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International Journal of Construction Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tjcm20

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To cite this article: Ali Saad, Saheed O. Ajayi & Hafiz A. Alaka (2022): Trends in BIM-based plugins development for construction activities: a systematic review, International Journal of Construction Management, DOI: 10.1080/15623599.2022.2093815

To link to this article: https://doi.org/10.1080/15623599.2022.2093815

Published online: 05 Jul 2022.

INTERNATIONAL JOURNAL OF CONSTRUCTION MANAGEMENT
https://doi.org/10.1080/15623599.2022.2093815

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Trends in BIM-based plugins development for construction activities: a systematic review

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ABSTRACT
With the emergence of vast technological advancements in the construction industry to address construction issues, BIM is foreseen as a potential utilization environment. To expand BIM performance in addressing contemporary construction issues, there is currently an uprising trend of plugin development. This paper reports a systematic review of BIM-based plugins, by exploring their nature, areas of application, and their implication on productivity and efficiency. Using a systematic review approach, the study narrows down vast literature and critically analyses 34 developed plugins from 34 different articles. Findings suggest that custom-build plugins are excelling in vast areas utilizing key construction processes like automation, including Health and Safety and Lifecycle assessments, as they are proven to drive productivity and efficiency towards cost and time savings as well as error minimization. Moreover, based on the commonalities between the extracted plugin systems, a framework that could facilitate a better understanding of the programming dynamics in developing BIM-based plugins is presented. Value: This paper offers future research of the insights needed to better understand the directions of BIM-based plugin development and captures BIM evolvement towards more problem-solving potentials.

KEYWORDS
Building information modelling; plugins; contemporary construction issues; it in construction

Introduction

Technological advancements are being recognized in vast non-construction related industries, proving an exceptional potential to be utilized in the AEC industry. Such technologies enhance project management and labour productivity (Karim et al. 2013), labour risky practices (Biggs and Williamson 2012), time and cost overruns (Asiedu et al. 2017), and address severe environmental impacts (Ijigah et al. 2013) like air pollution (Wang et al. 2018) and construction waste (Gulghane and Khandve 2015). To address the challenges facing the construction industry, BIM is gradually being recognized as a gateway for technological advancements. BIM is excelling in management, planning, design, and other activities towards the successful delivery of projects (Aryani et al. 2014). Since its emergence, BIM is maturing to be described as the use of technology and digitalization within the built environment. BIM benefits are represented by, but not limited to, enhancing performance (Lu et al. 2013; Ajayi et al. 2021), simplify complex processes (Olbina and Elliott 2019), maximize sustainability (Carvalho et al. 2021), enable competitive advantages (Ahankoob et al. 2021), increase efficiency (Duan 2021), and even proving vitally effective in building legalities (Atazadeh et al. 2017).

Despite that BIM is not yet fully acknowledged within the industry (Yuan and Yang 2020), BIM continued to mature among key construction multi-stakeholders, acting as a vital example of the diffusion of innovation across the construction industry's social system (Merschbrock and Munkvold 2014; Smith 2014; Papadonikolaki 2017; Wu et al. 2017). This can be substantiated by the ability of BIM utilization across all project's phases such as the pre-construction phase (Li et al. 2021), during construction (Elmualim and Gilder 2014), and even in the project's end-of-life phase (Shi and Xu 2021). Nevertheless, critiques suggest the end of the BIM era replaced by advanced platforms, describing a limited ability and functionality for BIM to address construction contemporary issues (Lee et al. 2021). However, through the development of plugin solutions to perform various tasks, developers are immensely proving that BIM can sustain innovation by developing plug-ins to tackle specific issues and add further values (Silva et al. 2017). Despite such approaches emerging as trends, it is being pointed out that the roadmap for developing such plugins is yet blur, making it challenging for developers and practitioners to better understand the plug-in developing criteria (Bueno and Fabricio 2018).

This review contributes to the knowledge of BIM practices in the construction industry by reflecting the extent where plug-ins could be developed to effectively tackle contemporary issues facing construction multi-stakeholders. In particular, the review seeks to understand the trends and areas where such plug-ins are excelling and their developing criterions. Hence, this study highlights the hidden potential of BIM solutions in evolving as a latent approach towards expanding existing capabilities. The aim is fulfilled through the following objectives.

A. To explore construction areas where plug-ins are effectively excelling
B. To investigate the drivers and benefits achieved behind BIM plugin development for bespoke issues

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C. To develop a framework that describe the developing criterion being followed in creating and validating BIM plugins alongside the associated challenges
D. To explore the productivity/efficiency benefits realised for tailored BIM-based software solutions.

Review methodology

This study adopts a systematic review methodology of collecting, evaluating, and analysing existing literature, an approach indicated as popular in summarizing large quantities of publications (Green 2005). Moreover, this approaches a credible methodology in revealing data towards explicit research questions (Tranfield et al. 2003). Hence, through a systematic review, the study (i) Identifies research database, (ii) develops an inclusion and exclusion criterion, and (iii) systematically highlights vital relationships between the studies. Data collected is subsequently analysed and interpreted against the main research aim and objectives.

The database

Choosing the right database is a key aspect in this study's systematic search. Scopus is described as the "largest single abstract database in the world" (Boyle et al. 2008, p.148), covering an enormous number of peer-reviewed journals when compared with other databases (Chadegani et al. 2017). Knowing that the study will look into BIM from a plug-in development perspective, there is a need to search outside the normal disciplines, where Scopus can facilitate this due to its multidisciplinary nature (Burnham 2006). The overall search is specific and explicit, requiring a unique set of search characteristics that Scopus offers within its latest updates (Bordignon 2019). Articles extracted from Scopus in line with the criteria discussed in the following section are deemed sufficient for review and critical analysis without the requirement of including another database for this paper. This is especially as manual searches of articles through Google scholar and other search engines returned only those articles that were already included in the study. A comparison between the key databases provided similar exposure to the same batch of publications, having Scopus as the main channel to feature all the Journals hosting these publications. The number of articles included is directly influenced by the contemporary nature of BIM plugins gaining popularity recently across academic research.

Inclusion and exclusion criteria

To restrict the search towards the context relevant to the research objectives, an inclusion and exclusion criteria of the data within the review is developed. The inclusion and exclusion criterion provides an ability for the researcher to focus the research towards the desired and specific considerations (Meline 2006). Studies included should be within the parameters of developing and testing a BIM developed tool, plugin, or add-in. Due to this study focusing on contemporary issues in construction, and due to most of "BIM" and "BIM Plugins" search results being between 2016 and 2021, as shown in Figures 1 and 2 respectively, only studies from 2014 onwards are included. The reason for choosing this specific time slot is due to the contemporary nature of the studies being limited but also evolving, proving that such trends of developing plugins for specific construction challenges are only gaining popularity within the chosen time period. Table 1 shows the inclusion and exclusion criteria.

Data collection

Keyword combination

Identifying the right keywords does not only act as a comprehensive approach towards searching for relevant articles, but also eliminate all unrelated articles that could impact the desired results (Ferrari 2015). The keywords combined includes, "Building Information Modelling", "Tool", "Add-in", and "Plug-in" or "Plugin", along with the development and reflection on where such tools are deemed effective.

Identification of articles

The Scopus search identifies 192 articles. Overall, only 34 articles of those are included after full screening and a critical review. This constitutes as 18% of articles collected from the overall search. The limited number of articles is substantiated by the modern direction that such trend of developing BIM plug-ins is not yet fully acknowledged by the industry, acting by itself as a

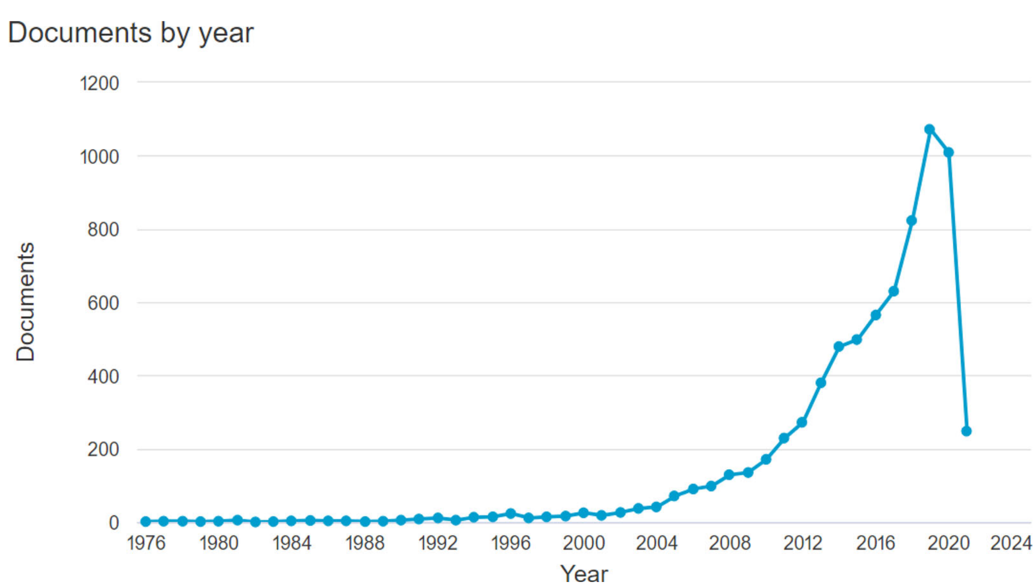

Figure 1. Analysis of 7196 articles in scopus reflecting publications of "BIM" with respect to the years.

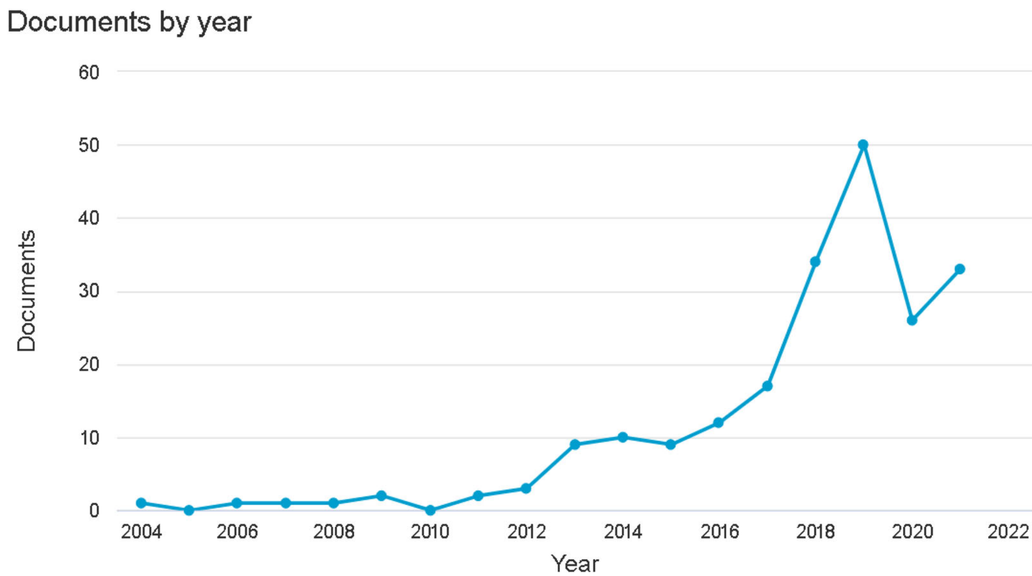

Figure 2. Analysis of 211 articles in scopus reflecting publications of "BIM Plugins" with respect to the years.

Table 1. Inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Study Type	Journal Articles, Conference Articles.	Reviews, Policy Analysis, conceptual, theoretical
Condition	Developing method, developed plugin/add-in, BIM-based.	Test and evaluation, undetailed plugin developing method.
Language	English	Other languages
Dates	2014-2021	–
Sector	Construction	Non-Construction related

Table 2. Search Codes with respect to Number of Articles Extracted.

#	Search Code	N# Articles Extracted
1	TITLE (BIM AND Plugin AND Developed}	10
2	TITLE (BIM AND add-in}	7
3	TITLE-ABS-KEY (BIM AND construction AND plug-ins)	10
4	TITLE-ABS-KEY (construction AND plug-in OR plugin AND BIM)	2
5	TITLE-ABS-KEY (BIM AND API AND develop)	5

limitation to more resources. Further insights about the search are illustrated in Table 2 and Figure 3.

Findings

The findings detailed in this section are categorized into area of use, main functionality in solving a contemporary construction issue, and the developing criteria followed. Table 3 details the included articles reporting the 34 retained plug-ins.

Figure 4 presents the distribution of the developed plugins across regions. Countries like the UK and China have the most published research reflecting a developed plugin which is justified by their nature in embracing BIM as a primary solution within their construction activities. Figure 5 reflects the years of publications which is increasing each year as such plugins and their usage to address specific tasks are gaining more popularity among practitioners and academics.

Areas of use within the industry

The plugins' areas of use are diverse and have covered different construction disciplines. This confirms the need represented by Ghaffarianhoseini et al. (2017) for the use of BIM beyond simple activities towards exploiting far more substantial benefits. The findings of this study moreover align with Ayman et al. (2020) who predicts developing BIM solutions towards playing more vital roles and better expansion. Figures 6 and 7 illustrate the different areas of construction that have benefited from the focus of the custom-build plugins, featuring areas like Health and Safety, design, and energy consumption across the life-cycle, providing a variety of their usage to address specific construction tasks.

Analysis and discussions

Bim plugin development

This section extracts an overarching understanding of the developing criteria by identifying a) the role of Application Programming Interface (API), b) the programming aspect, and c) the supporting tools to expand plugin functionalities.

Application programming interface (API)

API establishes a data connection between the software, like Revit, and the database of SQL server (Ali et al. 2020). Moreover, API creates data exchange between the developed plug-in and the core system of Revit (Sameer and Bringezu 2021). This creates a connection between API and the information stored in the database. As the API expands the connectivity of the plugin as reported by Jalaei et al. (2020), ensuring the external application has an effective interaction with Revit (Jin and Gambatese 2019). This creates a new connection between the plugin and the software, through the API, not only by facilitating the communication between the plug-in and Revit (Chileshe et al. 2019), but also by creating a link with the

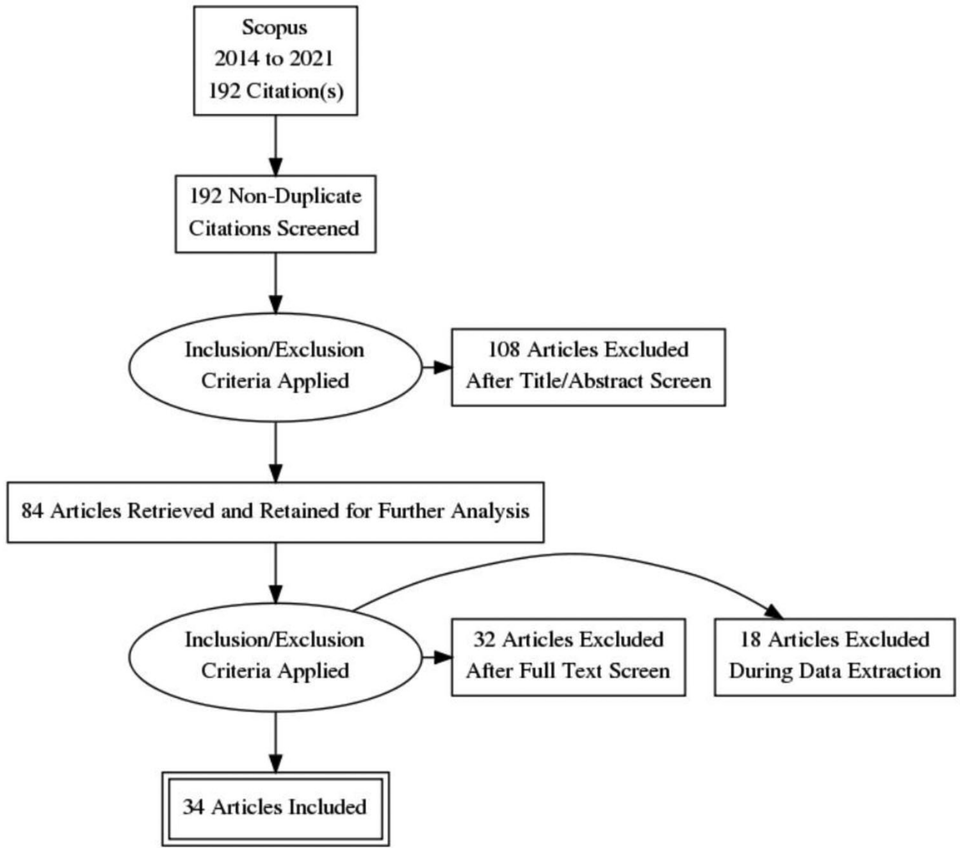

Figure 3. PRISMA Flow Diagram.

database towards enabling a project data extraction (Gao et al. 2019). Hence, there is an integral connection between API in facilitating the communication between the key attributes of the BIM plugin development criteria (see Figure 8). Furthermore, another interesting trend reflected by the collected articles is the extensive reliability on Revit as a software to feed into the above relationship, such trend emerged particularly from critically analysing the articles. This implies a dependency to link Revit's function as a key factor in the plug-in development criteria having over 70% of the collected articles mentioning the said software throughout their plugins' development phase.

Programming platforms and languages

Articles representing the developed plugins relied on two main frameworks .Net (Das et al. 2015; Jin and Gambatese 2019; Pham et al. 2020) and Microsoft Visual Studio (Kazado et al. 2019; Ali et al. 2020; Rodrigues et al. 2021). With regards to the preferred programming languages, the authors uses Python (Singh et al. 2020), and C++ (Pham et al. 2020) throughout their plugin development, where the rest of the authors utilize C# as their main programming language (Zhang et al. 2018; Chen and Nguyen 2019; Sameer and Bringezu 2021). Apart from those languages being firmly used for the actual plugin development, such languages are optimized to perform further tasks like statistical analysis (Singh et al. 2020), report generation (Gao et al. 2019), and plugin integration with supporting tools (Chen and Nguyen 2017). Hence, the programming language preferred is C#, where this relies on a framework to be built, and languages can perform independent tasks (see Figure 9).

Supporting tools

To optimize the outcome of the plugin development, the authors are utilizing supporting tools to help the overall capability. As shown in Figure 10, one of those tools is "Dynamo", an open-source platform that offers visual programming and scripting alongside the API towards achieving more capabilities (Sadeghi et al. 2019). Dynamo tends to enhance Revit (Pham et al. 2020) and assist users to modify models efficiently with more customization flexibility (Gao et al. 2019). Moreover, there is a direction to integrate different commercially known tools within the development process, facilitating different tasks, and is represented by Microsoft Excel and MS Project (Pham et al. 2020), Navisworks (Hasan et al. 2019), Google Maps (Jalaei et al. 2020), and Revit Macro Manager (Kannan and Santhi 2018). Hence, this proves the extent of where more tools could be integrated to further optimize the BIM-based plugin. Figures 11 and 12 show the relationships between feature integration, programming requirements and information exchange systems as the key components of BIM-based plugin development.

BIM plugin evaluation criteria

Authors evaluate and validate the plugins functionality conceptually by experimenting those within the software, or practically within real-life projects. For instance, Hasan el al. (2019) tests the plugin through Revit, Zhao and He (2021) and Yuan et al. (2019) through relevant and existing detection projects, and other authors prefer existing BIM conceptual designs (Choi et al. 2018; Jin and Gambatese 2019; Rad et al. 2021). More coherently, some authors tend to use more complex evaluation criterions like Finite Element Analysis (Ninić et al. 2020), critically

Table 3. 34 developed plugins extracted.

Resource	Plug-in	Area of Use	Country	Date
(Singh et al. 2020)	Building Performance Simulation Plugin	Design Stage (Energy Consumption)	Belgium	2020
(Rad et al. 2021)	BIM- LCCA Plug-in	Design Stage (Estimation)	Canada	2021
(Ninić et al. 2020)	The IGA-Revit interface Plug-in	Automation in Construction (Technical - Tunnel Engineering)	UK	2020
(Rodrigues et al. 2021)	Job Hazard Analysis Plugin	Health and Safety (Pre-Construction)	Portugal	2020
(Ali et al. 2020)	BIM-Based Claims Management System (BIM-CMS Plugin)	Communication (Claims and Disputes)	Pakistan	2020
(Chen and Nguyen 2019)	BIM-WMS Plugin	Planning (Supply Chain Management)	Taiwan	2019
(Farooq et al. 2018)	Electrical System Estimation and Costing Tool - ESECT Plugin	Design Stage (Estimation)	India/Saudi Arabia	2018
(Das et al. 2015)	Social BIM-Cloud Plugin	Communication (Enhancement)	Hong Kong	2015
(Pham et al. 2020)	Workplace Planning TSF Plugin	Health and Safety (During Construction)	South Korea	2020
(Kazado et al. 2019)	Building Sensor Technology Plugin	Life Cycle (Energy Consumption)	Canada	2019
(Hasan et al. 2019)	BIM-Centred Hybrid BEM-FEM Add-in	Automation in Construction (Structural)	Egypt	2019
(Sadeghi et al. 2019)	Dynamo Add-in	Life Cycle (Information Management)	USA	2019
(Jalaei et al. 2019)	Waste Calculator Plugin	Life Cycle (Waste Management)	Canada	2019
(Choi et al. 2018)	Variable refrigerant flow (VRF) type air conditioning system	Life Cycle (Energy Consumption)	South Korea	2018
(Liu and Issa 2014)	Accessibility Checker Add-in	Maintenance	United States	2014
(Zhao and He 2021)	Visualized Structural Health Monitoring Plugin	Automation in Construction (Marine Engineering)	China	2021
(Sameer and Bringezu 2021)	Sustainable resource application (SURAP) Plugin	Design Stage (Estimation of Environmental Impacts)	Germany	2021
(Jalaei et al. 2020)	LEED Credits Checker Plugin	Design Stage (Estimation of Environmental Impacts)	Canada	2020
(Akanbi et al. 2019)	D-DAS solution	Life Cycle (Life Performance)	UK	2019
(Ma et al. 2019)	FE-CMM Evaluation Plugin	Health and Safety (Fire)	China	2019
(Yuan et al. 2019)	Automated Rule-Based Inspection Plugin	Health and Safety (Pre-Construction)	China	2019
(Parn et al. 2019)	CoS MoS Plugin	Health and Safety (During Construction)	UK	2019
(Zhang et al. 2018)	Energy Optimization Linkage Plugin	Life Cycle (Energy Consumption)	China	2018
(Ma et al. 2017)	C-Compass Plugin	Communication (Enhancement)	Taiwan	2017
(Eleftheriadis et al. 2015)	RobOpt Plugin	Automation in Construction (Structural)	UK	2015
(Lu et al. 2021)	Safety at the Design Stage Linkage Plugin	Health and Safety (Pre-Construction)	China	2021
(Rotilio et al. 2019)	Integrator Plugin	Health and Safety (Pre-Construction)	Italy	2019
(Jin and Gambatese 2019)	BIM Formwork Deign Plugin	Health and Safety (Pre-Construction)	United States	2019
(Kim et al. 2016)	Automated scaffolding-related safety Plugin	Health and Safety (Pre-Construction)	United States	2016
(Chileshe et al. 2019)	Construction Salvage Software Plugin	Planning (Reverse Supply Chain)	Australia	2019
(Gao et al. 2019)	Building Energy Simulation and Optimization Tool	Life Cycle (Energy Consumption)	UK	2019
(Kannan and Santhi 2018)	CONSTaFORM Add-in	Design Stage (Constructability)	India	2018
(Pärn and Edwards 2017)	FinDD Plugin	Communication (Enhancements)	UK	2017
(Chen and Nguyen 2017)	Web Map Service (WMS) Plugin	Planning (Transportation Sustainability)	Taiwan	2017

analysing heating outcomes against demands (Gao et al. 2019; Ma et al. 2019), and other technically specific approaches (Liu and Issa 2014; Parn et al. 2019). Ali et al. (2020) adopts the traditional way of referring qualitatively to the industry experts, using their input and insight. In addition, some authors evaluate the functionality and applicability of their developed plugins using real life case studies to simulate and evaluate the performance of the developed plugin system. These are further detailed in Table 4.

The evaluation of plugin system differs from one author and plugin system to others, but they all have a common goal to test the reliability and effectiveness of such innovations. However, there is currently no one size fit all approach to system validation, arguably due to the bespoke nature of the plugins and their functions as differently perceived among both academics and practitioners. For instance, plugins such as the claim management system developed by Ali et al. (2020) and FinDD API by Pärn and Edwards (2017) automatically lend themselves to collaborative means of evaluation due to multi-stakeholder involvement in the system use. In this instance, the systems were evaluated by the industry experts using co-design approach. Conversely, the electrical system estimation and costing tool by Farooq et al. (2018) and the LEED credit checker plugin by Jalaei et al. (2020) do not involve multi-stakeholder use of the plugin system. Thus, such systems are mainly evaluated through simulated or case study projects.

Drivers towards BIM plugin development

To have a better understanding on the future direction of developing BIM-based plugins, this section identifies the potential drivers to adopting such approaches.

Coping with uncertainty

The less blurriness and uncertainty in a project, the more enhancements in its performance (You et al. 2018). Collected plugins show more certainty towards energy demand (Choi et al. 2018; Singh et al. 2020), life-cycle costs (Rad et al. 2021), logistical issues (Chen and Nguyen 2019), occupational costs (Farooq et al. 2018), and even workforce safety (Yuan et al. 2019; Pham et al. 2020). More coherently, plugins are utilized mostly in

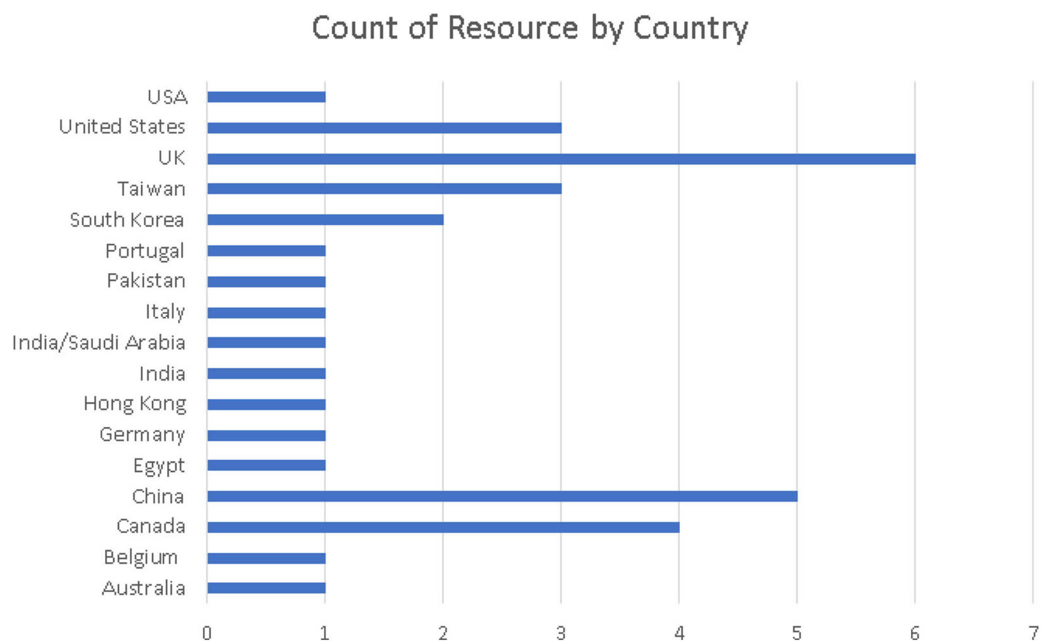

Figure 4. The distribution of the articles/developed plugins among their countries.

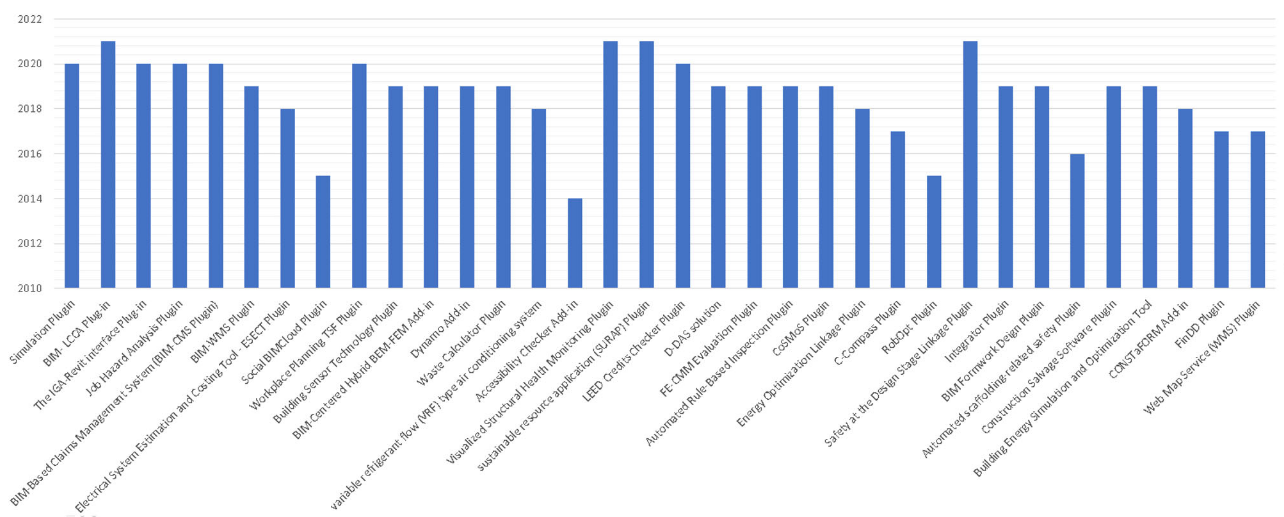

Figure 5. Developed plugins distribution per year of publication.

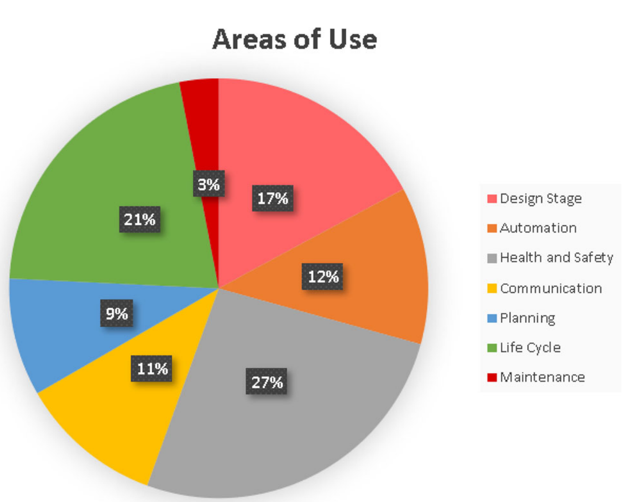

Figure 6. The percentages of the collected plugins against areas of use.

health and safety, addressing the gap discussed by Akram et al. (2019), for the need for tools to support decision making in unclear safety related matters. Moreover, plugin developments can meet the needs drawn by Lu et al. (2017), which identifies a gap in the link between BIM capabilities and green development. The functionalities are further enhancing collaboration between multi-stakeholders, confirming the data from Pezeshki and Ivari (2018), in the capabilities of BIM and Revit to tackle such challenges and uncertainties. Hence, the developed plugins demonstrate how BIM plugins could address uncertainty and project predictability.

Exploiting BIM capabilities

BIM offers myriad benefits in vast construction-related activities, where the option of further harvesting those capabilities and potentially enhancing decision making processes (Gholami et al. 2013). For instance, achievements recorded include more

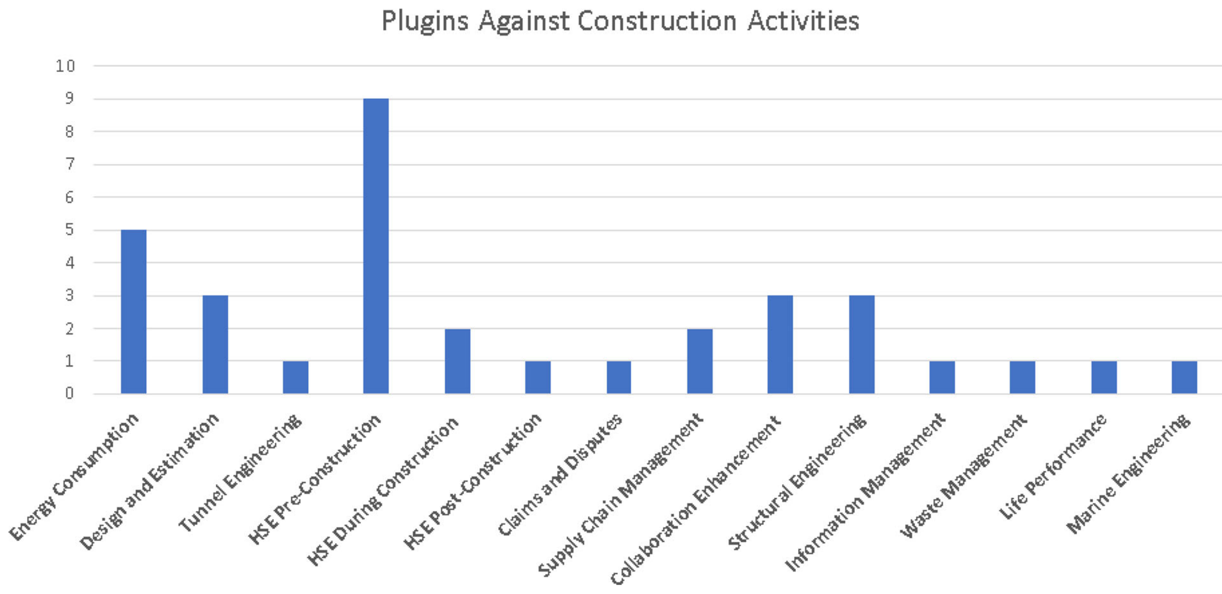

Figure 7. Diagram reflecting the plugins against their functionalities.

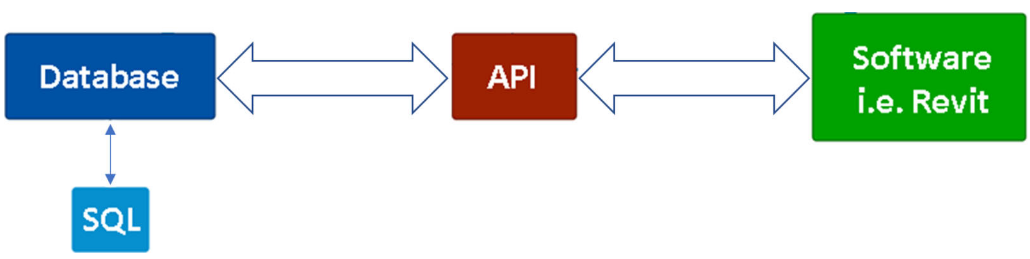

Figure 8. Relationship between API and the key attributes of the plugin development.

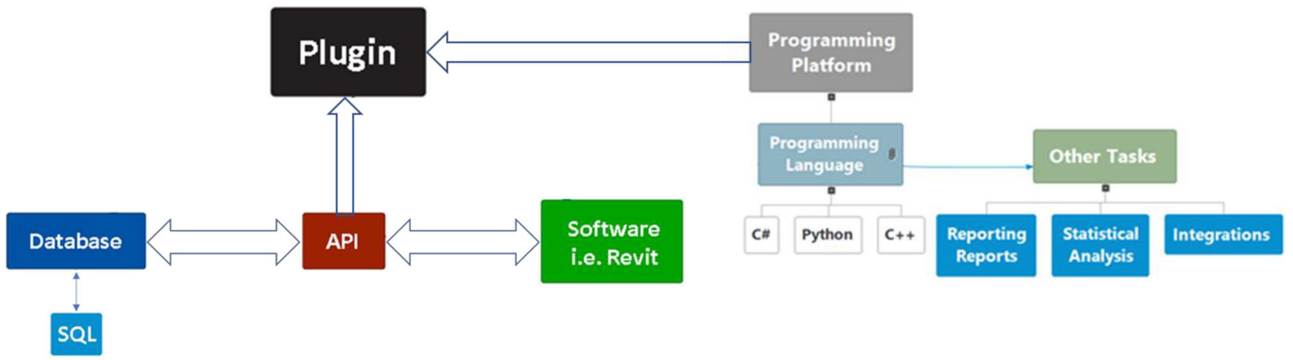

Figure 9. Relationship between plugin development and programming.

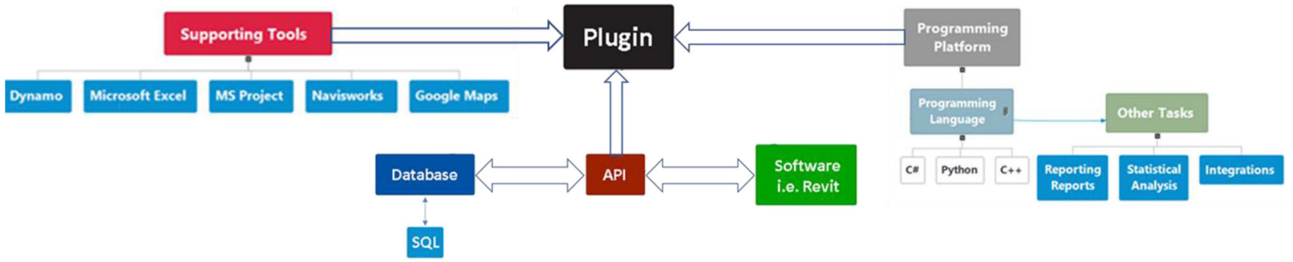

Figure 10. Conceptual modelling of the BIM plugin development criteria.

Table 4. Authors evaluating the developed plugins through case studies.

Project Description	Plugin Resource
A 12-storey commercial building having an area of 11,850 sqm: Located in Montreal, Canada.	(Jalaei et al. 2019)
A three-storey medium-size office building having an area of 1200 sqm	(Singh et al. 2020)
A five-storey building having an area of 12.000 sqm	(Kazado et al. 2019)
A two-storey educational building having an area of 9,567 square feet: Located in USA	(Sadeghi et al. 2019)
A three-storey multi-family building: Located in Germany	(Sameer and Bringezu 2021)
An office building having an area of 13,685 sqm: Located in Calgary's downtown, Canada	(Jalaei et al. 2020)
A three-storey office building: Located in southwestern part of the UK	(Akanbi et al. 2019)
A four-storey concrete frame structure (under construction) having a total height of 27.5 m	(Zhang et al. 2018)
A prototypical steel framed structural system	(Eleftheriadis et al. 2015)
A Commercial Building having an area of 56,000 sqm	(Kim et al. 2016)
A factory project having LEED Gold certificate: Located in Southern Taiwan	(Chen and Nguyen 2017)
A three-storey building: Located in Vietnam	(Chen and Nguyen 2019)
A residential building having an area of 320 sqm	(Pham et al. 2020)
A three-storey private building	(Lu et al. 2021)

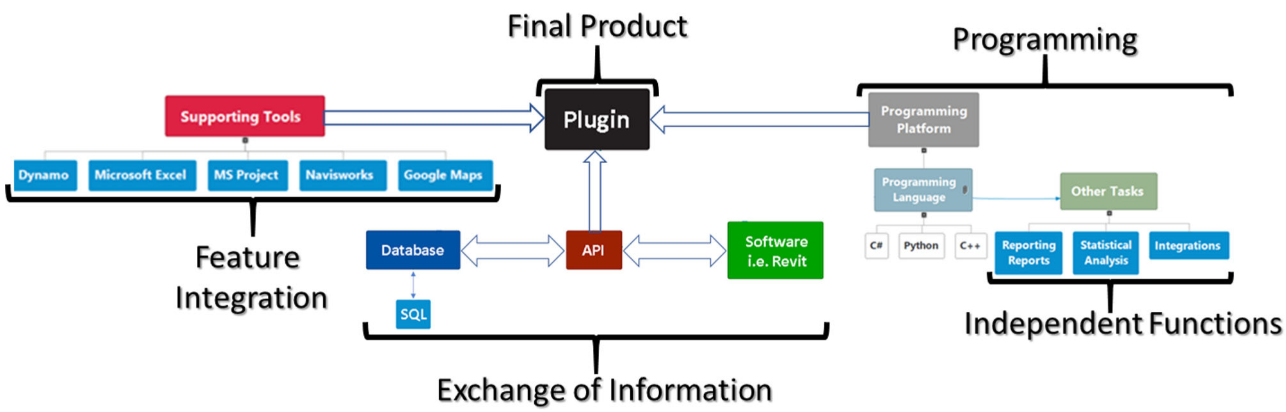

Figure 11. The conceptual framework of BIM plugin development processes.

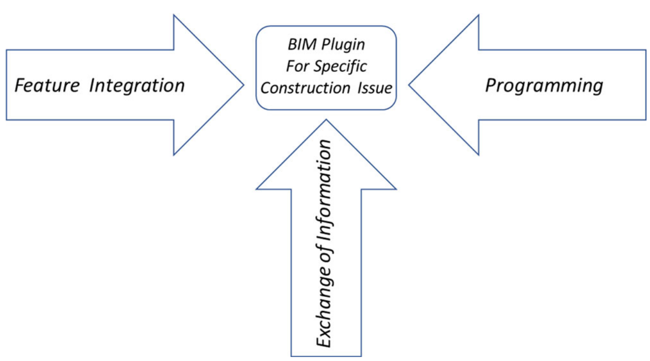

Figure 12. Simplified conceptual model of BIM plugin development criteria.

accessibility (Liu and Issa 2014), improved visualization and monitoring abilities (Zhao and He 2021), better analysis of project information (Kim et al. 2016; Ma et al. 2017), and additional diversity in digitalization across key construction activities. Hence, plugins can be considered as a channel to further utilize BIM capabilities which in return are acting as a vital driver for its development.

Sustainability and environment

To address sustainability and environmental degradation, it is important to meet certain requirements at a very fast pace. From the collected developed plugins, several authors had environmental sustainability as the main drive towards creating plugins. For instance, some authors consider minimizing the impact of construction on natural resources in optimizing the design process (Jalaei et al. 2020; Sameer and Bringezu 2021), while Akanbi et al. (2019) aims to address environmental impacts by a better end-of-life early assessment approach, and Eleftheriadis et al. (2015) through a more efficient use of existing materials. These sets of study demonstrate how custom-built plugins are been driven by the quest for whole life sustainability of buildings and construction process.

Competitiveness

Competitiveness is derived from the desire of sustaining innovation and growth (Cantwell 2003). In vast construction activities, expanding BIM to achieve better potential tend to be limited (Jalaei et al. 2019; Rad et al. 2021), ignored (Ma et al. 2019; Lu et al. 2021), or approached with very limited research and attention (Zhang et al. 2018; Chileshe et al. 2019; Jin and Gambatese

2019). Demonstrated technologies in BIM and its success reflect vital success through the advantageous competitiveness it offers to construction firms, but this is conditional to how effective the deployment of such technologies is, and by whom (Kang et al. 2013). Thus, plugin development contributes to better competitiveness, crucial for construction stakeholders in addressing construction limitations, acting as a driver for its implementation.

Bim limitations and constrains

BIM is effective in tackling complex construction projects; however, it is also hindered by several fundamental limitations and constrains that might slow the pace of its capabilities (Lin et al. 2016). The collected plugins revealed that plugin solutions are often developed to circumvent the limitations in existing BIM tools. For instance, Hasan et al. (2019) developments include solutions towards overcoming BIM's standard potential loss of structural details. Moreover, other authors address the interoperability issues restricting vast exploitation and data consistency (Das et al. 2015; Sadeghi et al. 2019). Similarly, Chen and Nguyen (2017) creates a solution that address the weak ability of BIM tools in reflecting map applications for transportation analysis. Hence, while the existing BIM tool might not excel in attaining multifarious needs within the construction environment, the potential for creating custom-built plugins proffers opportunities for addressing their limitations.

Exploiting technological advancements

Utilizing technology is a key aspect in thriving and evolving especially in sectors with limited technological adoptions (Gottlieb et al. 2017). It is derived that authors of the developed plugins exploit the potentials for advancing BIM capabilities through technological advancement. For example, Parn et al. (2019) develops a plugin that utilizes technology to extract safety data associated with working in confined spaces. Similarly, Pärn and Edwards (2017) highlights how technological attributes, added to plugin developments, can provide deeper and more comprehensive analysis towards the growth of building data. Accordingly, the incorporation of existing technologies and the ability of plugins to act as integrators of such advancements can be described as one of the vital drivers of BIM plugin development.

Automating manual processes

Construction processes formulate a complex system that can result in a very poor success rate in the main three dimensions of cost, time, and quality if kept unimproved (Wood and Gidado 2008). The collected plugins reflect an attitude, throughout their developments, towards aiming to address such complexities lurking within the main construction activities. Kazado et al. (2019) addresses the previous use of spreadsheets that proved to be ineffective in handling and understanding large data sets. Moreover, Rad et al. (2021) emphasizes the need for tools to replace current manual practices when dealing with vital information, to a more effective solution. Similarly, Kannan and Santhi (2018) identifies the significant requirement of a tool to provide more effective identification of the constructability of various structural framework systems. Hence, the complexities and excessive manual input required in certain construction activities, and aspiration for enhancing the processes, are one of the major drivers of BIM-based plugin development.

Impacts of the plugin solutions on productivity and efficiency

To achieve effective efficiencies in projects, harmonising improvements and process enhancements is vital for the overall success (Artto and Dietrich 2007), where productivity in construction lacks such rational (Karim et al. 2013). A relationship is noticed between the functionality of BIM plugins and the overall outcome like saving time and cost, minimizing errors, and enhancing accuracy.

Facilitating processes and time savings

The relation between time overruns and productivity is inversely proportional, indicating that the more a construction project overruns its scheduled time, the less productivity is achieved by the key employees (Ameh and Osegbo 2011). The plugins prove a substantial improvement in time, by automating potentially time-consuming activities, and acting as the most significant benefit within their functionalities. With respect to time improvement, minimizing the modelling time required reflects significance (Ninić et al. 2020), due to the ability of the plugin to directly solve time-extensive processes. Another aspect enabling more time savings is the functionality of the plugins in minimizing human tasks, which have been marked as vital through taking over workloads traditionally executed by the stakeholders categorized by exchanging big files (Das et al. 2015), or drafting a time-consuming documentation (Jalaei et al. 2020). Moreover, plugins tend to save time in their automatic and instant functionalities such as automatic calculations (Lu et al. 2021), visualization (Kim et al. 2016), and minimization of manual works needed from BIM users (Chen and Nguyen 2017). On the other hand, plugins are influencing the time dimension and tend to overlap with further vital key construction concerns like achieving less energy consumption faster through optimization (Kazado et al. 2019; Singh et al. 2020), creating higher client satisfaction in completing fundamental processes quicker (Ali et al. 2020), and even excelling in ensuring more safety additions to the workplace through a time-saving approach to detect potential risks (Yuan et al. 2019). Therefore, plugins are influencing productivity through their abilities to ensure more time savings are achieved through automation.

Enhancing cost performance through productivity

Productivity is a fundamental goal that key-stakeholders aim to continuously sustain and increase, where less performance will ultimately lead to higher costs, and more productivity in return leads to more profit, creating a linear relationship (Gunduz and Abu-Hijleh 2020). Acting as one of the main functionalities of the developed solutions, plugins are proving to be effective in exploiting this relationship and contributing to cost savings through productivity enhancements. For instance, Rad et al. (2021) reports a reduction in the total costs through the plugin's ability to reduce seismic-damage calculations in the design phase. Moreover, Jalaei et al. (2019) and Akanbi et al. (2019) develop plugins capable of achieving vital cost reductions through minimizing waste by optimizing the use of materials. Enhancements added to the design stage in maximizing the phase-output similarly result in less overall construction costs (Pham et al. 2020). Therefore, the consequent implications of productivity for project cost performance clearly show how custom-built BIM-based plugin solutions are not only enhancing productivity through automation, but also reducing project costs.

Error minimization and accuracy

Reducing error in BIM practices would not only maximize the required outcome, but also ensures better efficiency achievement (Sacks et al. 2010). It is noticed that plugins developed are making processes more effective and optimized (Chen and Nguyen 2019). In analysing the findings, the plugins reflect a vital contribution of decreasing numerical errors that in return ensure the success of their application (Ninić et al. 2020). For the solution developed by Parn et al. (2019), one of the important constraints is the human error within the process, and it is described as excellently tackled (Parn et al. 2019). The plugins not only excel in minimizing errors emerging from BIM processes to increase the overall productivity and efficiency of the solution, but also have a much more added accuracy. For instance, Hasan et al. (2019) achieves a more accurate information transfer that adds value to the analysis process within its role, while Sadeghi et al. (2019) reports data received by the stakeholders to be very explicit, accurate, and simple without any unnecessary vagueness that might influence their productivity. Moreover, it is also noticed that the developed plugins had a much more extended function in achieving more accuracy in many domains like restoration of historic buildings (Eleftheriadis et al. 2015; Ma et al. 2017), structural analysis (Jin and Gambatese 2019), and decision making (Kannan and Santhi 2018). Hence, error minimization and accuracy enhancements are key outcomes by the development of the plugins towards more efficiency and productivity to the overall construction-related activities.

Plugin development limitations and challenges

Throughout the development of the collected plugins, limitations and challenges endured by the authors emerge. Due to the plugins being case-dependant, and vary in their functionalities, the analysis is reflected in a generalized tone. First, Ali et al. (2020) describes that the challenge within their plugin development is the actual need to manually input quantities in the event of any design amendment that also required to be imported manually in Autodesk. Another challenge described by Kazado et al. (2019) is the inability to develop the 2D data, in their specific case, into a more visualized data that is enhanced by a more practical viewing and searching criterions.

Moreover, Liu and Issa (2014) describes that the main limitation in their case is in the inability of file conversions to solve the interoperability of such formats for better use,. Similiarly, Jalaei et al. (2020), mentions that such a constraint require data to be entered manually as a mitigation. On the other hand, Yuan et al. (2019) highlights an interesting opinion in the need for special knowledge, specific to the case of the plugin, towards effective implementation as a condition alongside the programming skills. Therefore, challenges and limitations do exist within the development of plugins, acting as potential constraints to their wider use.

Future directions and proposed research

Overcoming BIM limitations

BIM is associated with limitations and constrains that might slow the pace of its capabilities (Lin et al. 2016). Understanding the difficulties faced by the authors throughout their plugin developments can yield better coherence for future research. Singh et al. (2020) reports that future research should focus on the integration of machine learning models, which currently have several limitations within BIM practices, but it has significant potentials. Other limitations are described as lack of proper accuracy of the developed plugin (Jalaei et al. 2020), and unsuitability of the plugin in dealing with multiple scenarios (Zhang et al. 2018), where those require further research to overcome and achieve a better product. Pärn and Edwards (2017) describe future research as vital in addressing inflexibility and validations, reporting the need for researchers to seek guidance from other technologically advanced industries towards overcoming those plugin limitations. Thus, notwithstanding the huge potentials of the plugins, limitations still exist in several cases that require more in-depth research to overcome such constrains.

Evolving with technology

It is vital continuously integrate modern technologies to keep evolving and thriving (Gottlieb et al. 2017). The authors suggest the need to imitate existing technological advancements, like Google's browsing technology (Kazado et al. 2019), and Google Maps (Chen and Nguyen 2019), to further enhance plugin's capabilities. Moreover, the existence of advanced technologies like data mining and automation opportunities can reduce flaws that would make the plugin more effective (Yuan et al. 2019). Integrations with modern technologies like Virtual Reality (Ma et al. 2017), Artificial Intelligence (AI), and Augmented Reality (AR) (Pham et al. 2020), are avenues that would establish the advancement needed to address contemporary construction issues. Additionally, Kim et al. (2016) recommends investigating the applicability of integrating hardware technologies, rather than only software advancements, like wireless sensors and tracking devices, that can further increase the functionalities of their plugin. Hence, and as concluded by Ninić et al. (2020), plugins are effective in the present time, but by adopting and integrating more technologies, results could be even more significant.

Extending plugin functionalities

Gholami et al. (2013) reports the potential to extend BIM capabilities, where this seems applicable to BIM plugins as well, creating rich opportunities for future studies harvesting such capabilities. For instance, Choi et al. (2018) recommends future research to focus on BIM simulations that will increase their plugin's effectiveness. Moreover, Sameer and Bringezu (2021) and Rad et al. (2021) report the ability of their applications to thrive in project phases, other than what was initially intended for, that can result in resolving key construction issues. Additionally, Eleftheriadis et al. (2015) concludes their work by sharing that their plugin is "easily expandable", where researchers can develop and test their plugin to make it customisable and can be utilized in vast project stages. Hence, the current state of plugins is subject to change for even being more extended to achieve further functionalities.

Propositions and considerations

Alongside the recommendations and conclusions reporting the need for future research in developing plugins, authors provide several propositions to be considered in future research. There is a need for a standardization approach to be initiated in plugin developments to make such innovations more feasible in real projects (Hasan et al. 2019). Sadeghi et al. (2019) reports the need to test plugins on different project types which will enhance the validation process. Coherently, some authors include propositions for more bespoke future works like developing a plugin that can effectively handle different construction claims (Ali et al. 2020), and the development of inferences within plugins that can increase their accuracy (Farooq et al. 2018). Such propositions can be considered by researchers investigating similar attributes within BIM plugin development in the future.

Conclusion

This study reflects BIM's continues evolvement, through a systematic review, by critically analysing 34 developed plugins from 34 scientific articles. The study reveals the preferred plug-in developing criteria, drivers behind such developments, and the impact of those solutions on productivity and efficiency. The study also highlights the challenges facing the authors throughout developing plug-ins and the perspective future research opportunities created as a result. Despite the explicit implication of the findings that each tool has bespoke strengths and weaknesses, these trends are noticed to be emerging and are being suited at an interesting pace in the recent few years, reflecting the potential of such solutions in shaping the future of BIM in the construction industry. Finally, the study identifies a framework translating the relationships between the developing criteria among the included resources alongside the evaluation of each. Developed plugins presents a robust connection across vast parameters linking those to a software, database, programming platforms, and supporting tools. Plugins are proving to be effective in addressing construction challenges through expanding BIM abilities to reach tasks priorly less acknowledged.

Moreover, the study also highlights a dependency on Revit as a popular software in most of the developed plugins' development phase, which may indicate the effectiveness of Revit in enhancing the communication between different functions within the plugin. This paper hereby serves as a foundation to be the first to highlight the importance of understanding those trends which would enable BIM capabilities to be expanded to areas currently deemed less exposed. Future studies should attempt to research an effective and potentially standardized approach to test and validate plugins as a methodology, as current literature is discreet on the validation process. Moreover, research could focus on the possibility of a platform that can be utilized by construction researchers and practitioners with null or minimum programming background, as this can enable the vast majority to contribute through their experiences and knowledge in accelerating plugin development. Moreover, studies can focus on Revit's technical role in boosting these interfaces and its influence on the key processes of BIM plugin developments. Furthermore, future studies can investigate linking such approaches with BIM policies and contracts, like the BIM protocol, and study the necessary amendments needed to facilitate the integration of such developments within the industry and highlight their impact on the legal and contractual attributes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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