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ORIGINAL PAPER

An integrated building information modelling-based environmental impact assessment framework

Walaa S.E. Ismaeel[1] · **Rodina Abd El-Raouf Lotfy**[1]

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Abstract

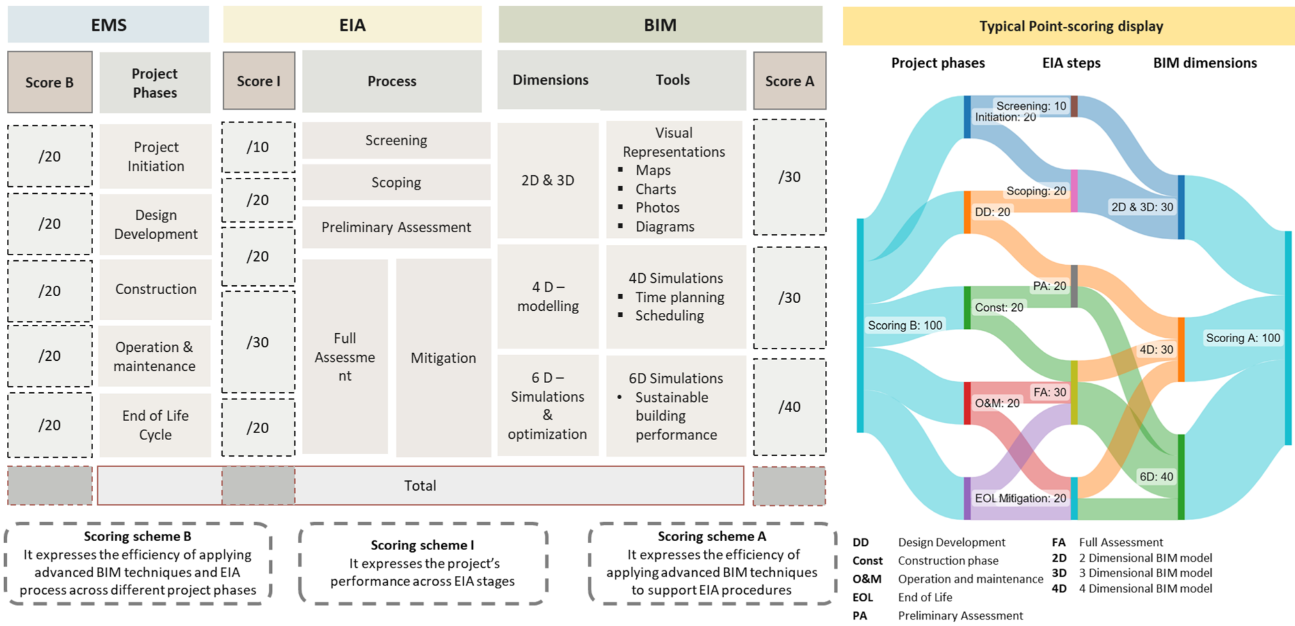
The application of Environmental Impact Assessment (EIA) studies faces many challenges, especially in developing countries. This problem was investigated in the existing literature and via a designed questionnaire among local practitioners. The reasons were mainly attributed to the seclusion of the EIA process across the project's phases, as well as the complexity of the EIA procedures. Hence, the research argues that Building Information Modelling (BIM) applications can be the key to resolve several associated problems to EIA either directly, or indirectly by streamlining Environmental Management System (EMS). Thus, a keyword-based scientometric analysis was used to define parameters and interrelations and establish network analysis for a proposed BIM-based EIA framework. The proposed framework presents scoring schemes to support three types of assessments: the efficiency of applying BIM techniques for an EIA process (Score A), proper integration of BIM techniques for different EIA steps (Score I) and proper integration of BIM techniques across project phases (Score B). It also shows the interplay of points between the three schemes via a Sankey diagram. The proposed framework was applied to compare three major construction projects in a developing country, the case of Egypt to pinpoint areas of drawbacks. The results pinpointed poor application of advanced BIM models to support sustainability analysis for EIA studies. This is in addition to imbalance of applying BIM applications across different project phases, it was notably less pronounced for the operation and maintenance stage as well as end of life scenarios. Also, poor integration of BIM tools could not support decisions related to the mitigation step. Hence, applying 6-dimensional BIM model shall enable developing mitigation measures and shall support design optimization during building operation and end of life phase. This novel approach presents the required level of verification and quality control procedure needed by decision-makers and environmental engineers to perform EIA studies and pave the way for further related research.

✉ Walaa S.E. Ismaeel
Walaa.Salah@bue.edu.eg

Rodina Abd El-Raouf Lotfy
rodina172723@bue.edu.eg

[1] Architectural Engineering Department, Faculty of Engineering, The British University in Egypt, El Sherouk City, Egypt

Graphical Abstract



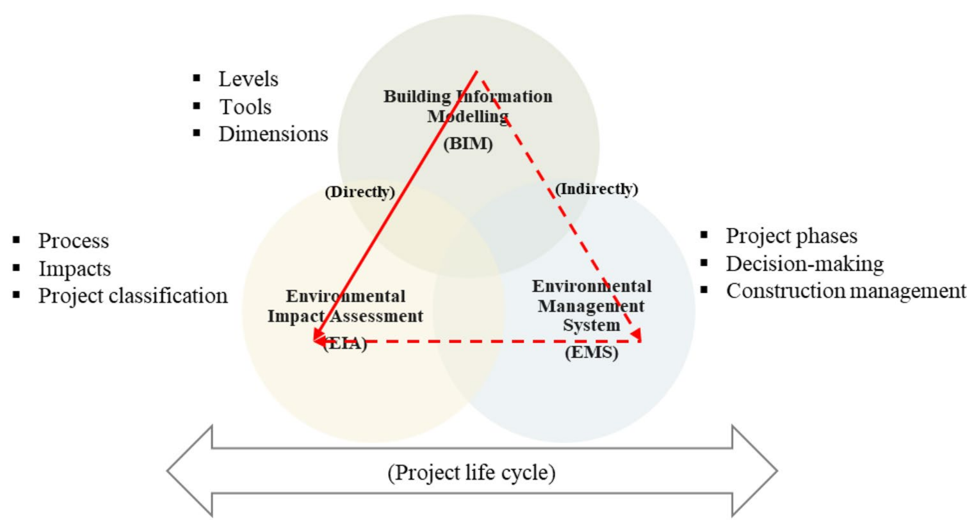
Keywords Building information modelling · Environmental impact assessment · Environmental management system

Introduction

The construction industry has significant implications for the consumption of energy, raw material use, and carbon dioxide emissions. Since 1970, there has been a significant increase in the employment of Environmental Impact Assessment (EIA) internationally and locally, whether mandated by law or to comply with international environmental standards (Unep/Setac 2016). The EIA method is used to assure that major construction projects are developed and maintained in a manner that sustainably preserves the environment (Elsayed and Ismaeel 2019). Nevertheless, it cannot be considered a common practice as it is perceived as a complex process. In addition, previous studies have pointed that the poor integration of applying EIA in the building process (Ismaeel and Elsayed 2018).

Hence, this study argues that BIM applications can be the key to resolve several associated problems to EIA either directly, or indirectly by streamlining Environmental Management System (EMS). The study pointed out problems

Fig. 1 The research hypothesis



associated with the application of each method in isolation and calls for the need to interrelate them to gain common benefits and overcome some of their challenges. In this regard, BIM enables modelling, simulation, visualization and optimization techniques to support the EIA process. This can be useful for environmental specialists, environmental assessors, project managers and decision-makers understand how to properly exploit the benefits of BIM applications for their EIA studies and how to integrate them as part of an EMS. The research hypothesis is shown in Fig. 1.

Literature review

This section sets the basis for the research hypothesis constituting the tri-dimensional relation of EIA, BIM and EMS. Sufficient background knowledge was provided according to the latest findings in the literature.

Environmental impact assessment process

The term Environmental Impact Assessment was established by The National Environmental Policy Act in 1969 as a non-binding framework, then was mandated by laws for major construction projects in 1971, and since then, provisions have been adopted across over 100 countries (Unep/Setac 2016). It is intended to provide a full account of the effect of a project/plan/policy on the surrounding environment. It follows international acknowledged standards and norms of practice to identify, predict, evaluate, and attenuate major negative impacts to acceptable levels. Accordingly, it presents reliable and complete data for decision-makers, thus, serving as a preventive technique and an early warning system against possible environmental disruption (Irizarry et al. 2013). It mainly considers aspects associated with the project and others with its natural setting. The former constitutes many considerations including building type, construction method, sources of energy used, the project's water use as well as the efficiency of materials and resources used among others. The latter constitutes factors related to the natural biodiversity and ecosystem services, and may better be described according to the vulnerability of the surrounding ecosystem and its carrying capacity (Ismaeel and Elsayed 2018). In this regard, the list of EIA-mandated major construction projects depends on national environmental laws and may vary according to the project type, scale, context and the type of energy and natural resources required for construction. Generally, this includes projects in vulnerable ecosystems, transportation and communication, mining and industry, irrigation, major road and transportation network, ports and airports, power plants as well as dams and reservoirs (Ismaeel and Elsayed 2018).

In an attempt to simplify the assessment process, scientists have divided it into a measure of inputs (energy, materials and resources) and outputs (waste and emissions). The least inputs and outputs achieved, the most resilient the project is defined (Onat et al. 2014). This is closely related to other forms of assessments including risk assessment and management, vulnerability assessment as well as Life cycle assessment (LCA). Nevertheless, it includes factors of uncertainty, hence, it requires robust means of quality assessment, monitoring, and control (IPCC 2007; Epa 2006).

A typical EIA process includes a sequence of steps (Badr et al. 2011). The procedure begins with Screening to ascertain whether the project requires an EIA, and the level of required assessment (Suwanteep et al. 2016). Further, it identifies environmental problems according to the project's type, region, sensitivity, and scale as well as the type and scope of its potential environmental impacts. This categorizes the project under consideration into classes A, B and C (Cashmore and Axelsson 2013). The Scoping step analyses crucial issues that are most anticipated as massive concerns during the EIA process, thus, reducing the risk of overlooking significant causes of the environmental problem (Hansen and Wood 2016). The Preliminary Assessment (PA) scrutinizes the need for environmental studies and offers the necessary background information to decision-makers. This constitutes a comprehensive overview of the project, and environmental regulations, in addition to an estimate of the magnitude, significance and spatial extent of the expected environmental impacts. A Full Assessment (FA) provides an accurate account of a project's environmental impact according to the defined impact classification and categories. This is followed by a Mitigation step that entails the avoidance, elimination, reduction, or control of a project's adverse impacts to accepted levels. Flexible modifications to the project's planning, designing, management and construction techniques, as well as changes to the project's surroundings may be considered as mitigation measures (Ismaeel and Elsayed 2018).

The role of building information modelling in the building sector

As construction projects are becoming more demanding and sophisticated, BIM applications have risen to automate, and modernize the industry's traditional work procedures (Safari and AzariJafari 2021). It has acquired considerable prominence in recent years to present digital representation of the physical and functional characteristics of a building over its life cycle (Jrade and Jalaei 2013). When compared to the conventional way, BIM projects can save project time by 7%, save 10% on contract value owing to early clash detection, and generate cost estimates up to 80% faster. This increases productivity, efficiency, quality, and sustainability while also minimizing errors and improving interdisciplinary project team coordination. The use of BIM applications can easily transfer distinct data into real-time information platform and decision-support system (Yan et al. 2011; Ismaeel and Mohamed 2022). Thus, it can synchronise data about building materials and their environmental impact (Anand and Amor 2017), enabling environmental analyses and fostering an insighted perspective of selecting building materials and products (Ajayi et al. 2015; Wang et al. 2011).

The core of BIM is the concept of sharing and exchanging information among project's stakeholders throughout the entire building's life cycle (Jin et al. 2019). It provides platform-neutral International Foundation Class (IFC) file format which can be read and edited by any BIM software for better coordination and interoperability, hence, remaining linked to a generalized central approach that houses all building-associated data (Costa et al. 2013). It also supports the decision-making process using its multifaceted data processing and problem-solving techniques through modelling, simulation, visualization and optimization of alternatives (Najjar et al. 2017).

In this regard, the Level of Detail (LOD) is used to indicate how much, and what kind of project information should be included in a BIM model (Dupuis et al. 2017). It comprises not only visual items or physical attributes, but also the levels and characteristics of building components, as well as the availability of data at each LOD and link information to them. This determines the precision and validity of the environmental analysis which is required for performing uncertainty and sensitivity analysis (Safari and AzariJafari 2021).

Also, BIM dimensions (D) help in comprehending construction projects and the practice of connecting more information and dimensions to the building model. It entails the addition of information about the phases of design, construction, and maintenance. These include 2D, 3D, 4D, 5D, 6D, and even 7D (Tirunagari and Kone 2019; Xu 2017; Konyushkov et al. 2020). The 2D model is the simplest kind of construction model, made up of a plain X- and Y-axis. The 3D model adds the Z dimension that describes the geometry, location and orientation of elements and components needed for conceptual designs, design development stage, construction documentations and details (Elakkad and Ismaeel 2021). The 4D displays time dimension required for scheduling resources, quantities, and project phasing, while the 5D includes cost estimate and time associations which supports predicting or forecasting the flow of cash and funds and the final cost of a project (Xu 2017). The concept of the 6D is linked to various aspects of energy efficiency and long-term sustainable development; hence, it validates design decisions or tests and compares diverse solutions. Last but not least, the 7D model often referred to as Integrated BIM or IBIM provides pertinent information that supports the project's management and operation throughout its life cycle ranging from insurance, handbook information, operation and maintenance cycle and future monitoring. Examples for BIM tools which can develop one or more BIM dimensions include Navisworks (Gilbert 2020), Synchro (Black and Sharp 2020), Tikal, Vico office, Powerproject and Fuzor (Konyushkov et al. 2020).

Environmental management system

An EMS can be considered as a field of study that combines the science related to project management in addition to that related to environmental engineering. Hence, all the inputs and outputs across a project's life cycle are considered through a life cycle thinking approach (Anand and Amor 2017). It follows typical project phases but with more responsibilities and actions for the environmental concern (The International Standards Organisation 2006). The Initiation phase includes the tasks that must be completed before a project can be approved or planned. The main purpose is to establish and define the project at a professional rate and relate it to assess the potential of the project site and estimate expected environmental problems (Safari and AzariJafari 2021; Ismaeel 2021). The Design Development (DD) Phase is when construction documents and design drawings are carried over from the conceptual design phase and to the environmental, mechanical, electrical, structural, and architectural components. The Construction (Const) phase accounts for onsite energy and water consumption, as well as the transportation from the manufacturer to the project site, direct material loss (solid waste) and transportation of waste from the construction site to landfill (Morsi et al. 2022). During, the Operation and Maintenance (O&M) phase, the data system's accessibility and efficiency are commissioned. It includes water use and electricity consumption, emission release and hazardous chemical agents as well as material replacement (Ismaeel et al. 2022). The end of a project's service life marks the beginning of the End of life phase (EOL). This records waste disposal rates, incineration rates as well as recycling and processing rates. Equally important, it accounts for any environmental impacts associated with incineration, landfilling or total deconstruction and demolition of the project including transportation to and from the site (Onat et al. 2014). The avoided burden method can be applied to investigate the environmental benefit from material recovery, reuse and recycling activities (Ismaeel and Ali 2020).

Proper planning via organizational and structural frameworks is an important pillar for an EMS. Thus, scheduling of key performance indicators, milestones activities, and deliverables are key for a successful implementation of a project (Wong and Zhou 2015). A quality control plan is an essential part of an EMS to ensure that the process adheres

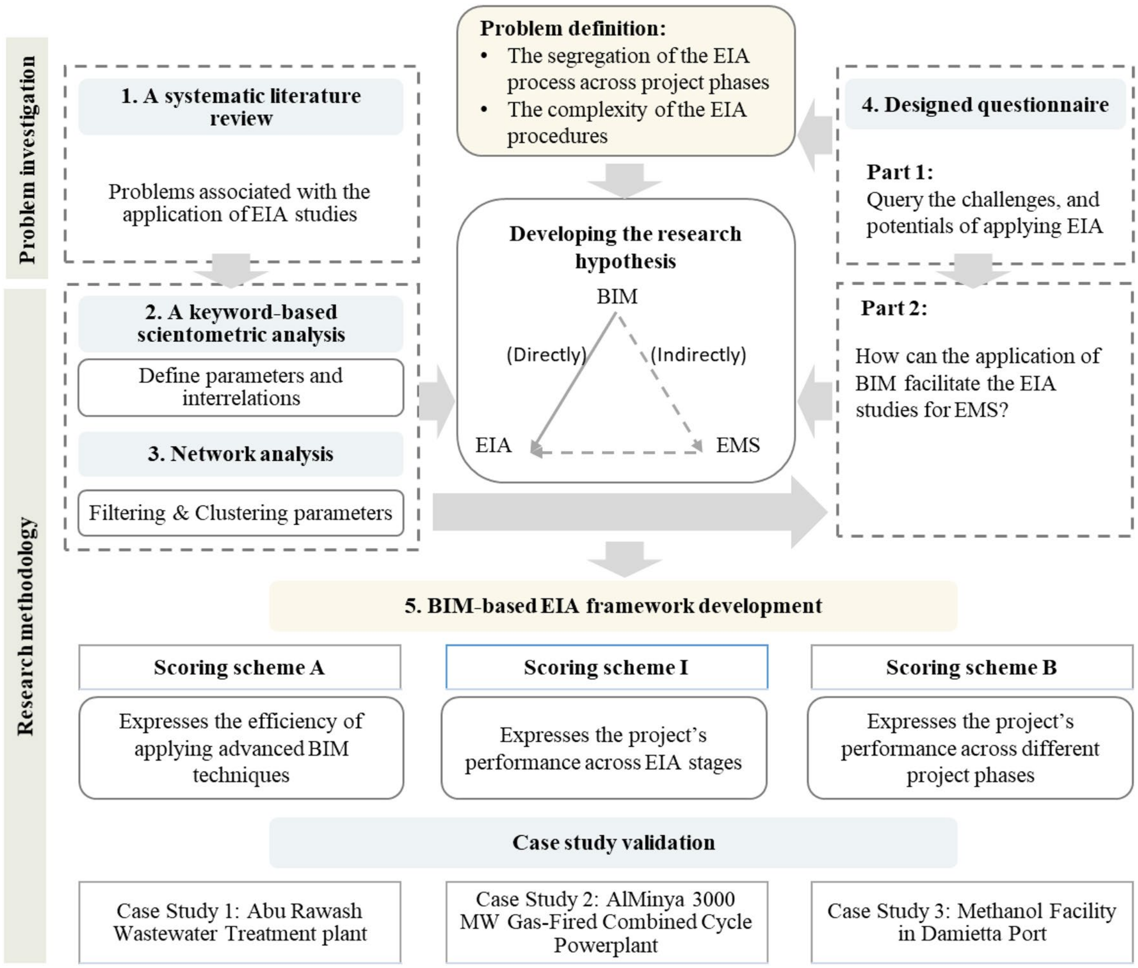


Fig. 2 The research plan

to the norms and regulations established at the outset of the project. Additionally, an EMS premised by the International Organization for Standardization (ISO) 14,000 comprises a mitigation plan, resources management plan whether for material-handling or construction waste management, and a monitoring plan (International Organization for Standardization 2015). This subsequently serves as the foundation for impact management and reduces the amount of construction and demolition waste (Morsi et al. 2022). Additionally, the decision-making process characterizes any EMS. In this regard, making informed and verified decisions using data is a process known as data-based or data-driven decision-making (Gilbert 2020). This enables evaluating and comparing alternatives for optimization. It should be supported by the right tool, method and accurate level of data acquisition. Another pillar is data sharing and exchange between different project parties, nevertheless, managing and coordinating these exchanges is a recurring difficulty for the construction industry, and there is a growing market for information management systems to help with this process (Elsayed and Ismaeel 2019).

This literature review section indicates that each term is currently receiving more academic attention; yet, to the best of the authors' knowledge, their interrelationship was not previously examined by other scholars. The core of EIA lied in its standardized process, defined impacts and project classification, but there is no guidance on when and how to integrate it into the building process and the required tools to facilitate its implementation (Ismaeel and Elsayed 2018). BIM offers constantly developing methods for data collection and processing through real-time decision-support systems capable of performing sophisticated coordination and interoperability (Ciribini et al. 2016). It supports modelling, simulation, optimization and coordination according to the project level of details and intended BIM dimensions. Finally, the advantages of conventional project management research and practise are presented through EMS, but from an environmental standpoint. It offers superior time management, task-oriented activity planning, and organization,

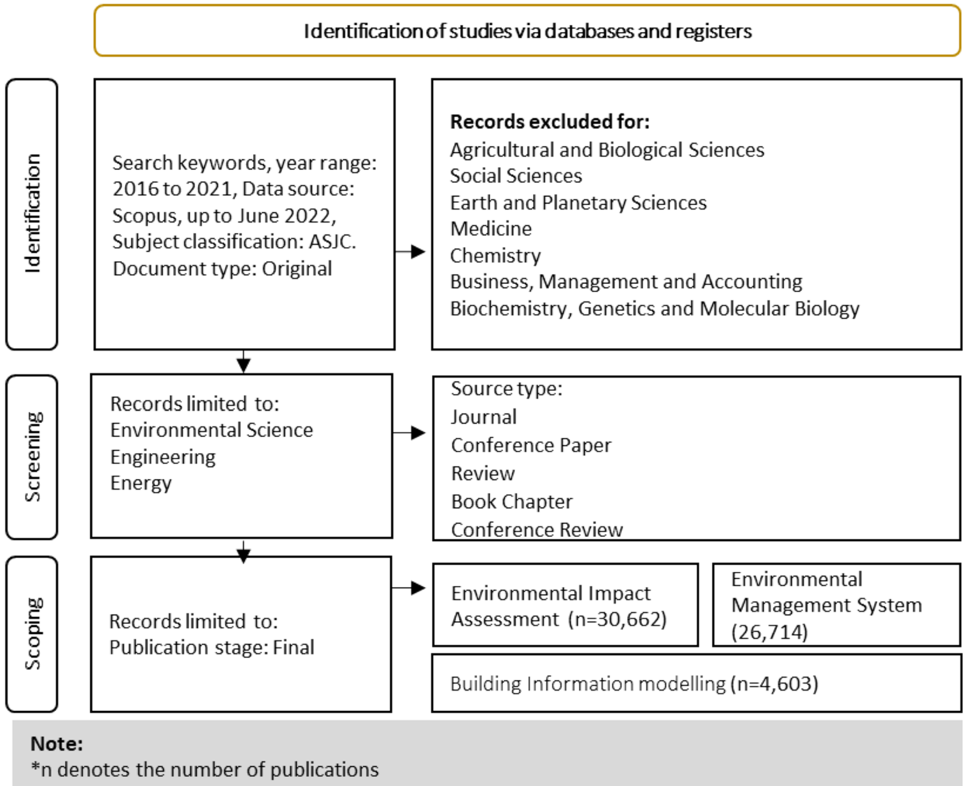


Fig. 3 The systemic literature review process, authors' elaboration using the PRISMA chart developed by MJ et al. (2021)

and it is more grounded to practice. Accordingly, this calls for the need to interrelate them to gain common benefits and overcome some of their challenges. In this regard, the applications of BIM in project management have been discussed in many studies, and fewer number of scholars have investigated the link between BIM and LCA studies which can be the first step for an integration with the EIA and pave the way for the discourse of this study (Ajayi et al. 2015).

Research methodology

The research methodology is shown in Fig. 2. This starts with the problem investigation through a systematic literature review, and via a designed questionnaire among local practitioners to query the challenges, and potentials faced by the practitioners while implementing the EIA system. Then, a keyword-based scientometric analysis was used to define parameters and interrelations and establish network analysis for a proposed BIM-based EIA framework. The proposed framework was applied to compare three major construction projects in a developing country, the case of Egypt.

Systemic literature review and Scientometric analysis

A systemic literature review covered a comprehensive investigation of English language scientific papers published from 2016 and 2021 following the steps shown in Fig. 3. The review covered articles, conference papers, journals, and other publications through the ScienceDirect database. This provided substantial background knowledge on the EIA system and its tools as well as its status in developing countries. Similarly, it investigated project management tools and mitigation strategies as well as BIM technology and its applications for green building design and construction. The query used principal keywords: Environmental Impact Assessment, Building Information Modelling and environmental management system.

Based on the Scopus database publication list, a keyword-based network analysis was performed using the VOSviewer version 1.6.18 (van Eck N. J. 2010). This investigated the co-occurrence of all keywords using the 'Full Accounting Association Strength' method and 15 minimum number of occurrences of authors' keywords. Non-relevant or repeated keywords were omitted and some clustering refinements were performed for consistency. This yielded three clusters as shown in Fig. 4.

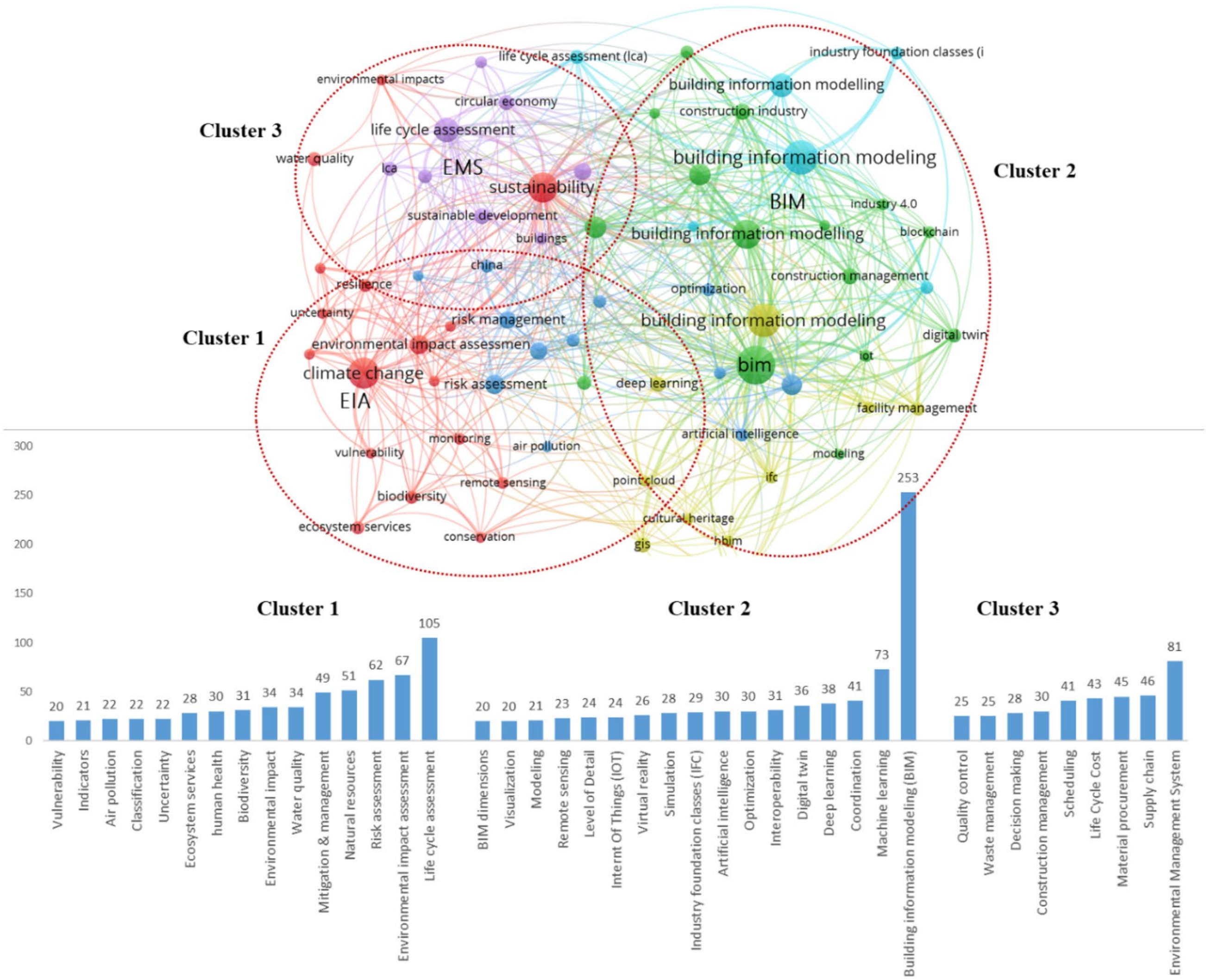


Fig. 4 Clusters of parameters using keyword-based scientometric analysis

Parameters in Cluster 1 related to EIA included

Vulnerability, Indicators, Air pollution, Classification, Uncertainty, Ecosystem services, human health, Biodiversity, Environmental impacts, Water quality, Mitigation & management, Natural resources, Risk assessment, Environmental impact assessment, Life cycle assessment.

Parameters in Cluster 2 related to BIM included

BIM dimensions, Visualization, Modelling, Remote sensing, Level of Detail, Internet Of Things, Virtual reality, Simulation, Industry foundation classes, Artificial intelligence, Optimization, Interoperability, Digital twin, Deep learning, Coordination, Machine learning and Building information modelling.

Parameters in Cluster 3 related to EMS included

Quality control, Waste management, Decision-making, Construction management, Scheduling, Life cycle Cost, Material procurement, Supply chain, and Environmental management system.

Survey design

An online questionnaire was carried out for participants in the field of building and construction industry in Egypt and disseminated through social media in addition to personal invitations for some professionals. It was available online using the following link: shorturl.at/nzIP3 from May–July 2022. The survey was divided into two parts; problem identification and problem solving with subsequent number of questions for each as shown in Fig. 5.

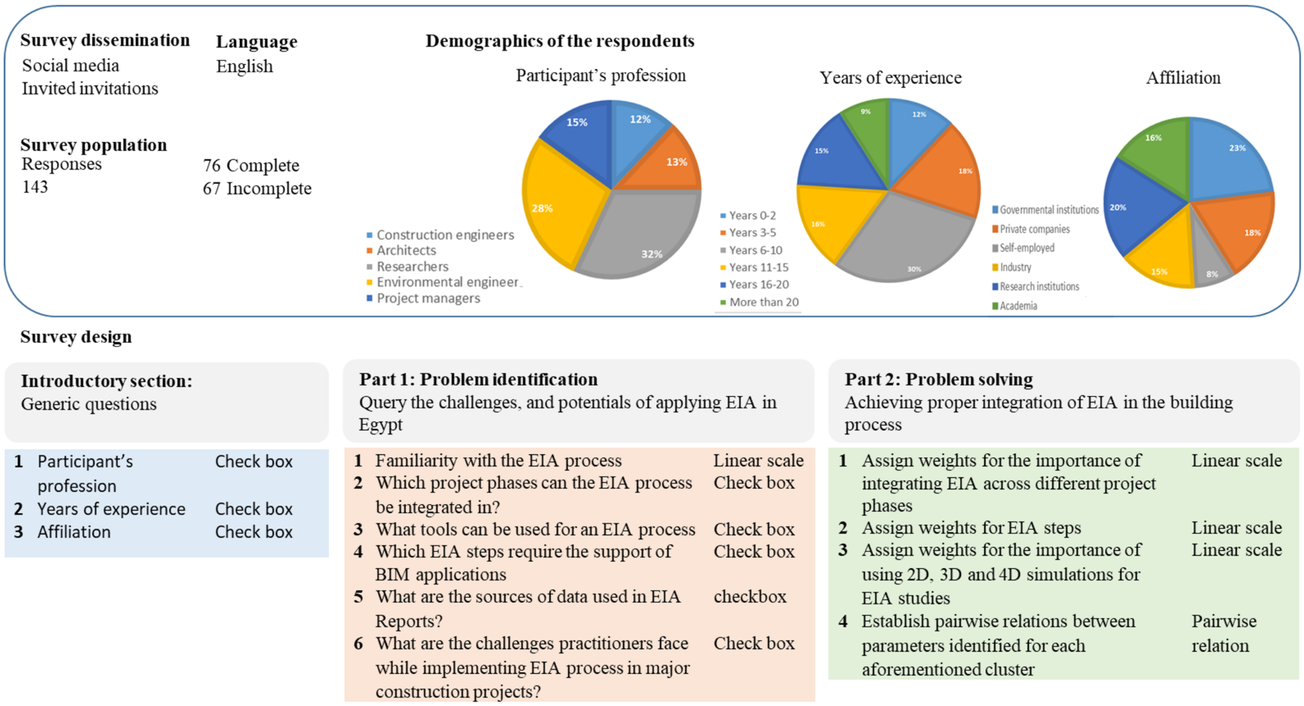


Fig. 5 Survey design

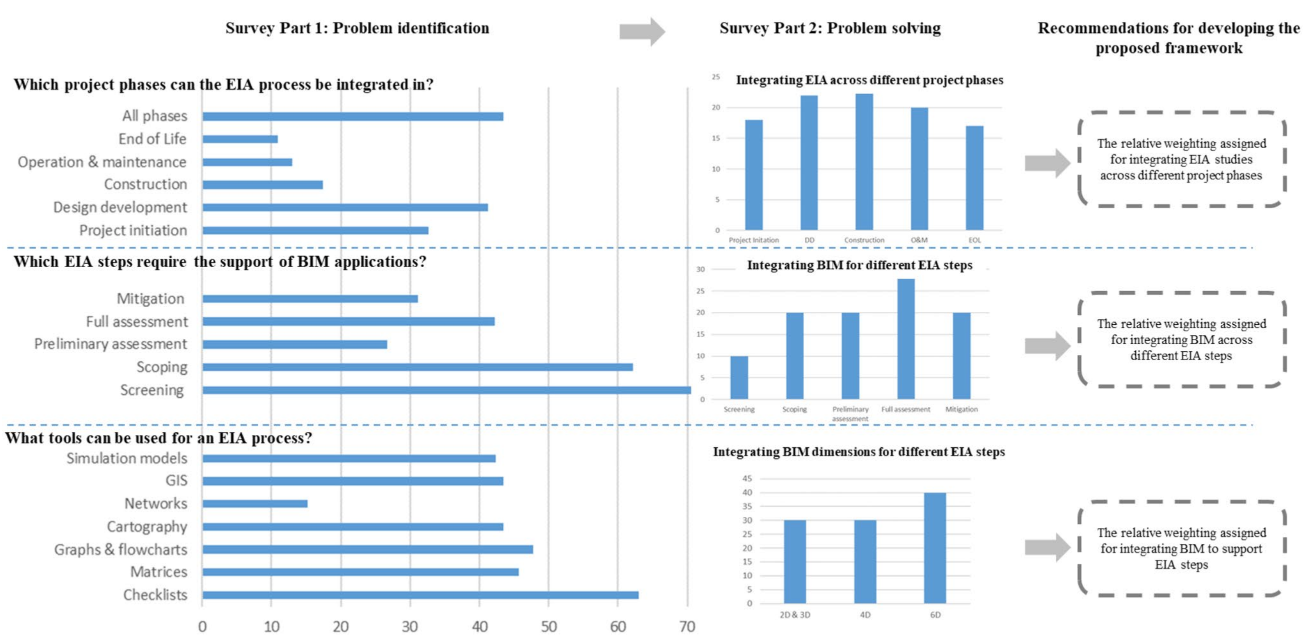


Fig. 6 Survey findings

The first part aimed to evaluate practitioners' familiarity with the EIA process, phases, and tools as well as the easiness of data acquisition and technical support. In addition to that, the survey inquired about the challenges practitioners face to perform EIA studies. The results showed that the main challenge is the seclusion of the EIA process across the project's phases, the complexity of the EIA procedures as well as poor practitioners' skills and competencies. This is in addition to challenges associated with data acquisition and poor technical and technological

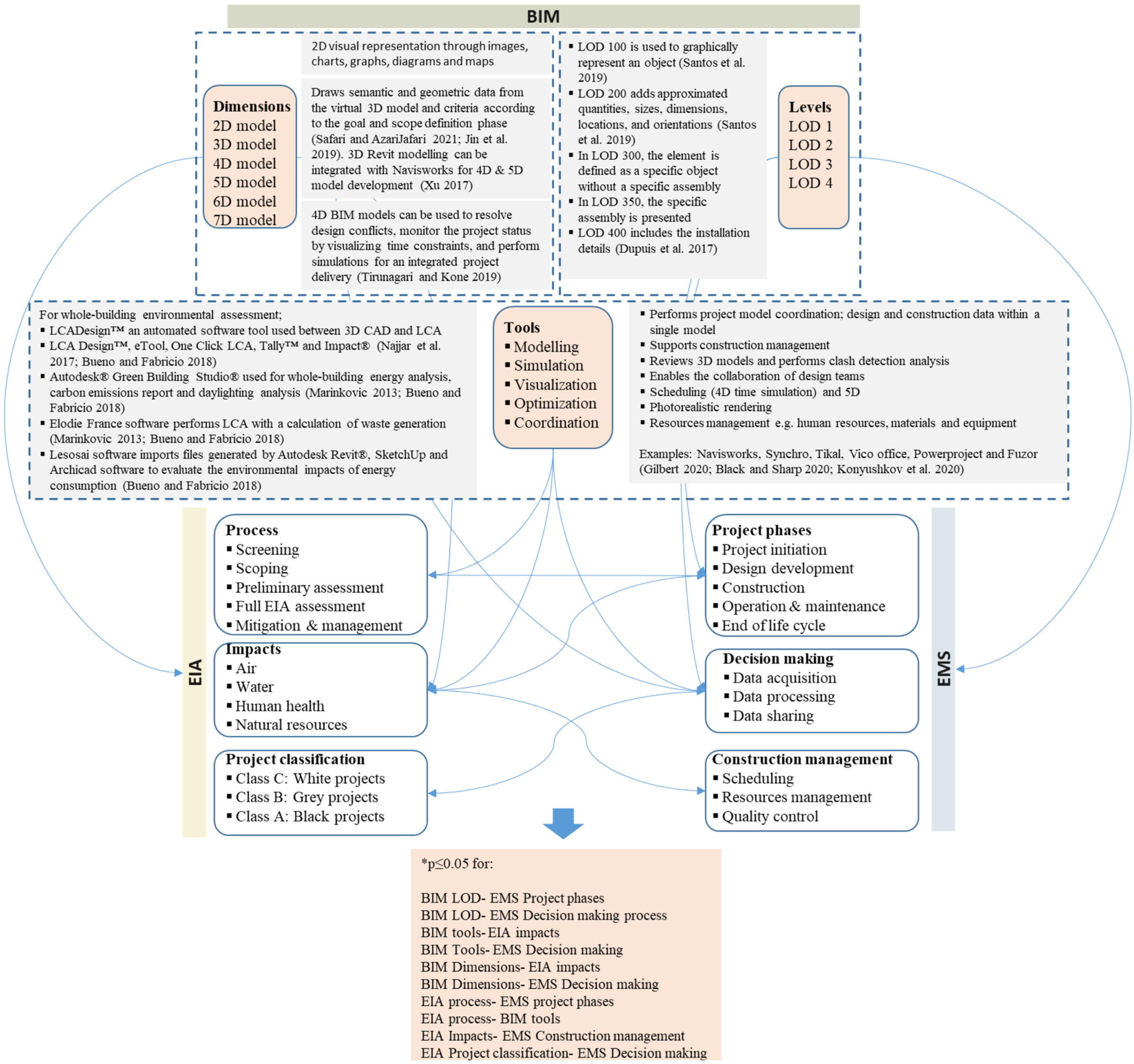


Fig. 7 Establishing the tri-dimensional relationship between BIM, EIA and EMS

aptitudes. As a result, practitioners still struggle to conduct an EIA and convey findings to non-expert decision-makers about the severity of the likely consequences and their characteristics. Inquiring about the range of available tools, it was found that 63% of participants used checklists, 47.8% used graphs and flow charts, this was followed by simple cause-effect matrices and the Geographic Information System (GIS), while only 2% used simulation models. Regarding data acquisition, 71% of practitioners relied on internet sources, 62% indicated that the data obtained from the national building research centre were sufficient, 51% used governmental database and 42% used material data sheets and Bill of Quantities.

Part 2 supported the problem-solving approach; hence, practitioners were asked to establish pairwise relations between parameters identified for each cluster. Accordingly, they assigned a relative importance weight for integrating EIA across different project phases, the EIA steps and proper BIM dimensions and tools. The results indicated the importance of using 2D and 3D for visual representation, 4D to model time and task schedule and 6D for environmental analysis. This indicated almost equal weighting for integrating EIA across all project phases, but greater relative weight for the full assessment step, as shown in Fig. 6.

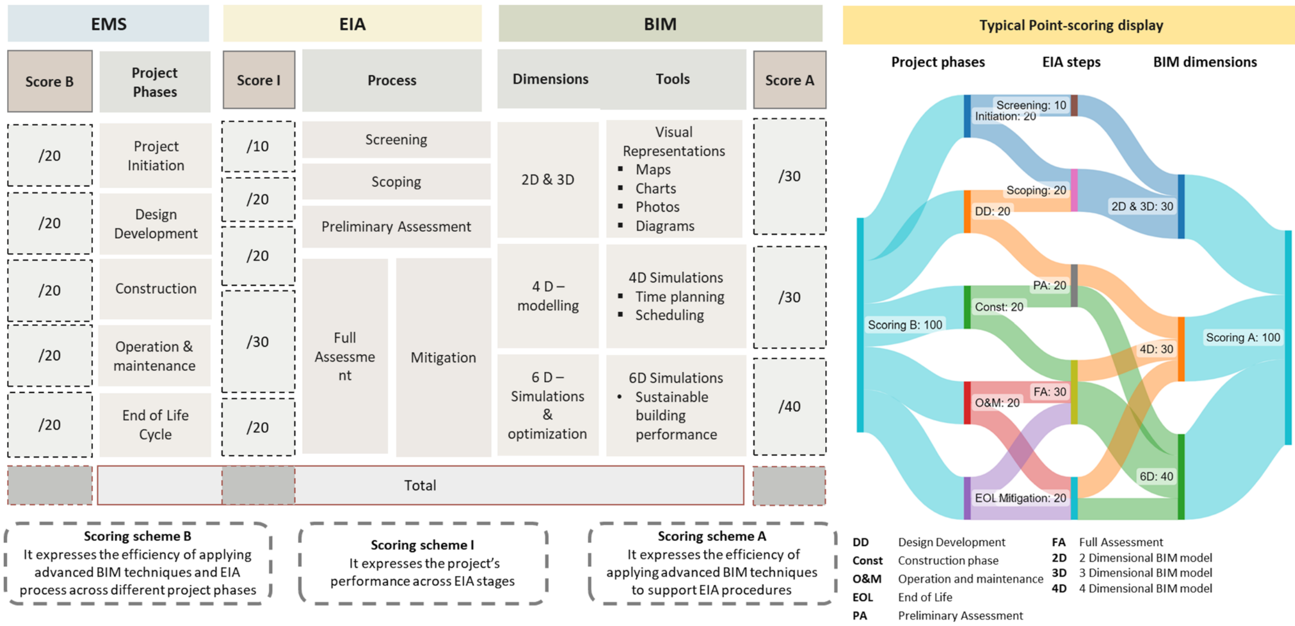
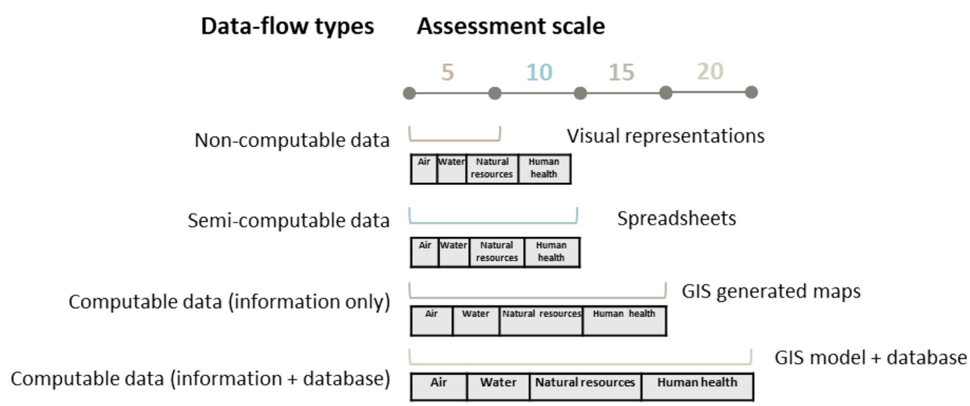


Fig. 8 The proposed BIM-based EIA Integrated Framework including a Sankey diagram developed using SankeyMATIC

Fig. 9 Example for Scoring Scheme A applied for spatial analysis



Establishing network analysis

Based on the survey results, the set of parameters defined in each cluster was down listed based on statistically significant relation $p \leq 0.05$ for linked parameters using Anova test. This step was intended to filter and select the most relevant parameters to the aims and scope of this research. The below network diagram in Fig. 7 establishes the tri-dimensional relationship between EIA, BIM and EMS.

BIM-based EIA framework development

A BIM-based EIA framework was developed as shown in Fig. 8 constituting a structured mapping to facilitate the implementation of the EIA process using BIM techniques. The framework adopts the typical five construction project phases; Project Initiation, Design Development (DD), Construction (Const), Operation and maintenance (O&M) and End of Life (EOL). EIA steps were allocated corresponding to each phase; Screening, Scoping, Preliminary Assessment (PA), Full Assessment (FA), and Mitigation. BIM dimensions were shown corresponding to each project phase and EIA step. This indicates a direct path by developing the tools that supports performing environmental analysis, and an indirect path by developing the tools to support an EMS and subsequently EIA studies. The relative weights of each of the project phases, EIA steps and the use of BIM dimensions were based on survey results. Hence, equal weighting was assigned for integrating EIA across all project phases, greater relative weight for the full assessment step, and more relative weight for employing 6D BIM dimensions for EIA studies. The framework incorporated three types of scoring schemes to support the decision-making process.

Score scheme A shown in Fig. 9 expresses the efficiency of integrating advanced BIM techniques to support EIA procedures. The weighting for this framework ranges from 0 to 20 and is divided into four equal intervals. The scale reference is based on the level of data exchange mode displayed for the EIA studies as indicated by previous studies (Succar 2009; Laakso and Kiviniemi 2012). This can be performed in four different data-flow types: (1) non-computable using images, (2) semi-computable using spreadsheets, (3) computable data which transfers information only, and (4) computable data which transfers both the information and database. It depends on coverage of all defined impact categories (air, water, natural resources and human health) required for the analysis to obtain full credit for each assessment level. Giving example of the use of spatial mapping analysis, a score of 0–5 indicates that basic, simple maps were used for visual representation. A scale of 5–10, includes the utilization of BIM software to develop the maps in a sort of semi-computable spreadsheet. The scale from 10 to 15 implies the use of the proper level of BIM dimensions to develop spatial analytical maps. Lastly, from 15 to 20 depends on sharing the model and associated database which enables further processing of data and interoperability with other software programs.

Scoring scheme I indicates the integration of BIM applications for each EIA step which is directly linked to project phases in Score scheme A. Score scheme B expresses the efficiency of integrating advanced BIM techniques across different project phases. The weights are equally distributed among the typical five project phases; each takes up 20 points reaching to overall 100 points. This ensures balanced account of environmental concerns by adopting a life cycle approach. A point-scoring display using Sankey diagrams is used to show the points-interplay across the three scoring schemes.

Case studies

Since 1936, Egypt has ratified numerous regional and global environmental conventions, accords, and partnerships. The Egyptian Environmental Affairs Agency (EEAA) determines the required level of EIA studies for the proposed development project and set follow-up action plans for projects' execution. Several national legislations, including Law 4/1994 and Law 9/2009 for the environment, are in place to protect and preserve the environment (EEAA 1982). In this respect, new building projects, as well as the expansion or renovation of existing facilities, necessitate an EIA study to categorize the projects based on their environmental impact. The EIA principles, according to Law 4/1994, include regulations for: (1) acceptable air temperature, pressure and air pollution, (2) applying specific planning restrictions to developments along or near the shoreline, and (3) drainage of liquid wastes, (4) Hazardous and Solid Waste Management, and (5) ambient noise levels. Projects are classified into three classes; White Projects cause minimal impacts that are typically approved after a quick screening stage. Projects with likely environmental impacts that necessitate thorough screening and scoping to identify the extent and magnitude of expected impacts are classified as Grey Projects. Black Projects are defined as those with substantial environmental impacts that necessitate a full account of their impacts on the environment. This corresponds to the World Bank classification of C, B and A project class, respectively (Cashmore and Axelsson 2013).

This section includes comparative analysis using case studies for major construction projects in Egypt. The data were obtained from the publicly shared reports at the EEAA website. Also, all three projects are consistently categorized as project Category C which necessitated a full EIA report according to the EEAA (EEAA 1982).

Case study 1: Abu rawash wastewater treatment plant

It was established in 2010 in Giza city. After the latest enhancements were completed, the project's total treatment capacity was 1.2 million m^3/day (primary treatment). As a result, secondary treatment facilities were required to purify the water of receiving streams. In addition, a large increase in sludge volume necessitated the construction of additional sludge treatment facilities. The environmental impacts during the construction phase included solid waste, increased traffic, vibration, noise and dust. At the operation stage, serious consequences resulted due to the existence of heavy metals in treated sludge and effluent, and around the sludge lagoons, as well as odour and insects.

The EIA study included some basic 2D and 3D visual representations including maps and charts using google earth and geological maps. Since there was not enough data incorporating a very precise water quality model, it was very challenging to assess its environmental impact. As a result, based on the accessible data, rough approximations of water quality in terms of Biological Oxygen Demand load were made as part of the 4D analysis. Nevertheless, the report didn't include any 6D simulations or more advanced analysis to assess the environmental conditions.

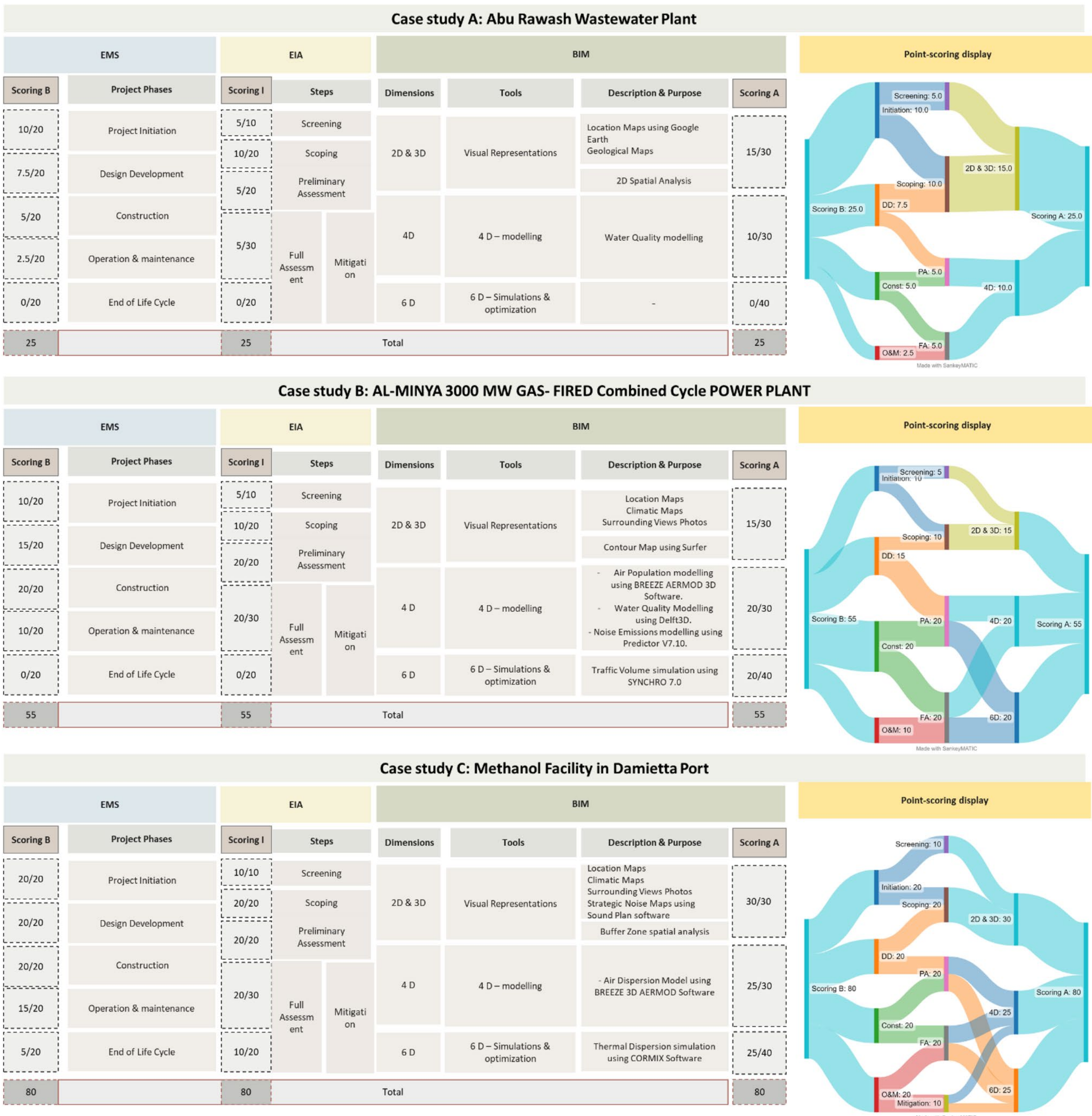
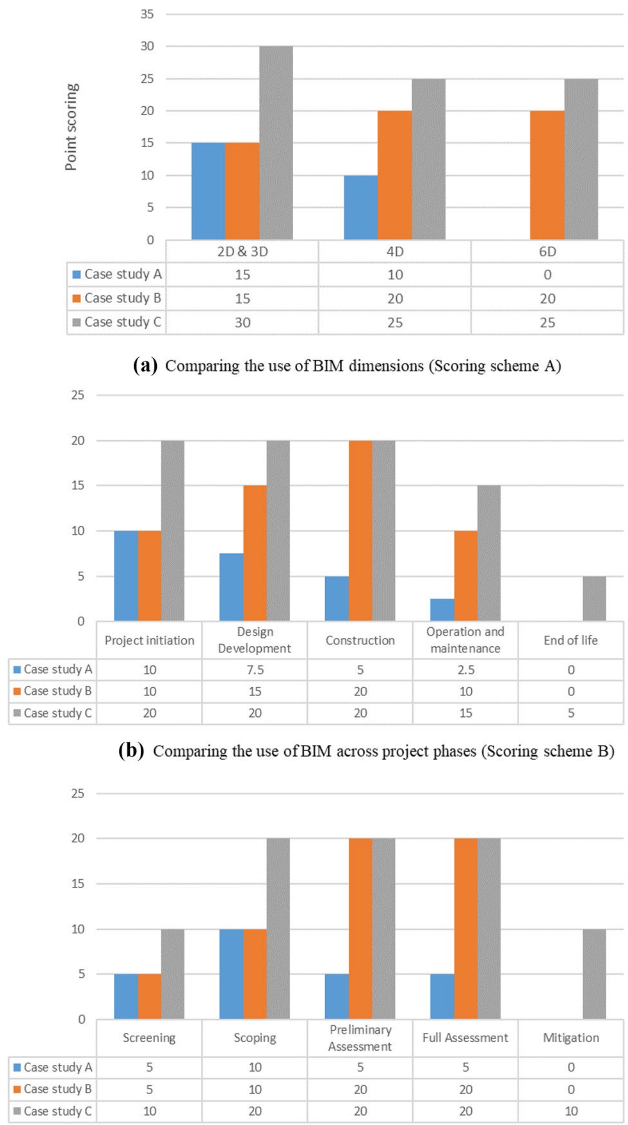


Fig. 10 Comparing the application of the proposed framework for the three case studies

Case study 2: AlMinya 3000 MW gas-fired combined cycle power plant

It was established in 2012 in Minya city. It is considered one of Egypt's largest thermal power plants. The environmental impacts include dust stack emissions, air pollution, aquatic toxicity, and noise pollution. The EIA report comprised 2D and 3D visual representations and spatial analysis that included google earth maps, climatic maps, surrounding view photographs. This is in addition to 4D modelling used for project scheduling and models. Moreover, the report integrated extra advanced tools for 6D simulations such as the ("BREEZE 3D" https://www.environmental-expert.com) which is a globally recognized software used to simulate the propagation of air pollution from power plant stacks. The software determined the dispersion and concentrations of pollutants in the neighbouring regions, taking into consideration the wind's climatic and geographic properties.



(a) Comparing the use of BIM dimensions (Scoring scheme A)

(b) Comparing the use of BIM across project phases (Scoring scheme B)

(c) Comparing the use of BIM for different EIA stages (Scoring scheme I)

Fig. 11 Comparing the three case studies using the proposed framework for scoring schemes A and B

In addition to that, ("Delft3D"), (http://www.oss.deltares.nl) a versatile integrated modelling software that simulated two-dimensional hertz plane and ("Flow-3D", https://www.flow3d.com) for water quality modelling were also used. The extent of noise emissions from the site was measured by ("Predictor Software", https://www.flow3d.com). Lastly, 6D models included the use of Synchro Studio software for an advanced traffic analysis, optimization, and simulation.

Case Study 3: methanol facility in damietta port

It was established in 2005 in Damietta city. The project entailed building and operating methanol plants. The project was implemented using a two-phase production strategy

Table 1 Summarizing the main differences of the three case studies

Project phase	EIA step	BIM dimensions and tools			Case study 1		Case study 2		Case study 3	
					Purpose	Software	Purpose	Software	Purpose	Software
Project Initiation	Screening scoping	2D& 3D	Visual representations	Charts Diagrams	Location map	Google earth	Location map	Google earth	Location map	Google earth
					Geological maps		Climatic maps		Climatic maps	
Design Development					–	–	–	–	Strategic noise map	SOUNDPLAN
	Preliminary Assessment			Photos	Surrounding view photos					
Construction	Full assessment		Spatial analysis		2D spartial analysis		2D spartial analysis		2D spartial analysis + Buffer	
		4D	4 D—modelling Scheduling and time analysis		Purpose	Software	Purpose	Software	Purpose	Software
Operation and Maintenance					Water quality modelling	–	Air pollution modelling	SYNCHRO 7.0	Thermal Dispersion Model	CORMIX
End of Life Cycle	Mitigation	6D	6 D—sustainability Simulations & optimization		–	–		BREEZE 3D	Air Dispersion Model	AERMOD
Total score					25		55		80	

Google earth: (https://www.earth.google.com),(BREEZE 3D): (https://www.environmental-expert.com), Synchropro: (https://www.bentley.com) with 3,600 metric tonnes of methanol per day for each of the two phases. The environmental impacts included air pollution, terrestrial ecology and biodiversity, noise pollution, topographic changes, and visual impairment as well as soil pollution. This case study had more detailed strand for integrating the tools across different project phases using 2D and 3D analysis. This encompassed visual representations for identifying the location using google earth, climatic maps, and strategic noise maps using the ("Sound Plan Software"). Additionally, some mitigation measures were taken according to the GIS buffer zone studies. Escalating to the 4D analytical level, air dispersion measures were taken by the ("BREEZE AERMOD" software, https://www.environmental-expert.com). Finally, the 6D analysis included the thermal dispersion model using ("CORMIX Software", https://www.CORMIX.com) which simulated the expected temperature differentials between the outflow discharges and the recipient environment.

Comparing the application of the proposed framework for the three case studies is shown in Fig. 10 showing the interplay of points between the three scoring schemes.

Results

Analysing the case studies shows the seclusion of the EIA process across projects' phases. It is used more during project initiation to comply with the national environmental laws. Hence, more effort is demonstrated for the Screening, Scoping, preliminary and full assessments. Nevertheless, the application of BIM techniques is still basic for all project phases relying on non-computable and semi-computable data exchange and processing methods. This provides limited potentials for further exchange and processing of the data and hinder optimizing decisions to mitigate projects' environmental impact. Hence, this explains why the mitigation step in the EIA process had least attention across all three case studies.

Case study A scored the least points in Scoring Scheme A, applying 2D and 3D BIM models for visual representation, least share for 4D models and none for 6D models. Hence, for scoring scheme B, a decelerating trend of point scoring was noticed across its life cycle. This is because the 2D and 3D BIM models cannot support life cycle decisions and have least benefit across subsequent project phases. This also explains why the use of 2D and 3D can support the screening and scoping steps but has limited benefit for the preliminary and full assessments which require further profound 4D analysis to account for time changes. Further, it has limited benefit for the mitigation step which requires not only accounting for the effect of time but additional sustainability concerns. Case study B has demonstrated better application of BIM tools; 2D and 3D, 4D and 6D in Scoring scheme A. This showed better performance across different project phases (Scoring scheme B) but unfortunately there is missing account of mitigation measures which affected Score Scheme I. Case study C scored the greatest points with more application of 6D BIM dimensions in Scoring scheme A. This supported the integration of EIA across different project phases including end of life scenarios (Score Scheme B), and different EIA steps with significant contribution to generating mitigation measures (Score Scheme I).

Hence, the directly proportional relation between the use of BIM tools enables better integration of the EIA process and support critical decisions across different project phases. Figure 11 compares the three case studies using the proposed framework and scoring schemes and Table 1 summarizes main points concerning the three case studies. It is noted that some tools were repeatedly used in the three case studies e.g. the air dispersion modelling using BREEZE AERMOD 3D, https://www.environmental-expert.com. Overall, this falls out as an indication for the existence of several BIM tools and software programs that should be integrated within the EIA study to cover different environmental aspects of the project.

Discussion

The discourse concerning EIA can be considered dual-faceted; for some scholars, it is internationally grounded standard process of environmental assessment (Suwanteep et al. 2016), for others, it is context-related depending on potentials and challenges in exact place and time (Badr et al. 2011). Hence, the multiapproach methodology adopted in this study ensured comprehensive coverage aiming to investigate the problem associated with existing challenges to the application of EIA, and how can the application of BIM support EIA studies for environmental management system. Thus, the advantages of BIM for streamlining the application of EIA studies can pave the way for a win–win situation for minimizing buildings environmental impact. Further, the research method and proposed framework can be replicated and reproduced in other contexts allowing a full understanding and a global validation.

The integration between the EIA process with BIM tools was not clearly established, nevertheless, the relation between LCA and BIM was discussed in previous studies. The complication of the LCA process as well as interoperability of data were main concerns. The integration of BIM tools with project management received greater share in literature i.e. for construction and waste management (Yeheyis et al. 2013) but least share for environmental analysis (Morsi et al. 2022).

For consistency, the three case studies were located in the same context with concurrent establishment. They also belonged to the C class with major environmental impact, hence, requiring full EIA studies. This ensured a fair base of temporal, technical and technological conditions for comparison showing the different magnitude of applying BIM application. Scrutinizing case studies shows the draw backs in carrying EIA studies and lack of using advanced analytical, computational and simulation tools. Hence, applying BIM techniques shall revolutionize the method environmental studies are carried. This shall facilitate the process of data processing, analysis and sharing as well as incorporating management and mitigation strategies through the construction and operation phases. It shall also enable developing alternatives and adopting an optimized selected decision-making process. In sum, it can be concluded that failure to score points under scoring scheme A was directly related to failure to gain points under scoring scheme B and I. This directly proportional relationship supported the research hypothesis which indicated the necessity to develop the use of BIM tools to enable better integration of the EIA process and support critical decisions across different project phases. Also, it is needed to have a paradigm that sees BIM as an integration of product and process modelling and management rather than merely a collection of technology and procedures. Hence, there is a need for a framework that strives to fill the gap between academic and industry conceptions of BIM by offering a research and supply composition that is flexible to their complementing but distinct needs.

Conclusion and recommendations

The application of EIA studies faces many challenges, especially in developing countries. This problem was investigated in existing literature and via a designed questionnaire among local practitioners. The reasons were mainly attributed to the seclusion of the EIA process across the project's phases, as well as the complexity of the EIA procedures. Hence, the research argues that BIM applications can be the key to resolve several associated problems to EIA either directly, or indirectly by supporting EMS. This tri-dimensional relationship was not explored in previous studies and reflected the complex nature of the process and research contribution to the existing body of literature.

The proposed framework intends to assess the efficiency of applying BIM techniques to facilitate the integration of EIA studies across different project phases. It presents a critical assessment that points out areas of precedence and drawbacks. The proposed framework was applied to compare three major construction projects in a developing country, the case of Egypt: showing the interplay of points amongst the three concepts via a Sankey diagram. The research pinpointed existing challenges under three main points: (1) poor application of advanced BIM models to support sustainability analysis for EIA studies, (2) imbalance of applying BIM applications across different project phases; it was less pronounced for the operation and maintenance stage as well as end of life scenarios, and (3) poor integration of BIM tools to support the mitigation step. Hence, the study recommends applying the 6-dimensional BIM model to enable developing mitigation measures and support design optimization during building operation and end of life stages. The directly proportional relation between the use of BIM tools enable better integration of the EIA process and support critical decisions across different project phases and EIA steps. This novel approach presents the required level of verification and quality control procedure needed by decision-makers and environmental engineers to perform EIA studies and pave the way for further related research. Hence, the proposed framework can be included as part of the EIA final report and project measurement and verification follow-up records. It can also be developed to account for cost and other economic aspects. Further, the analysis presented had put the discourse of this study into a wider perspective, and pinpoint directions for future research to account for a range of multidisciplinary interrelated parameters. This is because BIM applications are continuously developing with advancements in the Internet of Things, Information Communication Technology, Artificial intelligence, Deep learning and Machine learning.

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Declarations

Competing interests The authors declare no competing interests.

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