 2022).

Several jurisdictions have issued BIM guidelines, such as the Digital Engineering Framework in New South Wales, Digital Implementation of Queensland Infrastructure (BIM Implementation Principles), and Victoria Digital Asset Strategy.

3.7.3. Future digital construction development plan

In 2019, the Australian BIM Advisory Board (ABAB) developed the Australian BIM Strategic Framework. Four main strategic action areas provide clear directions for the adoption and requirements of government BIM: establish and adjust standards and ensure an open and universal data environment, strengthen procurement and contract arrangements, and promote the development of skills and building capabilities (ABAB, 2019).

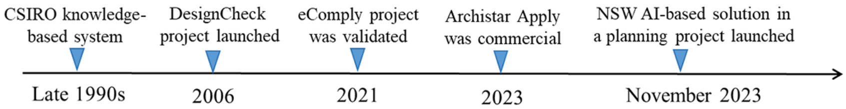

Figure 8. Timeline of BIM-based building e-Permit system development in Australia

In August 2020, Standards Australia [SA] published the Smart Cities Standards Roadmap. The roadmap proposed eleven recommendations based on five key objectives, which include supporting the implementation of existing smart city frameworks and policies, improving knowledge sharing and cooperation within Australia, ensuring that Australia can influence the development of global and national standards for smart cities, improving data accessibility and interoperability across Australia, and supporting Australian communities in developing smart city strategies and initiatives (SA, 2020).

In January 2021, the ABAB published a position paper "Digital twins". The emphasized suggestion is to support the open data exchange standards necessary for digital twin interoperability developed by organizations such as buildingSMART, Open Geospatial Consortium, ISO, and IEC (ABAB, 2021a).

4. Summary and analysis

The review in Section 3 is summarized in Table 1. This section summarizes and analyzes the BIM-based building e-Permit system adoption status, adoption backgrounds, and future digital construction plans.

4.1. Summary and analysis of BIM-based building e-Permit system adoption status

Many countries have established national unified building e-submission platforms, such as Singapore's CORENET and the UK's planning portal. However, owing to differences in administrative systems in some countries, each state, province, or city tends to establish their own separate building e-submission platform. With the maturity of automated code checking systems, an increasing number of countries are integrating automated code checking systems into their administrative approval. Singapore began this field very early. The CORENET X project, which just ended in 2023, combines the approval systems of seven government departments and has strong practical guidance significance, representing the forefront of application in this field.

Meanwhile, the UK and South Korea have large-scale research teams. The UK brought together various social forces from businesses, academia, and other sectors through the D-COM NETWORK to promote the implementation of automated code checking. The South Korean government funded an eight-year national level BIM research and development project, and the KBIM e-submission process was explored and deepened. The implementation of a BIM-based building e-Permit system requires joint efforts from the industry and academia.

AI is the latest research trend that is being explored. As mentioned in the BIM Handbook 3rd version, the future development direction of BIM is AI BIM (Sacks et al., 2018). South Korea, China, Australia, and other countries are actively exploring the application of AI technology in the field of e-Permit construction. Following the KBIM project, South Korea is currently undertaking another five-year scale AI-based architecture design automation project.

Although China started relatively late in the field of BIM-based building e-Permit systems, it has devised effective policies to promote automated code checking systems and has also explored their application in various provinces and cities. Shenzhen is in the lead, attempting to align itself with international standards and adopting the SZ-IFC data format.

By comparing these BIM-based building e-Permit systems, one of the main differences is that the submitted BIM file format is different. It is evident that some countries are based on IFC, while others are based on BIM files in other formats. Owing to the fact that a BIM project may be completed using different BIM software, developing a code checking system for each BIM software can also be a burden in terms of system development and maintenance. As IFC is the international standard data format in the field of BIM, most software now supports the IFC data format. Therefore, many countries are exploring the implementation of permission review based on IFC (Eastman et al., 2011; Kim et al., 2020). IFC is an internationally recognized information standard that may not be well integrated with local situations. Some countries and regions are exploring the localization of IFC. For instance, Singapore's regulatory requirements contain terminology not predefined in IFC subtypes and properties (e.g., Barrier Free Accessibility). This necessitates developing localized IFC version (e.g., IFC-SG) through adding region-specific subtypes and properties to enable BIM-based building e-Permit.

4.2. Summary and analysis of adoption background

BIM-based code checking is a deeper application in the field of BIM, and the adoption of BIM-based building e-Permit systems is closely related to the level of attention that each country places on BIM technology. Most of the countries investigated started early in the application of BIM, with clear policies and goals for BIM implementation, including corresponding roadmaps and guidelines for the standardized application of BIM technology.

By comparing these adoption background in different countries, in terms of the BIM roadmap, each country has a clear BIM route plan based on its own situation. According to their roadmap, corresponding BIM standards and guidelines have been established. Singapore has the strongest mandate policy for BIM, and since 2015, buildings larger than 5000m^2 must be submitted using BIM. The mandatory BIM policy in Singapore has significantly increased the popularity of BIM in the country and played a good role in promoting the implementation of the CORENET X system. Multiple government departments and agencies in the United States, such as GSA and USACE, have established clear BIM policies. This policy model facilitates the flexible application of BIM technology to projects in different fields. Besides Singapore and the United States, other countries are also actively exploring the formulation and

Table 1. Summary of BIM-based building e-Permit system adoption in different countries

Efforts \ Countries		Singapore	Norway	UK	South Korea	USA	China	Australia
Adoption status of BIM based building e-permit system	Building E-Submission platform	CORENET	ByggSøk	Planning Portal	SEUMTER	There is no unified national submission platform	There is no unified national submission platform	There is no unified national submission platform
	Submitted data format	a. Native File Format (.rvt, .db1, .dgn, .dgn, .dgn, .pln) b. Lightweight File Format (.dwf, .pdf, .bimx)	IFC, Native	COBie, Native, PDF	IFC, native	BIM file for site safety plans in New York City	XDB in Hunan province, SZ-IFC in Shenzhen city, "EDM" / "SDM" in Shanghai city	BIM file for Archistar Apply in Victoria State
	Current research activity	Corenet X project	eByggesak, eByggesak Proff	D-COM Network	Technology development of AI-based architecture design automation project	National Building Information Management Program (NBP) – model-based approaches to permitting	Development of AI based drawing review System Survey and Design Program	AI in NSW Planning Project
Adoption background	BIM mandate policy	Buildings exceeding 5000 m² should be submitted using BIM starting from 2015	BIM was mandated on all public sector projects starting from 2010	Model based BIM (Level 2) mandated on all public sector projects by 2016	FPS mandated BIM since 2016	GSA mandated BIM since 2007	By the end of 2020, the proportion of integrated BIM application projects for central specific purposes should reach 100%.	No mandatory at federal government level
	BIM Roadmap	Singapore BIM roadmap (2010)	Maturity ladder for digitalisation	UK BIM maturity model	Master plan for architectural policies (2009)	USACE BIM roadmap (2012)	Development plan of engineering survey and design industry of 14th five-year plan (2021–2025)	AIA BIM roadmap
	BIM standards/ guidelines	Singapore BIM guide, BIM essential guides	SIMBA 2.1 for new project and SIMBA X for existing project	UK BIM Framework	Basic Guidelines for BIM in the Construction Industry, Execution Guidelines for BIM in the Construction Industry	National BIM Standard Version 4	Unified standard for building information modeling; Standard for building information modeling in construction; Standard for classification and coding of building information model; Standard for design delivery of building information modeling and Standard for storage of building information model	NATSPEC national BIM guide
Future digital construction development plan		Construction and Facilities Management Industry Digital Plan	Digital Roadmap 2.0	Digital Built Britain Level 3 Strategic Plan	Roadmap for (Architectural) BIM Activation (2021–2030)	U.S. National Building Information Management Program	Guiding Opinions on Promoting the Coordinated Development of Intelligent Building and Building Industrialization	Australian BIM Strategic Framework, Smart Cities Standards Roadmap

implementation of BIM policies. For example, the UK promotes the application of BIM technology by setting specific goals, such as mandating the use of Level 2 BIM in all public sectors by 2016; Norway has issued a series of BIM delivery requirements through Statsbygg to guide industry practices. These countries have their own unique BIM policies, but they all aim to guide the application of BIM technology through the government guidance to promote the digital transformation of the construction industry.

The application of BIM in public projects plays a crucial role in promoting its practical applications. During the project execution process, experience is summarized and corresponding BIM application guidelines are developed. For example, GSA's eight BIM guide series is not only an important reference for owner organizations in the United States, but also in other countries (Cheng & Lu, 2015).

Additionally, most of the investigated countries are exploring ways to align themselves with international standards. For example, the UK BIM framework utilizes the information management framework provided by the ISO 19650 series to develop standards and guidelines for implementing BIM in the UK. The latest NATSPEC National BIM Guidelines contain several concepts and principles described in AS ISO 19650, which fully adopts ISO 19650.

4.3. Summary and analysis of future digital construction plan

Each country has a clear plan for the future development of its construction industry, and it is also widely recognized that BIM technology plays a fundamental role in supporting the development of intelligent construction and smart cities through underlying data.

The VDC mentioned in Singapore is an additional application of BIM technology in the construction field. CFMIDP also mentions the three-step process of digital journals, where BIM belongs to STAGE 1 as the foundation. In STAGE 2, coordinated regulatory approvals and rule-based model checkers can be performed. Stage 3 focuses on data verification and an AI-driven decision support system.

The UK also mentioned in the "Digital Build Britain Level 3 Strategic Plan" that BIM Level 3 will change the operation of the global construction industry. Digital Build Britain will be based on the BIM level 2 "data exchange" process and further develop into Smart City. The suggestion emphasized by ABAB in Australia is to support the open data exchange standards required for digital twin interoperability developed by organizations such as buildingSMART, Open Geospatial Consortium, ISO, and IEC.

China has also proposed accelerating the integrated application of BIM throughout the lifecycle of the construction industry, promoting its application in building approval systems, and promoting integration and linkage with city information modeling (CIM) platforms to improve the regulatory capacity of informatization.

4.4. Discussion

By comparing and analyzing the adoption status of BIM based building e-permit systems, adoption backgrounds, and future digital construction plans in various countries, the authors analyze and summarize the common measures in adopting BIM-based building e-Permit systems in these countries.

To promote the BIM based building e-permit system, it is important for the government to emphasize the application of BIM technology. It is necessary to develop guidelines and related development plans for BIM technology. The application of BIM in public projects plays a crucial role in promoting its practical application. Project experience could be used for developing BIM application guidelines.

Subsequently, the use of BIM technology could be mandated starting from public projects and BIM models will be submitted for approval. However, although these countries have obtained BIM models through building permits, the review of drawings is still based on traditional 2D drawings, and BIM models are only used for reference. With the development of code checking technology and the improvement of project digitization, these countries are gradually exploring the application of code checking in the building permit process. Later on, the BIM based building e-permit system gradually emerged. Singapore was the first country to attempt to merge seven building administrative approval departments into one, and the CORENET X project is at the forefront of this field. Because IFC is international standard BIM data format, many countries tend to use IFC as the file format for submission (Kim et al., 2020).

Owing to the excellent scalability of BIM data, it has advantages in integrating with other technologies such as GIS technology. On the basis of obtaining BIM data through building permission, various countries are expanding the application of BIM data into smart cities. For example, the Digital Built Britain Level 3 Strategic Plan in the UK.

One of the main obstacles in the construction industry is the lack of smoothness in the process of building permit checking. This issue can be attributed to several factors, including complex and frequently updated building regulations, and inefficient traditional review systems based on 2D drawings. To address these challenges, the adoption of BIM-based building e-Permit systems offers a promising solution. It could facilitate the checking process and reduce reliance on manual review. With the rapid development of machine learning (ML) and artificial intelligence (AI) technologies, it presents new opportunities for automating the building permit checking process. AI-based checking systems have the potential to significantly improve the efficiency and accuracy of compliance checking by analyzing complex building regulations and BIM models in real-time.

Recently, many studies have explored the integration and application of AI in the field of construction. For example, the AI-based architecture design automation project in South Korea and AI-based solution in a planning project by the NSW government. AI integration is the latest research trend in BIM-based building e-Permit system. We conducted a separate review on AI integration research in BIM-based building e-permit systems.

5. Further review on AI integration into BIM-based building e-Permit system

In this section, the authors will investigate studies on the integration of AI into BIM-based building e-Permit systems to gain a comprehensive and in-depth understanding of the present content and methods of AI for BIM-based building e-Permit system, and sort out the relevant research trends.

5.1. Research method

To collect the latest literature available on AI integration into BIM-based building e-Permit systems, Scopus was chosen as the literature database because it has a wider coverage in the field of construction research compared with other databases and has advantages in interdisciplinary research topics (Yin et al., 2019; Jiang et al., 2023).

As of November 2024, the following retrieval code was used in the Scopus database: ((TITLE-ABS-KEY ((“Automated code checking”) OR (“Automated compliance”) OR (“e-Permit”) OR (“Building permit”) OR (“Rule checking”) OR (“Building permission”) OR (“Construction permit”) OR (“Planning permit”)) AND TITLE-ABS-KEY ((“AI”) OR (“Artificial intelligence”) OR (“NLP”) OR (“Natural language processing”) OR (“Computer version”) OR (“Smart city”)). "TITLE-ABS-KEY" refers to the title, abstract, and keywords. The resulting articles were filtered to focus on research published between 2014 and 2024. A total of 114 documents were obtained according to the above retrieval code.

Considering the dearth of articles on AI Integration into BIM-based building e-Permit systems, several data collection criteria were employed as follows: 1) Subject area: computer science, engineering, social sciences; 2) Document type: conference paper, article, review, book chapter; 3) Representativeness of research content: manually filtered by reading keywords, title, and abstract. Following the first two stages, the number of documents decreased from 114 to 79. At the end of the third stage, the number of documents decreased from 79 to 31. The main journal sources include Advanced Engineering Informatics, Automation in Construction, Journal of Computing in Civil Engineering, etc. (Jiang et al., 2023).

Upon analyzing these 31 articles, the main focus was on the application of AI on the code compliance checking system. Two main types of content are involved, one is the interpretation of rules and the generation of checking logic, with 26 articles, accounting for 83.9%. The second category is Semantic Enrichment, with five articles, accounting for 16.1%. For the interpretation of rules and the generation of checking logic, it is primarily divided into three aspects: Text classification, Information extraction, and Information transformation (Zhang & El-Gohary, 2015). Therefore, the authors will select and analyze relevant articles from four aspects: Text classification, Information extraction, Information transformation, and Semantic enrichment, to summarize and analyze the research trends of AI integration into BIM-based building e-Permit systems.

5.2. Research summary and analysis

(1) Text classification

Before translating building code provisions into computer interpretable rules, it is necessary to classify the text of the code to filter out irrelevant textual information (Zhou et al., 2024). In 2016, Zhou and El-Gohary proposed two text classification methods, one based on machine learning algorithms and the other on ontology-based multilabel methods to classify environmental regulatory provisions to support automated compliance checking (Zhou & El-Gohary, 2016a, 2016b). Uhm et al. (2015) proposed the application of context free grammar (CFG) in natural language processing (NLP) and classified morphemes into four categories: object (noun), method (verb), strictness (modality), etc. Zhou et al. (2022) proposed a new universal rule interpretation framework that combines NLP and CFG to parse regulatory text like a domain specific language.

(2) Information extraction

The information extraction of regulatory provisions refers to extracting semantic information from textual building regulatory documents (Zheng et al., 2022). Zhang and El-Gohary (2017) proposed semantic NLP technology to automatically extract regulatory information to achieve automated compliance checking. Guo et al. (2021) proposed using NLP to extract rule terms and the logical relationships from textual building regulatory documents. Owing to its pre-training and few-shot learning capabilities, large language models (LLMs) provide powerful language understanding with minimal labeled data. Chen et al. (2024) proposed combining LLMs and deep learning models to extract structured information from regulatory texts. Karmakar et al. (2024) adopted a method based on LLMs to extract ontologies in the form of concepts and relationships.

(3) Information transformation

Information transformation refers to the process of transforming extracted information into logical clauses to support inference in compliance checking (Zheng et al., 2022). Zhang and El-Gohary (2015) proposed a rule-based semantic NLP method to automatically convert information instances extracted from building supervision documents into logical clauses. Xue and Zhang (2022) proposed a new regulatory information transformation ruleset expansion method to extend existing rule sets by adopting an iterative approach. Yang and Zhang (2024) proposed a new framework that utilizes prompt engineering and the Generative Pre-trained Transformer (GPT) model for transforming building code information into a specified logical programming language automatically.

(4) Semantic enrichment

Missing, incomplete, implicit, and/or incorrect information are the main obstacles for automated code compliance checking. Before checking, extensive preprocessing of the input model is required to supplement mission information. The use of AI for semantic enrichment could largely automate this process (Bloch & Sacks, 2020). Meanwhile, support for compliance checking is limited owing to the lack of necessary information for code compliance checking in BIM models. Zhang and El-Gohary (2016a) proposed using semantic NLP technology and pattern matching based rules to automatically extract candidate concepts and relationships from building code documents to extend the IFC schema. Zhang and El-Gohary (2016b) proposed using machine learning-based relationship classification to predict the relationship between each pair of matched concepts to extend IFC schema. Bloch and Sacks (2020) proposed clustering information types for semantically rich building information models. Owing to the manual creation of BIM models, it is inevitable that errors would occur in input information. Sun and Kim (2022) proposed a method that combines AI-based object recognition and space-object relationship to identify BIM object name. To ensure the integrity of MEP BIM models, Wang et al. (2022) proposed running three types of graphic algorithms on a graphic database to detect single node and small clusters, and check the direction of fittings.

(5) Research analysis

For the rule interpretation and logic generation, recent methods combining NLP and CFG have been used to classify morphemes. The powerful language comprehension provided by LLMs with minimal labeled data has been leveraged in the latest research on applying LLMs on information extraction of regulatory provisions. Meanwhile, GPT models have also been studied for automatically converting regulatory provisions into logical programming languages.

For the semantic enrichment, owing to the limited coverage of BIM model information, it cannot fulfill all the necessary information requirements for code compliance checking. Therefore, some AI integration methods have emerged to expand IFC schema, such as using NLP techniques and pattern matching-based rules to extract candidate concepts and relations for extending IFC schema, etc. Meanwhile, errors can occur during modeling operations in BIM models or information may be missing in the exchange of BIM information between different software, which can affect the results of compliance checking. Therefore, some studies have used computer version technology, such as Multi-view Convolutional Neural Networks (MVCNN) technology for object recognition and knowledge graph (KG) technology for pre-checking the quality of BIM models.

6. Discussion and conclusions

Based on the information collected, it is evident that with the popularization of BIM technology, these seven representative countries have issued BIM-related policies, made corresponding BIM roadmaps, standards, and guidelines, and strived to integrate BIM into their building e-Permit process, and made a clear future digital construction plan. With the maturity of automated code-checking technology, an increasing number of countries are implementing automated code-checking technology to in the process of building administrative approval.

We extracted the adoption direction for driving BIM-based building e-Permit systems by summarizing the analysis in the third section, which included the following four viewpoints: mandatory policy orientation, standardization, internationalization, and intelligence.

(1) Mandatory policy orientation

BIM-based building e-Permit systems are primarily used by government departments and are linked to government administrative approval. A clear adoption plan at the governmental level is required to promote the implementation and application of BIM-based building e-Permit systems. Furthermore, corresponding mandatory policies are required to stipulate that building approval needs to be obtained through the submitted BIM documents. It is recommended to adopt a tiering implementation strategy, which can introduce BIM-based building e-Permit systems, starting with public projects and then expanding to private projects.

(2) Standardization

BIM-based building e-Permit systems are a further in-depth application of BIM technology, which is closely related to standardized BIM technology. This requires the formulation of unified BIM standards and guidelines at the national level to guide the standardization of BIM technology.

(3) Internationalization

We need an open development perspective and a sense of international alignment, including the BIM framework system and a data format that considers international alignment. Most countries have realized the importance of internationalization trends and are exploring methods to align their information frameworks with international standards. For example, in BNL, Norway has proposed to align with international information to ensure that the Norwegian industry can become a part of the European and international markets. Meanwhile, the U.S. is aligning itself with internationalization through the NBP project and is attempting to integrate ISO 19650 into the US market. It is recommended to establish standard alignment mechanisms, such as actively participating in international standard-setting organizations and working to align national BIM standards with international standards.

(4) Intelligence

Using AI to make e-Permits more intelligent, and the generated data can serve as the foundation for smart cities and intelligent construction. Importing AI into a BIM-based building e-Permit system can make building permit approval more intelligent. For the future development of the construction industry, various countries are transitioning toward smart cities and intelligent construction. Mining and applying building data through methods such as AI and big data are hot topics. BIM data are crucial for the construction industry. BIM data obtained through building approval are standardized building data obtained from the design stage, which is crucial for the development of the entire digital building industry. Various countries are building digital ecosystems for the construction industry that integrate the entire lifecycle from design to construction to operation and maintenance management. Based on obtaining standardized building data, further research on AI, big data, and other related fields can be conducted to lay the foundation for smart cities.

7. Research gaps and future directions

This review is primarily based on network resources. Owing to the limitations of network resources, they may not be able to fully reflect the actual situation in each country. Therefore, further interviews could be conducted with key stakeholders to gain a deeper understanding of the situation in different countries.

Several common issues need to be further addressed in the current adoption of BIM-based building e-Permit system.

(1) Current challenges

BIM-based building e-Permit is a further application of BIM technology and a new way of reviewing design drawings. Currently, several challenges hinder widescale adoption, such as technical barriers (e.g., IFC localization compatibility issues) and stakeholder resistance (e.g., low industry acceptance).

While countries are actively exploring the use of international standard data format IFC for BIM submissions, practical applications encounter IFC localization compatibility issues. Some countries and regions are exploring the localization of IFC, such as Singapore and Shenzhen in China, which have respectively localized IFC, such as IFC-SG in Singapore and SZ-IFC in Shenzhen.

Additionally, in the process of adopting BIM-based building e-Permit systems, resistance from stakeholders is another challenge. Stakeholders accustomed to traditional 2D drawing-based permit reviews must now learn new technical skills for BIM-based building e-Permit. Currently there are relatively few practitioners in this area, it results in low industry acceptance. This resistance could be mitigated through training programs, incentives for early adopters, and demonstration projects that highlight the efficiency and accuracy benefits of BIM-based building e-Permit. The BIM-based building e-Permit represents a further application of BIM technology, which is directly correlated with the industry's awareness and acceptance of BIM technology. This necessitates strengthened governmental promotion and support for BIM adoption, along with further optimization of relevant policies and guidelines.

(2) AI integration and future directions

The present BIM-based building e-Permit system is not mature and involves some common issues that need further exploration and research. For example, with the continuous updating of regulations, real-time updates and maintenance of checking rules are required. Quality issues with BIM models can result in inaccurate checking results, and the software interoperability issue can result in missing information during data transmission. Currently, the e-Permit systems in different regions are also in the exploration and application stage, and the status of the systems varies. With the development of new technologies, such as LLMs and knowledge graph, the application of AI integration into BIM-based building e-Permit systems is the latest research trend. Current AI integration research mainly focuses on rule interpretation, logic generation, and semantic enhancement, but there is little research on report generation. Generative AI has enormous potential in compliance checking, such as generating intelligent compliance reports to provide more efficient and accurate checking results, or providing optimization suggestions.

In the process of implementing the system, more research on AI integration is needed to improve the operability and applicability of the system. The authors point out several future technical priorities for AI integration as shown below.

Multimodal models: Compliance checking requires the integration of diverse resources, such as regulatory texts and BIM model data. Developing multimodal AI models capable of processing information from various data resources will enable more comprehensive compliance checking.

Real-time data interoperability: During construction projects, data from multiple sources are generated in real time. Enhancing the real-time data interoperability by dynamically converting such data into standardized formats (e.g., IFC) could support continuous compliance monitoring throughout the construction lifecycle.

In addition, the continuous development of regulations and the continuous updating of BIM models require real-time adaptive compliance checking. The dynamic compliance checking system driven by LLM can automatically adapt to regulatory changes and model modifications, which could be a promising research direction.

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Author contributions

H. W. Sun was responsible for investigation, paper conceptualization, paper methodology and paper writing, I. H. Kim was responsible for paper methodology, research guidance, paper review.

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