Journal of Building Engineering 100 (2025) 111789

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

A systematic review of literature on electric vehicle ready buildings

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ARTICLE INFO

Keywords:
Built environment
Electric vehicle (EV)
EV ready buildings
Charging systems
Zero carbon emissions

ABSTRACT

The demand for electric vehicles (EVs) has skyrocketed recently prompting the need to make EV charging systems readily available everywhere including residential and commercial buildings. This has given rise to the concept of electric vehicle ready buildings (EVRBs). The relevance of EVRBs include the promotion of construction of charging infrastructures at homes and offices of EV owners. The concept (EVRBs) also has prospects of reducing carbon emissions, a key theme in the net-zero agenda together with lower energy expenditure. However, the key issues surrounding this novel concept has not been extensively explored in the construction management research. Therefore, this paper aims at critically exploring literature to identify the key issues on EV ready buildings. The study's objectives include a) to explore the status of the readiness of buildings for EVs and b) to analyse the success factors for EVRBs. Systematic review of studies from Scopus, Web of Science, Google Scholar, PubMed, EBSCOhost, ProQuest, and PubMed was conducted in this article. The findings demonstrate that most of the ten classes of buildings are poorly ready for EV charging systems. Further, the findings reveal success factors for EVRBs such as green procurement practices, amendment of building codes (regulations) and strong stakeholder engagements to increase the awareness and acceptance of the concept among builders. As a review on an emerging concept, this article has demonstrated the need to incorporate EV charging systems in building practices which is a significant area for future studies in the built environment.

1. Introduction

The turn of the last century culminated with recent activism to transition to net-zero emissions to safeguard the climate have increased the use of electric vehicles [1,2]. The statistical records support this shift to Electric Vehicles (EVs) with year-on-year rate of 5.3 % of the global car purchase. It is expected that the EV sales could be 86 % of the global car sales by 2030 [3]. China, Norway, Germany, Canada, Australia, Belgium, United States and United Kingdom constitute the large market of EV sales [4]. A major concern of potential and current users of EVs is availability of charging systems. It is noticeable that almost all EV charging infrastructures are

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https://doi.org/10.1016/j.jobe.2025.111789
Received 29 September 2024; Received in revised form 27 December 2024; Accepted 4 January 2025
Available online 7 January 2025

found at public places such as shopping centres (malls), university campuses and designated places. Although, they are helpful they come with waiting time concerns and sometimes security risks where some owners perceive they could be attacked. According to Electric Vehicle Council, Australia [5], The Institute of Electrical and Electronics Engineers [6] and European Union [7], the support and preference for home-based EV infrastructures has reached all-time high with the push to install EV charging plugs in apartment buildings and workplaces [8]. However, around the world, many residential buildings do not match up to accommodate charging systems for EVs [9]. Thus, the call for EV ready buildings to address these growing demand of car users.

Making buildings electric vehicle (EV) ready involves retrofitting homes and commercial workplaces constant supply of electric energy and equipment to charge EVs [10,11]. It also refers to constructing new residential and commercial buildings with the needed electrical charging systems for electric vehicles [12]. The amount of electricity usage is relevant in EV ready buildings together with the costs of installation and regular maintenance [2,13]. Due to this, EV ready buildings have been marked by resistance from property owners and consumers concerning the cost of energy consumption [14,15]. These resistances have prompted governments in developed nations to support residents through financial rebates to purchase and install EV ready systems for homes [4,16]. Governments (local councils and national authorities) and major players in the building industry such as building regulators, owners, construction firms and investors are making strides to support to home and office builders to deliver EV ready buildings [17]. For instance, Electric Vehicle Council in collaboration with Australian Institute of Project Management in Australia are urging members to build EV friendly buildings to the tune of 17 % by 2030 [18]. Kelly, Samuel [19] and Axsen and Kurani [20] also found that more than 50 % of potential EV owners in the United States and United Kingdom support the charging of the cars in the home. The significant difference of the choice between charging at home and workplace compared to public charging stations is due to security of nearby buildings, well-protected neighbourhood and availability of parking lots.

There is a growing industrywide collaboration in the built environment with external support from governments to amend building codes to promote the installation of EV charging plugs in parking lots of residential and corporate apartments [21]. The current literature on construction and engineering management (CEM) is heavily silent on EV ready buildings. What constitutes EV charging station for residential buildings have almost no theoretical foundation in the CEM literature. Further, the benefits and challenges associated EV ready buildings for builders have not been articulated in past studies. Therefore, this study aims at critically assessing past literature and presenting the major themes (factors) on EV ready buildings. It includes objectives such as: a) to assess the status of buildings for EV chargers and b) to identify the critical success factors for electric vehicle ready buildings (EVRBs). The novelty of this study is found in the relevant themes serving as a checklist of matters of consideration for potential EVRB developers. This will enrich the understanding of contractors and project managers in the management of EVRBs. For investors in the built environment, this will be document to assess the potential benefits for green investments. Regulators and policymakers in the built environment will be equipped with information to make necessary changes to embrace this emerging concept. Theoretically, this study could serve as a guide and foundation for further studies among the scientific research community of construction management. The subsequent sections of the paper include methodology of the paper followed by the results and discussions, implications of the study, and conclusions.

2. Research method

2.1. Search strategy

Systematic literature review (SLR) forms the research method for this study. An SLR seeks to identify, summarise, and analyse the findings of all relevant literature to address specific research question while employing necessary measures to limit bias and random error [22,23]. To report the findings of SLR, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was the guiding protocol [24]. The updated 2020 PRISMA guidelines includes a 27-item checklist that provides a uniform standard that assist researchers to clearly, precisely, and thoroughly document and report on their review process and findings [25]. The guideline also addresses the risk of bias, reproducibility and quality issues that may surround the included data (studies) in the systematic review [26]. The research question formulated for the study is: what are the critical success factors on electric vehicle ready buildings? A list of relevant variants of words related to “electric vehicle” and “building” were generated from a preliminary reading on the subject matter as keywords. Comprehensively, the keywords for search of literature identified include: “electric vehicle” OR "electric cars” OR “electric* car” OR “electric car*” OR “EV cars” AND "buildings” OR “build*". These keywords were applied in these bibliographic databases: Scopus (Elsevier), Web of Science (Clarivate), EBSCOhost, ProQuest, Google Scholar, and PedMed. These databases were selected because they have a wider coverage of research publications on the subject matter (Kukah et al., 2021). The selected databases are also commonly used by researchers in the construction and engineering field to conduct literature review [25,27]. The initial outcome of the search in the bibliographic databases produced a total of 2063 (inclusive of peer-reviewed article, books, short notes, grey literature etc). The search for articles in the various databases generated the following counts of records: Scopus [6029], Web of Science [2398], ProQuest [27584], Google Scholar [17700], and PubMed [73].

2.2. Eligibility (criteria for selection)

The eligibility of the studies for inclusion and exclusion assessment were dependent on the following criteria. Firstly, articles whose titles and abstracts did not address EVRBs were removed but articles that portrayed the EVRBs were kept. Secondly, the choice of document type and source were limited to journal articles and grey literature of reports and thesis. All book chapters, book reviews, conference papers and opinion pieces on the sources of articles were excluded. Thirdly, the choice for language in the assessment process of the articles was English and all documents not published in English were excluded. Fourthly, a document is included if the content from introduction to conclusion cover the subject matter of electric vehicle ready buildings. All articles outside the subject matter were excluded.

2.3. Study selection process

At this stage, 53784 search outcomes from Section 2.1 were imported into the EndNote. Duplicate, abstract and title screening ensued using the search results. The goal of the duplicate assessment was to ensure there were no studies that appeared two or more times in all the bibliographic databases. Duplicates of 21482 documents were removed automatically to the trash section of the EndNote with 32302 documents left for further assessment. Afterwards, the first eligibility criteria (Section 2.2) was applied in the title and abstract screening. The screening resulted in 19458 documents removed with remaining documents of 12844. The application of the next two eligibility criteria from Section 2.2 produced 28 suitable articles for the analysis. The documents that were removed to attain the 28 documents were 12816 (source of articles = 8415, language = 3400 and content = 1029). The summary of the selection assessment process is shown in the PRISMA flowchart (Fig. 1).

2.4. Data extraction and analysis

Quality assessment for systematic reviews involves an appraisal of the methodological biases and fallacies of included articles in a review. Published studies are susceptible to biases and errors [28,29]. These vulnerabilities and methodological errors have the potential to skew the results of systematic reviews if they are not assessed and avoided properly [30]. Therefore, following the selection of the 28 relevant articles, the quality of all included studies was assessed independently by four researchers. Any disagreements regarding the quality of any of the included study was discussed amongst all four authors and resolved by consensus. The various appraisal tools that were used to critically assess the methodological quality of each study include the following four main appraisal tools. First, the Strengthening of the reporting of observational studies in epidemiology (STROBE), a quantitative quality assessment method was used to appraise the papers with research designs that were statistically and mathematically inclined [31]. The STROBE

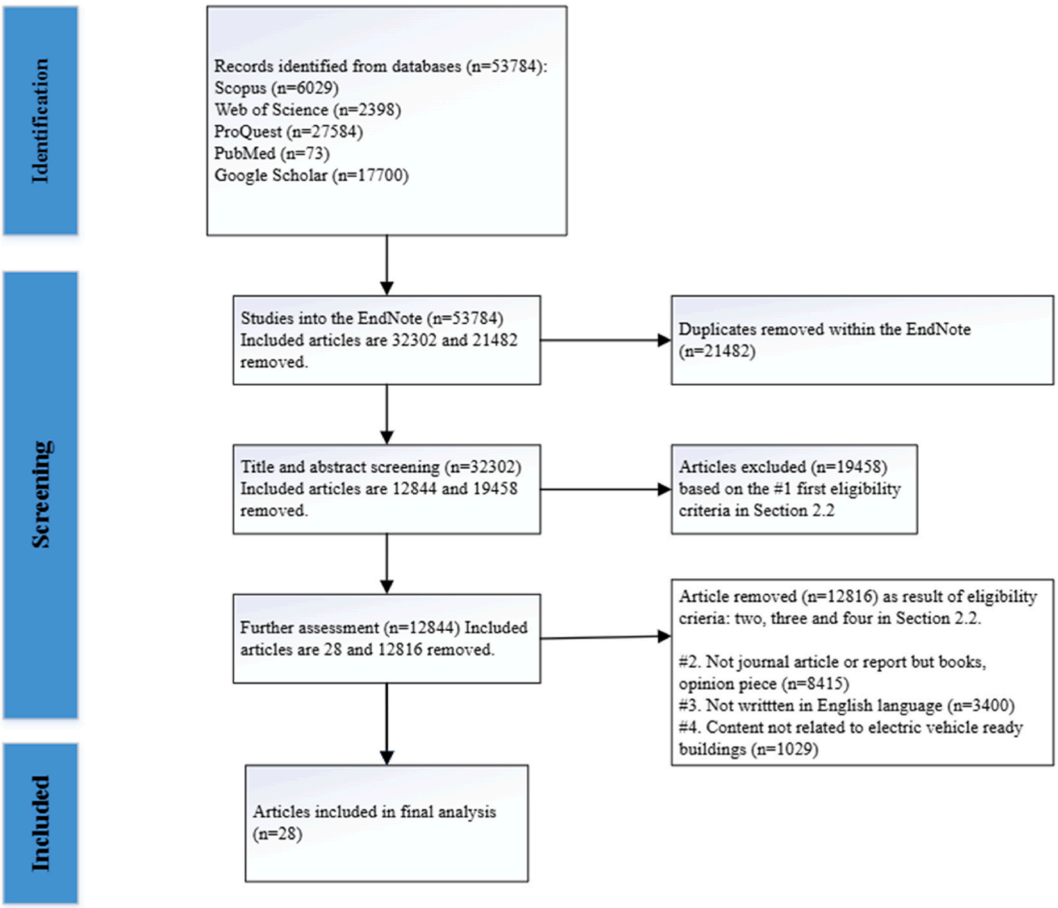

Fig. 1. PRISMA method flowchart.

rating assesses twenty-two questions. Secondly, the Quality of grey literature was assessed with Tyndall AACODS critical appraisal tool [32]. This tool uses six checklist items centred on authority, accuracy, coverage, objectivity, date, and significance to appraise the quality. The six quality criteria were scored on a three-point scale. There are several literature that utilised STROBE [33–35] and

Table 1
Characteristics and summary findings of the included studies.

Article (Year)	Document	Source	Country	Types of Projects	Research Design	Quality Appraisal tool	Quality Score
Bhundar, Golab [42]	Journal article	Energy Informatics	Canada	Buildings	Quantitative study	STROBE	5/7
Bianco, Delfino [1]	Journal article	Energy Conversion and Management	Italy	Buildings	Quantitative study	STROBE	6/7
Ding, Zhu [13]	Journal article	International Journal of Electrical Power & Energy Systems	China	Office buildings	Quantitative study	STROBE	6/7
Ghafoori, Abdallah [43]	Journal article	Applied Energy	United States	Commercial buildings	Quantitative study	STROBE	5/7
Gilleran, Bonnema [15]	Journal article	Advances in Applied Energy	United States	Retailed Buildings	Quantitative study	STROBE	5/7
He, Khazaei [44]	Journal article	Sustainable Energy, Grids and Networks	United States	Commercial buildings	Quantitative study	STROBE	4/7
Heredia, Chaudhari [45]	Journal article	Applied Energy	United States	Buildings	Quantitative study	STROBE	5/7
Khan, Sudhakar [46]	Journal article	Mathematical Problems in Engineering	Malaysia	University buildings	Quantitative study	STROBE	6/7
Khan, Sudhakar [47]	Journal article	Journal of Energy Storage	Malaysia	Residential buildings	Quantitative study	STROBE	7/7
Lopez-Behar, Tran [48]	Journal article	Energy Policy	Canada	Multi-Unit Residential buildings	Quantitative study	STROBE	6/7
Ou, Lin [49]	Journal article	Transport Policy	United States	Residential buildings	Quantitative study	STROBE	6/7
Palmiotto, Zhou [50]	Journal article	Sustainable Energy, Grids and Networks	United Kingdom	Residential buildings	Quantitative study	STROBE	7/7
Tian and Talebizadehsardari [51]	Journal article	Energy	China	Buildings	Quantitative study	STROBE	5/7
Uimonen and Lehtonen [52]	Journal article	Energies-MDPI	Finland	Office buildings	Quantitative study	STROBE	4/7
Wang, Li [53]	Journal article	Processes-MDPI	China	Commercial buildings	Quantitative study	STROBE	6/7
Zhou, Li [54]	Journal article	Energy & Buildings	United States	Smart buildings	Quantitative study	STROBE	7/7
Quddus, Shahvari [55]	Journal article	Applied Energy	United States	Commercial buildings	Quantitative study	STROBE	7/7
Sehar, Pipattanasomporn [56]	Journal article	Energy	United States	Buildings	Quantitative study	STROBE	4/7
Sørensen, Lindberg [8]	Journal article	Energy & Buildings	Norway	Residential buildings	Quantitative study	STROBE	5/7
McIntyre [57]	Report	Strata Community Australia	Australia	Residential buildings	Grey Literature	ACCODS	5/6
Rango [58]	Report	Electric Vehicle Council	Australia	Residential buildings	Grey Literature	ACCODS	6/6
UNSW [59]	Report	University of New South Wales	Australia	Buildings	Grey Literature	ACCODS	4/6
Ge [60]	Report	Australian Building Codes Board	Australia	Buildings	Grey Literature	ACCODS	5/6
GOVUK [61]	Report	National Renewable Energy Laboratory	United States	Residential buildings	Grey Literature	ACCODS	5/6
EnergyInnovation [62]	Report	UK Department for Transport	United Kingdom	Buildings	Grey Literature	ACCODS	4/6
UCLA [63]	Report	UCLA Luskin Center for Innovation	United States	Residential buildings	Grey Literature	ACCODS	5/6
ClimateXChange [64]	Report	Work Group UK	United States	Buildings	Grey Literature	ACCODS	4/6
Van Roy and Driesen [65]	Thesis	Arenberg Doctoral School	Germany	Buildings	Grey Literature	ACCODS	5/6

***Quality score interpretation: a)** Quantitative studies (STROBE) highly biased (0–2), medium level (3–5), least biased (6–7)**, and b)** Grey literature (reports and thesis) – low quality susceptible to bias (0–2), medium quality (2–4), highly quality for review (5–6).

AACODS [36–38] which helped in the validation of this systematic review. Relevant data was extracted from the 28 documents by the co-authors. The Microsoft Excel was the document manager collating all the information from the selected documents. Data extracted include authors' names; study setting; methodological approach adopted; project type and a brief focus/aim of the studies. The thematic analysis approach supported iterative examination of texts, words, statements, and phrases [39]. Coding of the extracted data ensued and the common patterns within the codes resulted in the formation of themes. The reading and thematic analysis of the data produced information to address the research objectives.

3. Results and discussions

3.1. Overview of articles

In summary, twenty-eight (28) articles were eligible in this research are represented in Table 1. A large part of the studies analysed (nineteen of the articles) were quantitative studies, eight reports and a thesis. Research articles assessed in this study had residential and commercial buildings as the subject matter of analysis. The studies also showed the contemporary nature of the issues on electric vehicles and buildings from 2015 to 2023. China leads in the global market for EVs but most of the studies have been conducted in Australia, United States and United Kingdom [40]. In Australia, for instance, the New South Wales Government is prominently involved in promoting EVRBs with financial incentives to homeowners and business to transition to EV friendly and zero emission buildings [41]. The descriptive results of the quality assessments of the articles portray very low and acceptable level of methodological errors. None of the papers had a high risk of bias which could have negative impacts on this review. In Table 2, the status of readiness of the classes of buildings are presented with the evidence that most business and residential buildings need retrofitting to catch up with the EVRBs standards.

3.2. Critical themes on EV ready buildings

The following key themes (factors) came out of the thorough review of the articles (Fig. 2):

1. Design and procurements

A major prerequisite in procuring suitable electric vehicle charging systems is holding a deep understanding of how their operators and drivers charge their cars [58]. Electric vehicles present new electricity "topping-up" challenges for engineers, installers,

Table 2
Buildings and EV Ready status.

Classification of Buildings	Description	EV Ready Status[a]	EV Ready Building Recommendations
Class 1	Single residential buildings such as terraced houses, duplexes, and row houses	Poorly ready (31–50 % Ready)	Rewiring and retrofitting for electric vehicle chargers
Class 2	Multi-unit apartment residential buildings such as multi-storey buildings	Medium level ready (51–70 % transition level)	Assessment, installation, rewiring, redesign, retrofit, refurbishment in Class 2 building ready for EV chargers
Class 3	Buildings other than Class 1 & 2 buildings such as hostels, boarding houses, dormitories, care facilities for children and aged, and guest houses	Very poorly ready (less than 30 % transition status)	Assessment, redesign, installation, rewiring, redesign, retrofit, refurbishment
Class 4	Caretakers' accommodation in Class 5 and 9 buildings	Very poorly ready (less than 30 % transition status)	Provide EV chargers as demanded by owners
Class 5	Commercial office buildings such as Law firms, office of accountants and government institutions	Medium level ready (51–70 % transition level)	Redesign, retrofit and install EV chargers
Class 6	Buildings for commercial activities such as shopping centres, restaurants, stores, and public laundry	Medium level ready (51–70 % transition level)	Retrofit the current buildings and input EV charging stations
Class 7	Storage-type buildings such as warehouses	Very poorly ready (less than 30 % transition status)	Initial design of warehouses must incorporate EV charger wiring systems
Class 8	Factory buildings used in processing, production, assembling and finishing	Very poorly ready (less than 30 % transition status)	Architectural designs should include EV chargers
Class 9	Public infrastructure buildings such as hospitals, schools, sport facilities and transport buildings	Medium level ready (51–70 % transition level)	Rewiring, redesigning and refurbishment of public buildings to accommodate EV chargers.
Class 10	They are buildings which are not habitable including swimming pool, private garages, antenna, mast	Very poorly ready (less than 30 % transition status)	Redesign, change status of buildings to increase EV charger wires

[a] Johnsson, Karlsson [66], Gałecka-Drozda, Wilkaniec [67] and Zhang, Pan [68].

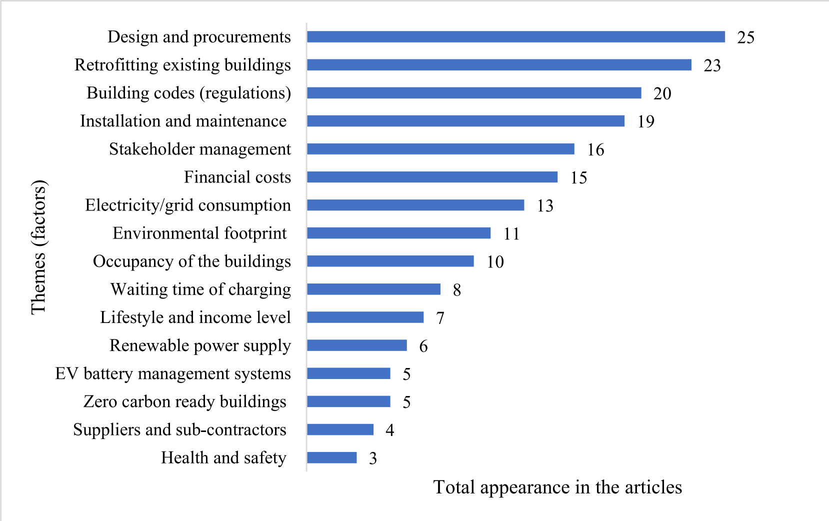

Fig. 2. Main themes (factors) on EVRBs.

procurement teams, asset owners and tenants that traditional cars with internal combustion engines (ICE) do not. ICE vehicles are generally refuelled at a petrol service station, forcing a specific visit while en-route or as the sole reason for the trip [69]. This is in stark contrast to zero and low emissions vehicles, which require drivers to regularly "top up" the car battery whenever there is an opportunity to do so. This is comparable to an individual charging their mobile phone at home at night, in the office, or simply when it is convenient [70]. The change from refuelling to recharging introduces a new driving and "topping up" behaviours.

2. Retrofitting existing buildings

The implementation of electric vehicle (EV) recharging infrastructure in stratum buildings through retrofitting is key in facilitating the widespread purchase and use of EVs in urban areas. The procedure at hand is the enhancement or alteration of pre-existing infrastructure to allow for the installation of EV plugs, considering both technical and regulatory considerations [71]. Numerous scholarly sources offer valuable insights pertaining to the issues and techniques associated with this subject matter. In retrospect, the process of retrofitting pre-existing buildings frequently includes evaluating and perhaps enhancing the electrical infrastructure to accommodate the installation of electric vehicle (EV) charging stations. This may entail augmenting the circuit's capacity and assuring its compatibility with various charger types, such as Level 2 or DC fast chargers ([72]. Furthermore, the strategic placement of charging stations within the parking area of the building holds significant importance. To optimise accessibility for residents and minimise installation costs, it is imperative to ensure the appropriate distribution and design of charging places. The process of retrofitting buildings to accommodate electric vehicle (EV) charging entails considering both the expenses associated with installation and the possible financial gains derived from offering EV charging services [73]. By considering the technical, regulatory, and economical dimensions, strata building owners and property managers can successfully undertake retrofits on current structures to facilitate electric vehicle (EV) recharging, so making a valuable contribution towards a sustainable and ecologically conscious future of transportation.

3. Building codes (regulations)

To ensure compliance with local building laws and standards, retrofitting endeavours must follow to the prescribed guidelines, which may encompass provisions for electric vehicle (EV) charging infrastructure. It is vital to possess a comprehensive understanding of and adherence to these standards to prevent legal complications and guarantee the preservation of safety [63]. When examining strata structures, it is crucial to consider the regulations and rules pertaining to strata, which may govern the procedures involved in the installation of EV chargers [57]. Appropriately, guidance from legal experts and property management professionals are effective in negotiating the intricacies associated with this building regulations.

4. Installation and maintenance

The exponential growth of EVs poses a distinct problem and potential advantage for residential and apartment complexes. It is crucial to underscore the significance of proficient implementation and upkeep of electric vehicle (EV) charging infrastructure [49]. These aspects play a central role in facilitating the extensive integration of EVs within urban settings, while concurrently safeguarding the enduring operability of these charging facilities. However, EVs typically necessitate lower levels of maintenance in comparison to vehicles powered by internal combustion engines. Electric vehicles (EVs) possess a reduced number of mechanical components and do not have regular oil changes. Though, they may still necessitate periodic maintenance for components such as tyres, brakes, and the battery. Prior to the implementation of electric vehicle (EV) charging stations, it is imperative to conduct a comprehensive evaluation of current EV ready infrastructures. This assessment aims to ascertain whether the structure possesses the capability to support the supplementary load generated by charging stations. According to Lopez-Behar, Tran [48], it may be necessary to upgrade the electrical system in numerous instances to guarantee smooth and uninterrupted functioning. The careful positioning of charging stations within residential and apartment buildings is a crucial factor to be considered. When considering the various requisite factors, it is imperative to consider elements such as accessibility, ease for inhabitants, and future scalability. According to Wang et al. (2018), empirical evidence indicates that a carefully planned placement and design of charging areas can optimise both utilisation and efficiency. Like other infrastructure, electric vehicle (EV) charging stations necessitate regular inspection and repair. This process includes conducting inspections to assess signs of deterioration, validating the integrity of electrical connections, and guaranteeing the comprehensive safety of the charging apparatus. Electric vehicle (EV) charging stations frequently have software that necessitates regular updates, rechecks and maintenance. The updates encompass potential advancements in the areas of charging efficiency, security enhancements, and compatibility optimisations. Failure to prioritise software upgrades might result in diminished performance and the possibility of exposing the system to potential security risks [74]. Therefore, it is imperative to emphasise that good maintenance include the provision of support to EV customers residing in both residential and apartment buildings. It is imperative to provide residents with comprehensive education and training regarding the appropriate utilisation of charging equipment, early reporting of any issues, and a thorough grasp of the billing or access procedures associated with electric vehicle (EV) charging. According to Sun, Zhao [2], the use of a proactive strategy has the potential to improve user happiness and promote the long-term sustainability of infrastructure.

5. Stakeholder management

The incorporation of EVs within residential and apartment complexes signifies a pivotal stride towards achieving sustainable transportation and mitigating carbon emissions [75,76]. Nevertheless, the procedure is characterised by its intricate nature, since it encompasses several parties involved, each possessing their individual interests and apprehensions. The successful deployment of EVs in various contexts is heavily reliant on the implementation of effective stakeholder management. The escalating enthusiasm surrounding EVs as a viable solution for mitigating greenhouse gas emissions and advancing sustainable transportation has prompted heightened endeavours to incorporate EVs within residential and apartment complexes. The integration of EVRBs in the built environment modules and practices encompasses multiple stakeholders, including residents, building owners, utilities, and government organisations. The biggest beneficiaries of EVs in residential and apartment buildings are the residents. The individual's areas of interest primarily encompass the availability and convenience of charging infrastructure, the affordability of charging alternatives, and the broader implications of electric vehicle integration on their quality of life. The successful integration of EVs in these environments heavily relies on the pleasure of residents [9]. The installation and maintenance of electric vehicle (EV) charging infrastructure is under the responsibility of building owners and managers. The individual's areas of interest encompass the assessment of return on investment, adherence to regulatory requirements, and the potential ramifications on property valuations. The establishment and maintenance of a strong relationship with building owners/managers is crucial for securing financial resources and ensuring the long-term viability of electric vehicle (EV) infrastructure [47,77]. Utilities play a pivotal role in facilitating the essential electrical infrastructure required to sustain electric vehicle (EV) charging operations. The individual's areas of interest encompass grid stability, demand management, and the potential for load balancing. The establishment of a dependable and effective charging infrastructure necessitates the cooperation and partnership with power providers [14].

Utilities play a pivotal role in facilitating the essential electrical infrastructure required to sustain electric vehicle (EV) charging operations. The individual's areas of interest encompass grid stability, demand management, and the potential for load balancing. The establishment of a dependable and effective charging infrastructure necessitates the cooperation and partnership with power providers (Zhang et al., 2015). It is imperative to establish unambiguous channels of communication and provide comprehensive education to stakeholders regarding the advantages and obstacles associated with the integration of EVs. According to Nishanthy, Raja [78], the implementation of regular updates, workshops, and information sessions has the potential to effectively mitigate concerns and foster support from many stakeholders. The implementation of incentives targeted towards inhabitants, building owners, and utilities has the potential to foster increased enthusiasm and financial commitment towards the integration of EVs. Incentives for EVs might encompass various measures such as tax credits, subsidies, or discounted electricity rates for the purpose of facilitating EV charging [56]. The establishment of formal collaboration agreements among stakeholders can effectively delineate and clarify the specific roles, duties, and expectations of each party involved. According to Kester & Günther (2019), it is imperative that these agreements encompass key aspects such as funding, infrastructure upkeep, and methods for resolving disputes. It is of utmost importance to actively interact with government agencies to exert influence on policy decisions and argue for the implementation of regulations that are conducive to the desired objectives. According to Palmiotto, Zhou [50], it is imperative for stakeholders to engage in public hearings and policy formulation processes to guarantee the inclusion of their interests. To satisfy the different interests and concerns of inhabitants, building owners, utilities, and government agencies, electric vehicle integration in residential and apartment buildings requires good stakeholder management. Successful EV integration can reduce greenhouse gas emissions and promote sustainable mobility; thus, stakeholders must collaborate to overcome hurdles and maximise advantages.

6 Financial costs

It is imperative to conduct a comprehensive evaluation of the financial viability of electric vehicle (EV) charging infrastructure. The performance of cost-benefit assessments serves to provide a rationale for the initial capital outlay and forecast the prospective financial gains derived from electric vehicle (EV) charging services. The profitability of the infrastructure is contingent upon building owners and managers using appropriate financial planning measures [79]. The investigation of many funding sources, including government grants, incentives, and collaborations with electric vehicle (EV) charging service providers, has the potential to substantially mitigate the expenses associated with both the installation and maintenance of such infrastructure. It is a common practise for governments to offer financial assistance to promote the advancement of electric vehicle (EV) infrastructure [41].

7. Electricity/grid consumption

Electric vehicles (EVs) have emerged as a potentially effective alternative for mitigating greenhouse gas emissions and addressing climate crisis. Hence, it is crucial to thoroughly analyse the ramifications of electric vehicle (EV) adoption within residential and apartment complexes with regards to grid electricity usage. The electricity usage in residential and apartment buildings is contingent upon the specific charging infrastructure that is employed. Level 1 chargers, commonly utilising conventional residential outlets, exhibit a reduced charging rate and, as a result, exhibit a lower hourly electricity consumption in comparison to Level 2 chargers or DC fast chargers. The significance of differentiating between these charging levels in evaluating consumption have been emphasised in building policies and literature [62]. The charging habits of devices have a substantial impact on the overall electricity consumption. Residential electric vehicle (EV) owners frequently opt to charge their vehicles during periods of reduced demand for power, sometimes referred to as off-peak hours, to take advantage of the associated cost savings resulting from lower electricity rates. However, comprehending and forecasting these patterns might present a hard task. The study conducted by Van Roy, Leemput [80] offers valuable insights into the optimisation of charging periods to minimise the impact on the grid, based on research conducted on smart charging systems and user behaviour. Even though, the electricity consumption of an electric vehicle (EV) is influenced by two key factors: the capacity of its battery pack and the level of charge it holds during the charging process. Charging a battery that is entirely depleted necessitates a greater amount of energy compared to charging a battery that is just partially empty. The significance of considering these elements in evaluating total electricity usage is emphasised in academic research [47]. Regarding the impact on the grid line, the potential impact on peak electricity demand can be observed with the broad integration of EVs in residential and apartment complexes. The simultaneous charging of electric vehicles by many owners during peak hours has the potential to exert strain on the electrical system. The academic literature explores the necessity of implementing demand management measures, such as time-of-use pricing or load shifting, to alleviate grid strain during periods of high demand [12,81]. As the use of EVs continues to expand, there may arise a need for changes in grid infrastructure to effectively handle the augmented electrical load. The aforementioned factors encompass the capacity of transformers, distribution lines, and substations. Tian and Talebizadehsardari [51] argued that engaging in proactive planning and making investments in grid upgrades can effectively guarantee the stability of energy supply. The integration of renewable energy sources into the electrical grid has the potential to mitigate the increased electricity demand resulting from the widespread use of EVs. Research has emphasised the possible collaboration between electric vehicle (EV) and renewable energy generation, which has the potential to facilitate mobility that is both cleaner and more sustainable, while also mitigating the strain on the power grid [82].

8 Environmental footprint

The exponential expansion of electric cars (EVs) is propelled by their capacity to alleviate the environmental consequences linked to traditional petrol and diesel automobiles. The manufacturing process of lithium-ion batteries, which are an essential element of EVs, is characterised by a substantial energy requirement and has the potential to generate significant levels of greenhouse gas emissions. Nevertheless, studies have indicated that the emissions can be counterbalanced throughout the operational lifespan of an electric vehicle (EV) due to the reduction in exhaust emissions [83]. EVs are notable reduction mechanism in greenhouse gas emissions during the operational phase in comparison to combustible vehicles [84]. Therefore, there is a decrease in air pollution and a reduction in the overall impact on climate change. Moreover, the recycling and disposal of batteries are crucial components of the end-of-life stage for EVs. According to Yuan, Zhang [85], the implementation of appropriate recycling and repurposing practises has the potential to mitigate adverse environmental effects in the revolution of recycling technologies. The environmental impact of EVs is based on sources of electricity generation in condition to environmental factors. Electric vehicles (EVs) that derive their electricity from coal-fired power stations may exhibit elevated emissions in comparison to EVs charged with renewable or nuclear power sources. The adoption of clean energy sources is of paramount importance to optimise the environmental advantages associated with electric vehicles [86]. Reducing the environmental impact of production requires using sustainable resources for electric vehicle components such batteries and rare-earth metals (Majeau-Bettez et al., 2011). The expansion of electric vehicle charging infrastructure needs to be done in a sustainable way, meaning that energy efficiency and habitat disruption are considered [87].

9. Demand and occupancy

The increased sales of EVs calls for household charging systems. Residents are increasingly seeking EV charging-capable residences, which is influencing real estate market dynamics [20]. As a result, residential projects are adjusting to support EV charging, with dedicated charging stations, carports, and parking facilities becoming increasingly widespread [88]. Residents living in multi-unit buildings confront distinct issues when it comes to accessing EV charging facilities. Building owners and associations are looking into options such as shared charging stations and charging spot distribution [89]. Adoption of electric vehicles contributes to lower local air pollution and greenhouse gas emissions, making residential areas more environmentally friendly. Residential regions with a high EV adoption may have higher energy demand. Load balancing requires smart grid technologies and demand management tactics [70]. Residents can collaborate on charging infrastructure improvements and environmental activities with EVs, which can increase community engagement. To support EV charging infrastructure in residential areas, local governments must modify zoning and building rules [90]. Financial incentives for the implementation of EV charging infrastructure, along with subsidies for low-income people, can encourage adoption [78].

10. Waiting time of charging

EV adoption in residential and apartment structures depends on charging time. Charging speed greatly affects waiting time. Residential and apartment buildings have Level 1 or Level 2 chargers, which charge slower than DC fast chargers. Researchers say Level 1 chargers can take hours to fully charge an EV, which can be inconvenient for users [91]. Waiting can affect residential EV owners' experiences. Theoretical research suggests that extended charging times may frustrate EV buyers [92]. High-speed charging infrastructure in residential and apartment buildings might be expensive and require electrical improvements. According to Conte and Contini [93], upgrading buildings with fast chargers is difficult and expensive. Multiple EVs in a household situation make energy management difficult. Scholarly studies show that energy management systems can cut waiting times and efficiently allocate electricity, but their implementation is difficult [94]. Scheduling and load management in smart charging solutions can optimise charging sessions and reduce wait times. Studies show that these systems prioritise EVs with low battery levels for faster charging [95]. Investment in Level 2 chargers with larger power capacity can drastically minimise waiting times. Academic literature implies these investments may be needed to meet home EV demand [96]. Some regions require new residential buildings to incorporate EV charging facilities with availability that reduce waiting times [85].

11. Lifestyle and income level

The studies have indicated that the EV usage tends to be more prevalent among households characterised by higher income levels. The disparity in income can be further exacerbated due to the higher initial costs associated with electric cars (EVs) compared to conventional gasoline-powered automobiles. The scholarly literature highlights the potential hindrance in accessing cleaner mobility choices for persons with lower incomes [20]. The financial constraints associated with the purchase and maintenance of EVs, coupled with the limited accessibility of charging infrastructure, can potentially impede the advantages that low-income households may derive from adopting EV technology. Lee, Choi [81] mentioned that the implementation of policies and incentives is necessary to enhance the affordability and availability of EVs for persons who are poor. Academic literature underscores the need of employing specific incentives and subsidies to enhance the affordability of EVs among persons with lower income levels. According to Viola [97], the implementation of such laws has the potential to create a fair and equitable environment, thereby ensuring that EVs are advantageous for individuals across all economic brackets. It is imperative to provide the accessibility of charging infrastructure in all neighbourhoods, irrespective of varying income levels. The importance of governmental interventions in facilitating the equal distribution of charging stations has been underscored by many studies [98]. The adoption of EVs in affluent neighbourhoods contributes positively to sustainable transportation. The social implications and lifestyles of EV users are evident in green consumption. The presence of financial inequality and the unequal availability of charging infrastructure can give rise to concerns regarding environmental justice and impede the extent to which low-income households can reap the benefits. It is imperative for academics, policymakers, and stakeholders to prioritise the resolution of these difficulties to guarantee the equitable distribution of the advantages of EVs across all societal sectors.

12. Renewable power supply

Residential photovoltaic (PV) systems are a major renewable energy source. Academic research suggests that EVs can act as mobile energy storage units for solar PV. Excess solar energy can be stored in EV batteries and utilised to power homes or charge additional vehicles [99]. Wind energy, both tiny and large, can support EV charging in residential and apartment structures. Studies have shown that wind turbines can be integrated into urban areas to create clean electricity for EVs [100]. Advanced energy management systems optimise building and EV charging renewable energy consumption. Li et al. (2019) stresses the need of clever algorithms that incorporate energy generation patterns and EV charging needs to maximise renewable energy use. Integrating EVs with renewable energy sources greatly reduces carbon emissions. EV charging using clean, renewable energy can reduce emissions significantly (Chen et al., 2020). EV charging with renewable energy can save residents and building owners money. Studies show the economic benefits of on-site renewable energy generation and EV operation expenses [96]. Irrespective of the benefits, intermittency hinders renewable energy integration. EVs provide temporary energy storage, allowing energy consumption flexibility. Scaling renewable energy and EV charging infrastructure involves significant investment. Adoption is accelerated by supportive policies, incentives, and public-private partnerships [101].

13. Zero carbon ready buildings

The integration of EVs inside residential environments is in accordance with Sustainable Development Goal 7 (SDG 7), as it facilitates the provision of accessible, cost-effective clean energy and zero carbon buildings. The research conducted by Ellingsen, Singh

[83] highlights the significance of EVs in zero emissions of carbon dioxide. These findings underscore the potential of EVs to contribute to a more sustainable energy landscape. The adoption of EVs plays a crucial role in mitigating climate change, which is a key component of Sustainable Development Goal 13. EVs for transportation is potentially significant in the climate action strategies [102]. The incorporation of EVs within residential and apartment complexes promotes the advancement of sustainable urbanisation, which is a fundamental goal of Sustainable Development Goal 11 (SDG 11). EVs reduce air pollution and enhance the quality of urban life, so making a positive contribution to sustainable urban development [103]. Residential EV adoption helps achieve net-zero emissions. EVs, especially those fuelled by renewable energy, can significantly cut greenhouse gas emissions [104]. EVs are more energy-efficient than ICE automobiles. Residential transport electrification can reduce energy usage, supporting net-zero energy goals [83]. EV use in residential and apartment buildings helps meet national and global carbon neutrality targets. Research shows that EVs reduce transportation's carbon footprint and comply with international climate commitments [41]. EVs can stabilise grids and integrate renewable energy sources as distributed energy storage units, helping climate goals and transition to low-carbon energy system for buildings.

14 EV battery management systems

Electric vehicles (EVs) have emerged as a crucial element of sustainable mobility, and their incorporation into residential and apartment complexes is experiencing an upward trend [1]. The Battery Management System (BMS) is important in monitoring and management of the health status of the EV batteries. The need of precise and up to date the safety data for maximising charging and discharging efficiency, extending battery lifespan, and guaranteeing dependable vehicle performance. The Battery Management System is responsible for regulating and monitoring the temperature of the battery to mitigate the risks associated with overheating and thermal runaway. The significance of BMS in enhancing performance and safety by ensuring temperature equilibrium among battery cells has been underscored in several studies [76]. The degradation of battery cells within an EV pack can occur in an uneven manner because of multiple reasons. Battery Management Systems (BMS) play a crucial role in maintaining cell balance by equalising the voltages across individual cells, hence contributing to the overall improvement of battery lifespan. The scholarly literature emphasises the importance of sophisticated balancing algorithms and their influence on battery performance [16]. In view of the implications on residential and apartment buildings, battery management systems (BMS) have the capability to enhance charging procedures to synchronise with time-of-use electricity rates. Scholarly research places emphasis on the possible economic benefits and reduction in strain on the power grid that can be obtained through off-peak hour charging or the utilisation of renewable power plants [95]. Enhanced safety protocols are necessary in residential and apartment block settings. BMS is a crucial factor in the safety of handling EV chargers in buildings to reduce overcharging, overheating, and maintain optimal voltage levels. The study conducted by Chai, Che [17] emphasises the significance of Battery Management Systems (BMS) in guaranteeing the safety of charging operations within confined environments. Battery Management Systems (BMS) have the capability to enable the flow of power in both directions, so allowing EVs to function as valuable assets to the electrical grid. The academic literature examines the capacity of EVs to contribute to grid stability and engage in demand response initiatives, thereby yielding advantages for both building occupants and utility firms It is imperative to prioritise the establishment of user-friendly interfaces and the seamless integration of building management systems (BMS) with building management systems [41].

15 Suppliers and sub-contractors

Supply chain challenges, a reliable supply chain for electrical plugs is required to support EV adoption in these contexts. The supply chain for electrical outlets must scale to satisfy increased needs for charging infrastructure as the number of EV owners in residential and apartment buildings grows [105]. It is vital to ensure that electrical plugs and connectors are compatible with various EV models. Thus, to ensure compatibility, standardization activities are required [106]. This is because, it is critical to maintain the quality and safety of electrical plugs. Therefore, to avoid such dangers, comprehensive quality control methods must be applied [107]. Electrical contractors are critical to the installation and upkeep of EV charging infrastructure in homes and apartments. They oversee assuring appropriate installation, adherence to safety regulations, and routine maintenance [108]. Contractors must be properly trained and accredited to work with EV charging equipment. Continuing education is essential for staying current with changing technologies [92]. Collaboration among stakeholders, such as electrical contractors, manufacturers, and building owners, is essential for optimizing the supply chain and tackling scalability issues [86]. Electrical plugs purchased locally can reduce supply chain complications and transportation-related emissions with strict quality standards and certifications for electrical plugs.

16. Health and safety

The growing prevalence of EVs in urban settings necessitates a thorough evaluation of the health and safety considerations linked to their utilisation within residential and apartment complexes. The process of charging an electric vehicle (EV) necessitates the manipulation of electrical equipment operating at high voltage levels. According to Qiu, Wang [109], empirical evidence indicates that the likelihood of experiencing an electric shock increase when charging equipment is either damaged or not maintained. The prioritisation of resident and maintenance personnel safety during the charging process is of utmost significance to minimise the inherent risks of combustion or thermal batteries. According to Dvořáček, Horák [70], scholarly study emphasises the significance of effective battery management systems, heat monitoring, and fire suppression methods within electric vehicle charging stations. The process of charging might result in the emission of gases, such as hydrogen and volatile organic compounds (VOCs), particularly during fast charging scenarios. To mitigate the risk of exposure to hazardous compounds in enclosed parking lots, it is imperative to ensure sufficient ventilation and implement air quality monitoring measures [17]. The concurrent charging of many EVs in residential and apartment buildings has the potential to result in the overloading of electrical circuits. The potential consequences of this situation include power outages and the introduction of safety hazards. The need of conducting electrical evaluations and considering prospective infrastructure upgrades to maintain grid stability is underscored by research findings [40]. The significance of prioritising safety in the design of charging infrastructure is emphasised in academic literature. The utilisation of high-quality apparatus, appropriate grounding techniques, and the incorporation of safety measures such as ground fault prevention have been identified as essential components [71]. The regular performance of maintenance and inspection procedures on charging equipment is of utmost importance to promptly detect and address possible problems. The need of conducting regular inspections and promptly addressing any identified problems or deficiencies has been emphasised in recent research [65]. The adequate training and education of inhabitants, building management, and maintenance workers are vital. According to Ghafoori, Abdallah [43], empirical evidence indicates that the implementation of comprehensive training programmes has the potential to enhance individuals' awareness of safety measures and their ability to effectively respond to emergency situations. The necessity of formulating and executing emergency response strategies that are tailored specifically to situations involving EVs demand protocols for managing incidental fires, electrical malfunctions, and accidents associated with the charging systems.

4. Implications of the study

4.1. Theoretical implications

In summary, this review work on EVRBs provides diverse theoretical contributions to EVs and building management in the construction industry. It also fills the knowledge gap on relating electric vehicles to important topics in building industry such as of sustainability, regulatory compliance, dynamic project management, economic viability, user-cantered design, resilience, environmental impact assessment, and stakeholder involvement. Through the application of theoretical frameworks, academic and industry professionals can gain a deeper comprehension of the intricate dynamics and potential advantages that emerge from the integration of EVRBs within the building industry. Although, there is a growing prevalence of electric cars (EVs) that has generated critical discourse among the scientific research community on readily available and dependable EV charging systems. It remains dispersed and not clearly explored in the construction industry. Existing studies on EVRBs have evolved as an innovative strategy for incorporating electric vehicle charging capabilities into the physical infrastructure of built environments. However, the theoretical advancements of EVRBs in the context of the building sector has potential for further investigations. With the findings in this study in-depth empirical studies are projected to be conducted.

4.2. Practical implications

In the context of project management, the significance of effectively managing projects within the framework of EVRBs cannot be overstated. The necessity for flexible project management systems and methodologies such as (agile and waterfall) is underscored by the dynamic nature of electric vehicle (EV) technology and the growing demands of customers. A study conducted [110], on dynamic project management places emphasis on the need of agility and flexibility in adapting to changing project demands. Also, the introduction of Economic Viability and Cost-Benefit Analys in construction projects necessitates a comprehensive and sophisticated economic evaluation. Thus, the integration of electric vehicle (EV) charging infrastructure entails upfront expenditures but offers possible long-term advantages such as enhanced property valuation and heightened tenant contentment. The assessment of the economic viability of EVRBs necessitates the comprehensive examination of not only the initial capital outlay but also the projected long-term returns and potential cost reductions which is traced to Wi, Lee [111] research on cost-benefit analysis within the construction field. The efficacy of EVRBs is contingent upon the acceptability and use by users, highlighting the significance of user-cantered design and human factors. The relevance of theoretical concepts derived from human factors and user-cantered design, as discussed by Sun, Zhao [2], is particularly pronounced within this specific setting. Gaining insight into the requirements and inclinations of electric vehicle (EV) users and occupants of buildings can serve as a basis for making informed design choices, so guaranteeing that EVRBs are designed to be user-friendly and easily accessible. The design and location of charging stations within EVRBs can be informed by the theoretical contributions derived from human-computer interaction and usability studies.

4.3. Policy implications

The concept of resilience and futureproofing is crucial to the adoption of EVRBs in buildings supported formidable regulations and building policies, as it necessitates a proactive approach that considers the dynamic nature of EV technology advancements. This underscores the significance of effectively adjusting to evolving conditions. Theoretical contributions in this context emphasise the necessity of including flexibility and scalability into construction projects. This enables the integration of modern electric vehicle (EV) technologies and the ability to accommodate additional charging capacity in the future. This means the inclusion of EVRBs requires a thorough evaluation of their ecological consequences aligning with the domain of environmental impact assessment (EIA). The evaluation of the ecological footprint of Electric Vehicle Rapid Chargers involves not only the assessment of their immediate environmental impacts but also the examination of their wider consequences on local energy networks, energy sources, and overarching sustainability objectives.

4.4. Social implications

From the Stakeholder engagement perspective and collaborative governance, these two play a crucial role in the effective implementation of EVRBs. These plans necessitate the active involvement and participation of diverse stakeholders, including as developers, government agencies, utility providers, users, and electric vehicle manufacturers. The significance of efficient communication and cooperation among varied stakeholders for the successful implementation of EVRBs is emphasised by theoretical perspectives on collaborative governance and stakeholder theory [112]. Electric Vehicle Ready Buildings (EVRBs) have impacts on the social status and the community planning into the net-zero emission era.

4.5. Environmental implications

The incorporation of environmental-friendly building practices plays a pivotal role in promoting sustainability in the construction sector [11]. The incorporation of electric vehicle (EV) charging infrastructure into buildings serves to encourage the adoption of sustainable alternatives. The statement is in accordance with a best practice framework proposed by Ghafoori, Abdallah [43] in the field of sustainable building. It underscores the need of mitigating the carbon emissions associated with construction projects and advocating for the adoption of environmentally conscious approaches. In view of the above, the successful integration of EVRBs necessitates strict adherence to dynamic regulatory standards, safety norms, and guidelines. This is consistent with the existing research on regulatory compliance in the built environment [113]. This necessitate why EVRBs require the implementation of a flexible strategy for managing compliance, emphasising the significance of adjusting to evolving legislation and standards.

5. Conclusion and recommendations

The goal of this study was to highlight the key themes (factors) and the status on EV ready buildings. It was clear from the review that practical models on integrating EV systems into construction buildings are lacking in the construction industry in many jurisdictions. This could be addressed in construction management as the world move towards net-zero and low carbon policies. The study also indicates high demand for EVRBs where there is preference for installing EV chargers at home and corporate buildings. The design and installation of EV chargers were found to be relevant for EV development in the built sector, but it comes with a huge cost that need to be properly managed. Further, the following key issues should be addressed for proper functioning of EVRBs. Quantitative data on EV charging in commercial and residential buildings is notably difficult to obtain. Currently, there is extant database on the home chargers for EVs in large EV markets presented in this study. In urban and major cities in these markets, the data is not even clear the number of EVs that charged at corporate offices. Moreover, sperate data do not exist for different house accommodations such as high-rise buildings, apartment units, and flats, among other building classifications. To address this challenge, a broad database should be built by researchers to support the operationalisation EVRBs and further studies. The study also acknowledges inadequate studies on the acceptance of construction of EV infrastructures into buildings in construction management. Critical issues such as contract management, subsidies from government, stakeholder management and modular construction have not been explored with weak theoretical foundation of this research areas. It is recommended that there must be awareness creation among construction professionals through education and training on EVRBs. In countries where EV sales keep rising, the policies on the charging of the EVs are hugely tilted toward public-focused charging stations. Although, the documents presented evidence of international demand from EV users to have their charging systems in the house and workplaces, this has not materialised in most EV markets. Emerging policies from the government and the building industry should favour the construction and maintenance of EV chargers in buildings. Existing policies should be amended to accommodate EVRB-related issues. The protection of consumers should be supreme and privacy laws guiding them should be strengthened to curb stealing private information. Consumer protection laws should be strengthened for building property owners towards proper installation and management of EV chargers. Governments should continue to support the funding of EVRBs because the installation costs are still expensive to private homeowners and small businesses. Public-private partnership financing and subsides are recommended to support EVRBs. In summary, the following recommendations are presented for future research. First, studies should investigate into how building owners are responding to EV charging infrastructures within their properties. An exploration of the perceptions and the level of satisfaction of owners should be studied in relation to retrofitting costs, indoor air quality, energy consumption and the impact of EVRBs on their lifestyles. Second, researchers should assess the building regulation gaps and propose measures to address the current regulatory challenges in embracing electric chargers in building management. Third, the perspectives of construction professionals on EVRBs should be explored including their level of knowledge and skill-set available on EVRBs. Fourth, the relationship between new construction technologies such as digital twins and artificial intelligence and EVRBs should be assessed. Fifth, the cost of electricity and other forms of power consumption should be analysed in future studies. This should be done together with the analysis of the prices of EV smart chargers, cost of living of occupants of the buildings, the charging period (time), inflation and interest rates. Sixth, there should be research on the source of funding of EVRBs. Also, the government support for construction of smart EV chargers in buildings is another area of research. In countries like Australia, United Kingdom (UK), United States (US), Cananda, and China, the governments are granting financial support to property owners to promote EVRBs. It will be interesting to see how governments in other countries especially in the global south are funding and supporting EVRBs in future research articles. The limitation of this study is from the document selection of journal articles and reports leaving out books, conference papers and a growing number of media articles on this topic. Another bias in conducting this review is the selection of documents only written in English. Therefore, the findings should be cautiously interpreted and applied because it is not the general representation of every type of document in every language.

CRediT authorship contribution statement

Isaac Akomea-Frimpong: Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Leonora Amponsah-Asante:** Writing – review & editing, Writing – original draft. **Annette Senam Tettey:** Writing – review & editing, Writing – original draft. **Prince Antwi-Afari:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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