

# Unpacking suitability for building vertical extensions: a multi-level clustering analysis of factors

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## ABSTRACT

Vertical Extension (VE) of buildings offers promising pathways for sustainable urban densification. This study conducts the most comprehensive systematic literature review to date on VE suitability, following PRISMA guidelines and using content coding in ATLAS.ti combined with co-occurrence analysis to ensure methodological transparency and reproducibility. A total of 119 publications were analyzed, and 88 suitability factors were synthesized. The research provides a systematic knowledge of multidimensional considerations in VE implementation by thematically classifying the factors, mapping them across three suitability levels – site, building, and design – and assessing temporal/geographic patterns. The findings indicate a pronounced emphasis on technical and structural aspects, especially at the building level, whereas softer features like community engagement and multi-scalar governance are inadequately examined. Site-level factors are significantly marginalized, which may restrict the scalability and contextual adaptability of VE strategies. The novelty of this work lies in providing a multi-level clustering framework that not only maps the distribution of factors but also critically interprets research gaps, offering an integrated reference for architects, engineers, planners, and policymakers. While the study is based on literature analysis, it establishes a transparent, reproducible basis that future case studies and multi-criteria decision models can build upon to achieve more holistic VE assessments.

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## 1. Introduction

Rapid urbanization, the scarcity of undeveloped land in urban areas, and the increasing population density are all contributing to the transformation of urban development strategies (Mao et al. 2020). In an effort to resolve the issues of environmental sustainability, economic efficiency, and land scarcity, urban densification strategies have become indispensable (Künzel et al. 2024). In this regard, Vertical Extension (VE) of existing structures is a promising solution that enables the creation of additional space without enlarging the urban footprint. Figure 1 shows schematic examples of VE, which is defined by Norell, Stehn, and Engström (2020) as “a vertical addition of a building volume that creates new or extends existing functions, both technical and operational”. In spite of technical and regulatory obstacles (Cherkas and Rimshin 2017; Napieralska and Attia 2023), VE can improve the spatial capacity of constructions (Napieralska and Attia 2023), decrease demolition debris (Bertolazzi et al. 2019), and facilitate the adaptive reuse of existing assets in accordance with standards of sustainability (Soikkeli 2016), through

“environmentally conscious” implementations (Khodadad et al. 2018).

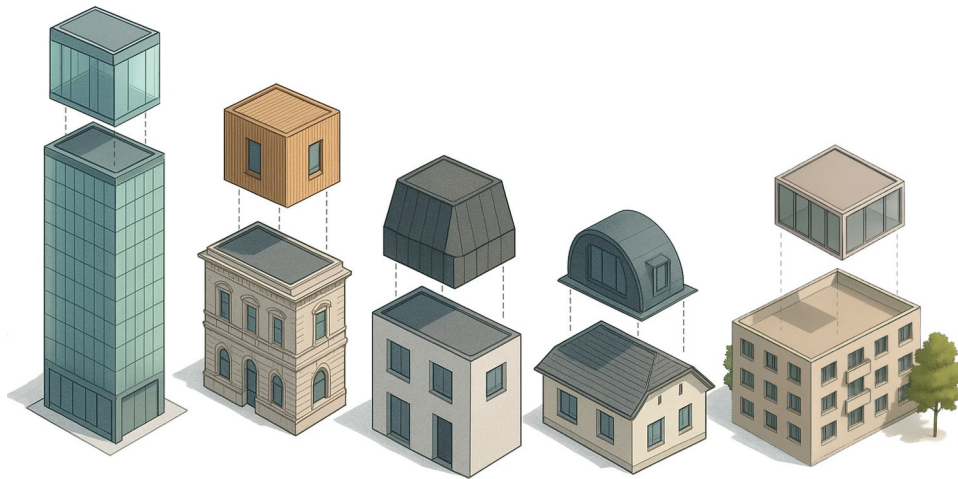
Despite the increasing academic and professional interest in vertical extension, the literature continues to be disjointed in addressing feasibility and suitability concerns. Several studies have examined specific aspects of VE, such as structural reinforcement techniques (e.g., Bhattacharjee, Sharma, and Bader 2020; Faiella et al. 2023; Heo et al. 2021), drivers and barriers (e.g., C. Gillott, B. Davison, and D. Densley Tingley 2022; Sundling 2019; Sundling, Blomsterberg, and Landin 2019), or energy saving/economic feasibility (e.g., Amer, Mahar, et al. 2019; Choi and Kim 2023; Spirkova et al. 2021); however, they predominantly concentrate on isolated or limited facets rather than offering a holistic overview of all pertinent factors. In this context, respective research offers significant insights yet ultimately lacks the comprehensive synthesis required.

In a recent literature review, Sanei et al. (2025) identified important terms and definitions, the main themes, and the research methods used in VE studies. Sundling (2019) presented a development roadmap

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**Figure 1.** Schematic examples of vertical extension on various types of buildings.

based on four Swedish case studies, identifying the critical planning and implementation stages for VE. A parametric LCA<sup>1</sup>-based digital framework was developed by Daher, Kubicki, and Marvuglia (2023) to evaluate the environmental and extension potential at the neighborhood scale. An industrial-scale concept was described by Soikkeli (2016), which involves the renovation and addition of floors to existing residential complexes using timber structures and updated fire regulations. Napieralska and Attia (2023) conducted an analysis of case studies from Germany, Belgium, and England, which positioned VE within a broader framework of sustainable housing policies in Europe. Amer, Mustafa, and Attia (2019) introduced a decision-making framework for the selection of prefabricated off-site roof-stacking systems, incorporating safety, logistical, economic, and environmental considerations.

Using surveys and interviews, C. Gillott, B. Davison, and D. Densley Tingley (2022) identified economic drivers, appraisal challenges, and sectoral resistance that influence the adoption of VE. Chamel and Dahlgren (2021) proposed an urban planning approach, endorsing the incorporation of additional floors in historic city centers to address demographic concerns. Amer and Attia (2019) established 37 sustainability indicators – encompassing environmental, economic, and social dimensions – via a literature study and stakeholder interaction. Julistiono, Oldfield, and Cardellicchio (2023a) examined patterns in VE, highlighting a recent surge in small-scale vertical expansions facilitated by technological advancements. In an additional study, they investigated the strategies of construction and stakeholder decision-making during VE procedures (Julistiono, Oldfield, and Cardellicchio 2023b).

Although each research provides unique insights – spanning innovation processes, environmental frameworks, policy settings, and stakeholder perspectives – none conducts a comprehensive compilation and analysis of VE suitability variables. Consequently, practitioners and academics do not possess a unified, organized reference that encompasses the extensive range of technical, regulatory, environmental, and design-related factors affecting VE viability. Likewise, the categorization of the suitability factors within the literature has been uneven and superficial. Prior studies generally categorize factors into broad classifications (e.g., structural or regulatory) without carefully organizing them into coherent domains that illustrate their fundamental relations and interactions. This has restricted our comprehension of the intricate interactions between various categories of factors and their collective influence on the feasibility of VE.

Furthermore, and perhaps most significantly, no prior investigation has examined the applicability of factors at multiple decision-making levels, including site-level constraints, building-level feasibility, and design-level adaptability. Although suitability criteria such as regulatory compliance and structural safety have been addressed, there has been negligible consideration of the interplay between these factors and contextual site conditions or design concerns. Consequently, there is a lack of insight into the relative emphasis placed on each level of suitability within the existing literature, leaving both researchers and practitioners without a clear sense of research biases or gaps. This research tackles these gaps – through a comprehensive literature review, thematic clustering, and temporal/geographic analysis – by:

- (1) Compiling the most comprehensive compilation of VE suitability variables present in the

<sup>1</sup>Life Cycle Assessment.

literature, encompassing technical, economic, environmental, regulatory, and design-related dimensions;

- (2) Thematically categorizing these aspects into cohesive classifications that more accurately represent their functions and interrelations;
- (3) Examining their distribution across three hierarchical suitability levels – site, building, and design – to uncover study biases and prevailing focuses; and
- (4) Analyzing the temporal and geographic distribution of thematic categories and suitability levels to reveal the evolution of research focus over time and across various regional contexts (it is challenging to ascertain whether the literature reflects globally relevant insights or is dominated by region-specific trends in the absence of an understanding of these spatial and temporal patterns).

This study surpasses previous narrative reviews by moving beyond a mere compilation of factors. Instead, it proposes a novel taxonomic framework that structurally organizes VE feasibility into a multi-level hierarchy. By mapping the epistemological boundaries of current research, this framework serves as a diagnostic means to reveal the systemic biases (e.g., technocratic bias) in the field. This shift from simple categorization to structural diagnosis establishes the necessary theoretical groundwork for future comprehensive decision-making models, distinguishing this work from standard descriptive reviews.

## 2. Methods and materials

This study conducted a systematic literature review using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards to ensure transparency, consistency, and methodological rigor throughout the review process. The initial segment of the findings from this literature review on VE has been recently published (Sanei et al. 2025), and this paper delineates the subsequent segment. The PRISMA 2020 framework was applied across all four of its main stages – identification, screening, eligibility, and inclusion – to systematically gather, evaluate, and refine the literature on VE.

During the identification stage, all potentially relevant publications were retrieved from the Scopus and Web of Science databases. These databases were selected because of their extensive coverage of high-impact, peer-reviewed articles and academic papers across several disciplines, hence guaranteeing the quality of the analytical content. Figure 2 depicts the utilized search strategy that was developed using a combination of relevant keywords and Boolean

operators to ensure comprehensive retrieval of articles pertinent to the study objectives. To ensure a comprehensive literature review, no constraints on time or article type were imposed.

Following the initial search, non-English works and duplicates were removed, and the screening stage commenced, involving a careful review of titles and abstracts to exclude works that were not pertaining to VE (either in a general context or particular features such as structural issues). If not clear, the full text was read during the eligibility stage, where the relevance to VE was evaluated. A total of 119 articles were finally incorporated into the ultimate analysis and were subjected to quantitative and qualitative content analysis. Following the PRISMA ensured methodological rigor, reproducibility, and minimized selection bias, making the statistical results more reliable for interpretation.

### 2.1. Content analysis

A quantitative and qualitative content analysis methodology (Newby 2014; Schreier 2014) has been employed to conduct the literature review. Content analysis is characterized as “the study of content ... by a reliance on a coding scheme based on a set of coding categories, a coder, and a body of text ... to which the coder applies the coding scheme to quantify the frequency of occurrences of coding categories” (Franzosi 2008). Content analysis serves to discern the information embedded within literary elements (Franzosi 2008). The coding approach in ATLAS.ti 9, a data extraction tool for content evaluation, was utilized for this purpose (Hecker 2025). ATLAS.ti enables researchers to handle large volumes of textual data efficiently by providing an integrated environment for data organization, thematic coding, and interpretation. Specifically, it facilitates structured analysis by enabling manual or automatic coding of textual data, the detection of co-occurrence patterns among codes to reveal conceptual relationships, and code-to-document mapping to visualize and quantify the distribution of themes across sources. These capabilities enhance the transparency, consistency, and traceability of qualitative analyses. The software has been utilized for content analysis in several papers, such as (Caballero-Rico et al. 2022; Khodadad et al. 2024, 2025; Moshood, Nawanir, and Mahmud 2022). Such practice stretches to literature reviews as well, as suggested by Kalpokaite and Radivojevic (2016) and Woods et al. (2016).

Accordingly, subsequent to the selection of pertinent articles, ATLAS.ti was employed to import and evaluate the full texts of the publications. The data collection process involved a comprehensive full-text analysis, focusing on the extraction of VE suitability variables. All significant and relevant information

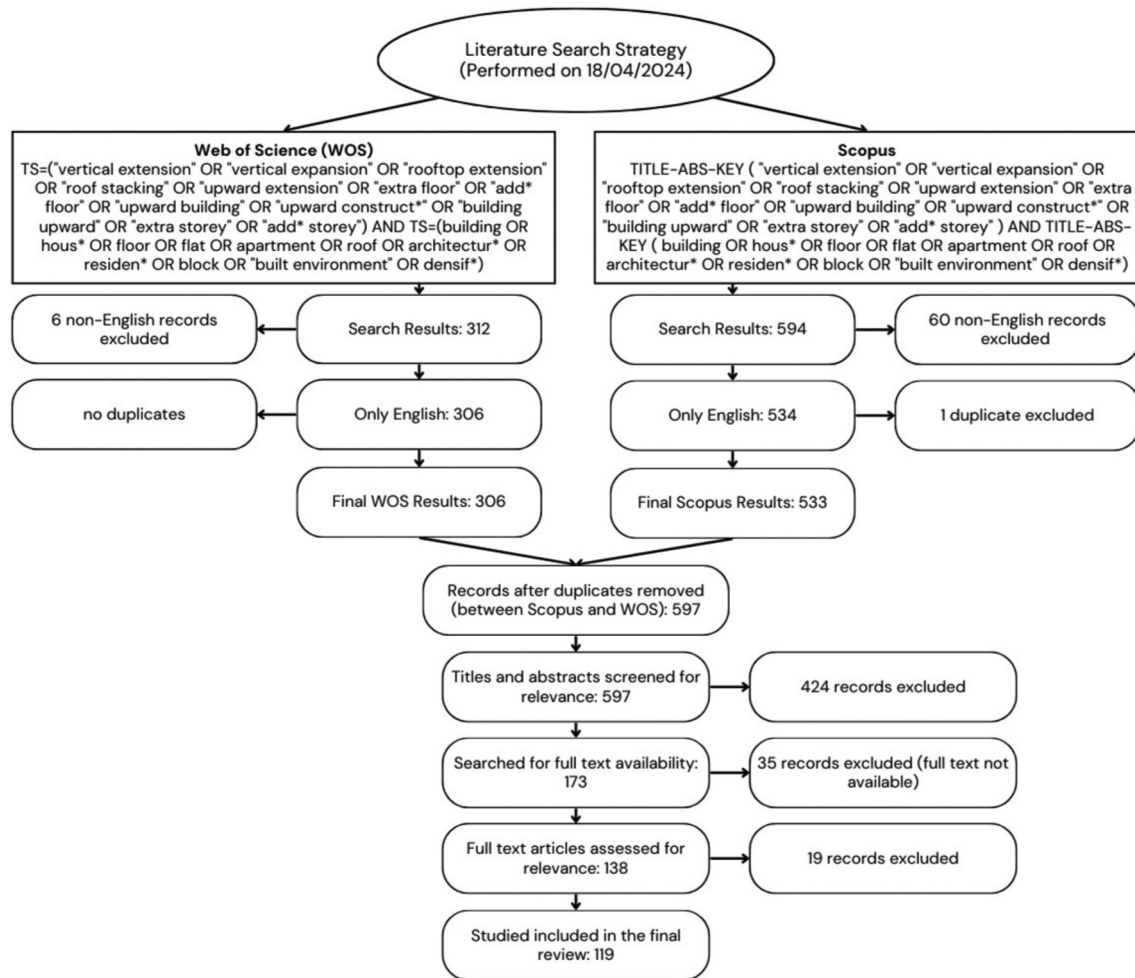


Figure 2. Literature search strategy flow chart, adapted from Sanei et al. (2025).

from the articles was thoroughly encoded using a manual coding procedure. Automatic coding was not used to ensure the reliability of the results. Likewise, inter-coder agreement checks and consistency reviews were conducted during data extraction and coding in ATLAS.ti to ensure reliability. This inductive methodology enabled the identification of categories and suitability levels from the data during the review. Thematic categories were created based on the aspects that the factors address. Additionally, the factors were listed in three suitability levels: site, building, and design, based on scales of suitability analysis. This means that the “site” level suitability factors can be used to see if a project’s site is suitable for the VE application (e.g., Accessibility, construction logistics, soil conditions); “building” level suitability factors could be used to realize if a building is suitable for VE (e.g., geometry, layout, structure, facilities); and “design” level suitability factors could be used to determine if a building’s design is suitable for VE (i.e., details of structural design, plan/layout, building prototypes, participatory design/management). Design level factors are usually more detailed or sensitive than building level factors. For instance, building-level factors

can be mostly observed or anticipated from outside the building, making their analysis more accessible, unlike design-level factors analysis, which needs more data and time, and is harder to apply on larger spatial scales. Therefore, site, building, and design suitability levels come in order when the focus of VE suitability shrinks from large spatial scales, like urban scale, to narrower neighborhood analysis, and finally, the detailed analysis of one specific building. As there are overlapping areas between factor categories or suitability levels, one factor may be listed in more than one category or suitability level. Figure 3 shows how the factors are distributed among different categories and suitability levels. Frequencies here illustrate the number of factors listed in various categories and levels, without considering the number of appearances in the literature.

The final data analysis was conducted using ATLAS.ti, with Excel and GPT-4o serving as supplementary tools. The following two stages were taken:

- (1) Code-to-Document Analysis: Subsequent to the coding procedure, a code-to-document analysis was performed with ATLAS.ti. This was

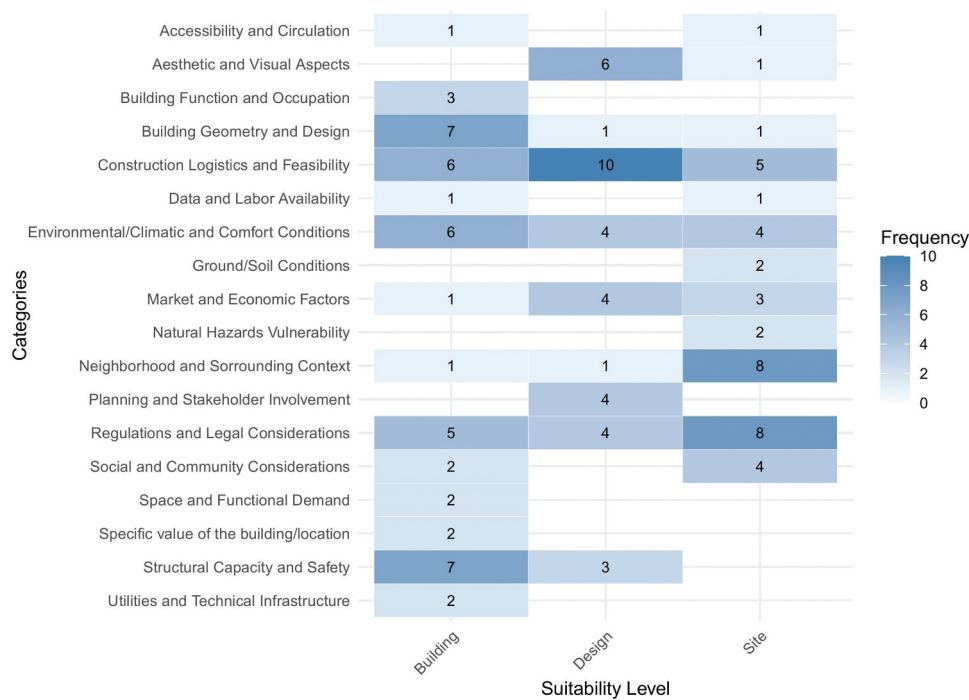


Figure 3. Distribution of factors listed in categories and suitability levels.

implemented to ensure that each code was calculated just once per document to prevent the over-representation of certain factors from highly detailed publications. This technique enabled a more equal assessment of the prevalence of diverse categories within the literature.

- (2) Co-occurrence Analysis: Co-occurrence analysis was used to examine the connections between the codes that were retrieved and the years and countries of publication. Co-occurrence data from ATLAS.ti were exported into Excel as part of the process, and further quantitative analysis was done there in order to investigate the frequencies and correlations between elements throughout the articles. The co-occurrence analysis and results representation were likewise done using GPT-4o, and the authors validated the results.

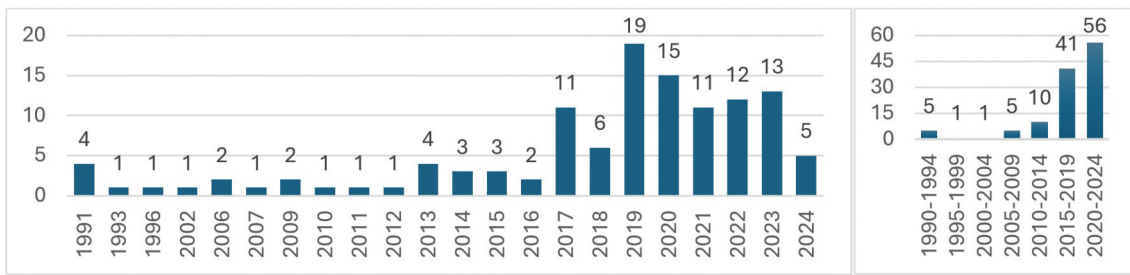
The methodological approach employed in this study closely matches its major research objective and topic, hence augmenting its academic rigor. The use of the PRISMA framework ensures methodological transparency and repeatability, which are vital attributes of any systematic analysis. Using a multi-phase, mixed-method approach, the study seeks to shed light on the development of discourse around VE suitability factors and the related temporal and geographical patterns. The rationale for conducting the frequency-based statistical analysis of factors is not only to provide a descriptive overview but also to uncover implicit biases, research priorities, and gaps in VE studies. By quantifying the occurrence and distribution of

categories, we aim to contextualize how technical, economic, or regulatory concerns have historically shaped the discourse. This approach ensures that the statistics are interpreted as indicators of research orientations rather than mere counts. The incorporation of inclusive database searches devoid of temporal or article-type limitations, together with manual software-assisted coding using ATLAS.ti, and co-occurrence analysis via Excel and GPT-4o, provides an in-depth and vast comprehension of the topic. This integrated methodology facilitates the detection of complex patterns across temporal and spatial dimensions and enables a systematic study of interconnections, so directly addressing the research objectives and enhancing the validity of the results.

It is acknowledged that this study, by design as a systematic literature review, focuses on internal methodological rigor (PRISMA compliance, co-occurrence analysis, and inter-coder checks). Consequently, it remains conceptually informative but untested, lacking external empirical validation (e.g., expert judgment or case-based testing) or comprehensive methodological triangulation, which is consistent with the established scope of foundational synthesis reviews and outlined as a key priority for subsequent work.

## 2.2. Temporal and geographical trends in VE research: general overview of literature

Figure 4 illustrates that the volume of publications on VE (all VE research, whether they include VE suitability factors or not), which started in 1991, has markedly



**Figure 4.** Quantity of articles published on VE research per year (left) and period (right).

escalated since 2017, reaching a peak in 2019 and sustaining elevated levels through 2024 (only a portion of the year 2024 was incorporated in the literature study). This increase signifies a growing scholarly and practical interest in VE, perhaps driven by rapid urbanization and the necessity for sustainable building. VE provides a solution to housing shortages without the need to expand city boundaries as urban populations increase (Julistiono, Oldfield, and Cardellicchio 2023a), reducing or stabilizing the human impact on the environment (Artés, Wadel, and Martí 2017). Moreover, regulatory revisions and revised building codes are promoting upward construction to optimize land use, which has prompted research on the policy implications (Argenziano et al. 2021). Technological advancements, such as modular and prefabricated methods, render VE more feasible by decreasing costs and construction times (Dind, Lufkin, and Rey 2017). Furthermore, environmental issues have intensified VE research, linking it with global objectives for reduced emissions and sustainable practices, supported by green certification systems (Sanei 2022; Sanei, Khodadad, and Calonge Reillo 2022, 2023).

South Korea dominates VE research with 19 publications (Figure 5), influenced by high population density, constrained land availability, and an emphasis on innovative construction methodologies (Cheng-Can and Jin-Tae 2017; Mun, Lee, and Kim 2024). The country's emphasis on seismic safety also plays a role (Faiella et al. 2023), which leads to improved urban environment safety (Khodadad and Sanei 2016). The United States and Italy follow with 11 papers each. VE is experiencing growth in the US as a result of the increasing interest in sustainable and energy-efficient construction and the presence of large metropolitan areas (e.g., Dutta et al. 2009). Italy's focus is regularly linked to the preservation of historic buildings while enhancing spatial efficiency in old urban areas (e.g., Esposito, Faiella, and Mele 2024).

The number of publications from China and Belgium is 10 each. Belgium advocates for VE to facilitate compact, energy-efficient urban construction, particularly in densely populated European environments, as demonstrated by Amer, Mahar, et al. (2019). In China, VE is essential for managing rapid urban expansion and land shortages. For

instance, research by Guo et al. (2012) underscores the need for structural evaluation in tall structures to further reinforce this trend. Following these leading nations, publication numbers decline significantly, with Sweden and Poland producing five and four papers, respectively, while the remaining countries contribute one to three papers.

This geographic imbalance suggests that a few countries dominate VE research due to strong contextual drivers such as demographic pressure, land scarcity, regulatory support, and technological investment. In contrast, other regions show lower contributions because urban densification pressures, policy incentives, and academic priorities differ. Therefore, the concentration of VE publications in South Korea, Italy, the US, Belgium, and China should be understood as both a reflection of national circumstances and an indication of global research gaps that warrant further cross-country comparative studies.

### 3. Results and discussion

#### 3.1. VE suitability factors and categories

A total of 88 VE suitability factors were compiled from the reviewed literature, categorized into 18 categories according to the elements they influence or pertain to (a single factor may belong to multiple categories; Table 1). The research indicates that "Structural Capacity and Safety" is the most often referenced category in the literature, with 342 mentions. The category is predominantly characterized by "Structural/foundation capabilities of the building" (91 references) and "(Estimated) VE additional weight/load" (83 mentions), highlighting a significant focus on the technical feasibility and safety of vertical extensions. This prominence is anticipated, since the structural stability of the current structure is the essential criterion for any vertical extension endeavor. Without sufficient load-bearing capacity and overall structural integrity, considerations like aesthetics or market viability are relegated to minor significance.

The subsequent category is "Construction Logistics and Feasibility" (325 occurrences), with specific

**Table 1.** VE suitability factors and categories.

Category	Freq.	VE Suitability Factor	Freq.
Accessibility and Circulation	33	Accessibility of VE (e.g., distance to public transportation/facilities/roads/green areas)	15
		Vertical circulation/elevator/lift (conditions, need for addition, etc.)	18
Aesthetic and Visual Aspects	67	Architectural/Facade design (compatibility of materials, comfort, harmony with surroundings, etc.)	24
		Building prototypes in the city	3
		Compatibility of materials	12
		Compatibility/distinguishability with respect to the existing building (architecture, structure, typology, etc.)	20
		Nice view/visual connection to outside	3
Building Function and Occupation	23	Sky line/view preservation	5
		(Prior) Industrial/retail/office function	7
		Base building's/VE's functions (e.g., adjusting additional functional requirements)	7
		Building occupation	15
Building Geometry and Design	81	(Adequate) floor-to-floor/ceiling height	1
		Actual height of the base building (e.g., number of existing floors)	6
		Architectural plan/layout/geometry of the building (rectangular plan, service shaft, elevator/staircase, orientation, etc.)	18
		Floor/surface area	21
		Non-restrictive/regular (structural) grid	7
		Parking area/rules (demand, access, distance, etc.)	5
		Roof geometry (flat roof, etc.)	11
		Construction convenience/difficulties (noise, dust, obstruction of roads, etc.)	13
		Construction logistics (generally mentioned)	10
		Construction/assembly safety	1
Construction Logistics and Feasibility	325	Degree of adaptability/repeatability/reversibility/flexibility	11
		Distance between buildings	15
		Distance to an aerodrome	3
		Distance to prefabrication/material plant or accessibility and transport of the (preassembled) components	1
		Ease of Maintenance	6
		Existing rooftop unit/equipment	9
		High/low level of construction (which floor)	3
		Lightweight structure (steel, timber, membrane, etc.)	1
		Materials properties (e.g., mechanical properties, high tensile strength, light weight, manufacturing adaptability, corrosive environment resistance, etc.)	47
		Modular design	76
		Non-restrictive/regular (structural) grid	19
		Offsite construction/Prefabrication (including semi-prefabrication and dry construction)	5
		Roof geometry (flat roof, etc.)	33
		Sound/noise insulation or control	13
		Space for on-site construction	8
VE design/assembly/construction time (daily schedule, total time, etc.)	10		
Vertical circulation/elevator/lift (conditions, need for addition, etc.)	36		
Availability of original design data	18		
Availability of skilled labor/designers	21		
Data and Labor Availability	25	4	

(Continued)

Table 1. (Continued).

Category	Freq.	VE Suitability Factor	Freq.
Environmental/Climatic and Comfort Conditions	220	(Micro)climatic conditions Air flow/circulation condition Carbon footprint of the building/extendable area Energy-saving demand/efficiency/potential of the building Level of comfort/wellbeing (living, thermal, visual, etc.) Materials properties (e.g., mechanical properties, high tensile strength, light weight, manufacturing adaptability, corrosive environment resistance, etc.) Natural light/solar gain/shading Need/opportunity for renovation/refurbishment/remodeling Nice view/visual connection to outside Groundwater level (high/low) Soil/ground conditions (type, bearing capacity) Cost efficiency/benefit (materials, construction, labor, rent, environmental costs, etc.) Land price (high/low) Market demand/drivers for real estate/housing/penthouse Market value/price for apartments/units (e.g., rent, sale) Real estate/market value valorization VE design/assembly/construction time (daily schedule, total time, etc.) Ability of the community to cope with natural/man-made disasters Protection/safety from hazards (flooding, hurricanes, high breezes, tremors, earthquakes, chemical degradation, etc.) Height of the surrounding buildings Neighborhood/area capacity for densification (urban services, infrastructure, etc.) Parking area/rules (demand, access, distance, etc.) Reform of the neighborhood Road/street/outdoor space width/size Site density (e.g., city center, suburbs) Site with/without traffic Space for on-site construction Ease of management and supervision Effective flow of information between residents and stakeholders Participation of architects/engineers/homeowners/stakeholders Participation/coordination in planning Air rights Fire safety measures/restrictions Government/Municipal support/plan (e.g., for densification) Heritage/protected areas restrictions (e.g., national parks or reserves) Individual requests for rooftop extensions Maximum allowed height Maximum permitted building density Parking area/rules (demand, access, distance, etc.) Size of the extension (e.g., number of added floors) Type of ownership (private/public) Urban sprawl and containment strategies VE-related regulations/guidelines (e.g., setbacks, height limit, etc.) Ability of the community to cope with natural/man-made disasters Feasibility of the residents' relocation Population density/growth or shortage in housing or workplace Social vulnerability (of the region) Social/residents' acceptance/disturbance/complaint	12 5 13 41 7 76 25 38 3 1 36 67 4 15 24 1 36 1 7 6 12 11 1 5 12 4 10 2 1 3 7 2 21 23 10 1 18 4 11 17 2 1 46 1 15 24 1 34
Ground/Soil Conditions	37		
Market and Economic Factors	147		
Natural Hazards Vulnerability	8		
Neighborhood and Surrounding Context	61		
Planning and Stakeholder Involvement	13		
Regulations and Legal Considerations	156		
Social and Community Considerations	75		

(Continued)

**Table 1.** (Continued).

Category	Freq.	VE Suitability Factor	Freq.
Space and Functional Demand	66	Need for additional space/unit (for family members, users, furniture, parking, etc.)	28
Specific value of the building/location	2	Need/opportunity for renovation/refurbishment/remodeling	38
Structural Capacity and Safety	342	Corporate/personal values or desires for the same site	1
		Historical/aesthetic values of the base building	1
		(Estimated) VE additional weight/load (e.g., per square meter)	83
		Building age/year of construction/service or design life of the building	20
		Compatibility/distinguishability with respect to the existing building (architecture, structure, typology, etc.)	20
		Need/opportunity for renovation/refurbishment/remodeling	38
		No need for structural reinforcement especially when occupied	31
		Non-restrictive/regular (structural) grid	5
		Seismic behavior of the structure	37
		Size of the extension (e.g., number of added floors)	17
Utilities and Technical Infrastructure	6	Structural/foundation capabilities of the building (including originally designed extra capacity for VE)	91
		Sewage/sanitation capacity	1
		Technical system capacity (e.g., heating system)	5

emphasis on “Materials properties” (76 mentions), “Lightweight structure” (47 mentions), and “VE design/assembly/construction time” (36 mentions). This emphasis highlights the growing intricacy of building procedures in densely populated urban environments and the necessity for efficient, lightweight, and/or modular solutions that reduce disruptions (Amer and Attia 2019; Aparicio-Gonzalez, Domingo-Irigoyen, and Sanchez-Ostiz 2020; Jellen and Memari 2018). The emphasis on prefabrication and offsite construction techniques (33 mentions) further reinforces a wider trend towards industrialized building practices in VE projects.

“Environmental/Climatic and Comfort Conditions” (220 mentions) is identified as a significant domain, underscoring the increasing environmental consciousness in architectural design. The literature prominently highlights “Material properties”, which is listed in this category as well (76 mentions), “Energy-saving demand/efficiency/potential of the building” (41 mentions), and “Need/opportunity for renovation/refurbishment/remodeling” (38 mentions), indicating a synthesis of environmental performance with structural and material factors. The convergence of environmental objectives with VE viability is likely influenced by worldwide decarbonization initiatives and evolving construction regulations and codes (Amer et al. 2017, 2020; Soikkeli 2016). Higher environmental awareness can also be associated with raising climate change concerns, significantly present in many regions (Khodadad et al. 2022).

Notably, “Market and Economic Factors” (147 mentions) garner significant focus, particularly “Cost efficiency/benefit” (67 mentions) and “Market value/price for apartments/units” (24 mentions). These variables illustrate the commercial viability perspective through which VE is frequently assessed (Pakhomova et al. 2019; Seo, Lee, and Won 2020; Spirkova et al. 2021; Vuckovic et al. 2017; Wijnants, Allacker, and De Troyer 2016). However, the fact that they are less common than structural and construction-related factors suggests that, even while profitability is crucial, technical viability still acts as the gatekeeper.

“Regulations and Legal Considerations” (156 mentions) is also prominent, with considerable attention directed towards “VE-related regulations/guidelines” (46 mentions) and “Government/municipal support” (23 mentions). This highlights how regulatory clarity or complexity can serve as a facilitator or impediment for VE initiatives (C. Gillott, B. Davison, and D. Densley Tingley 2022; Vuckovic et al. 2017). Ambiguities in zoning regulations, height restrictions, or heritage protections frequently hinder the fulfillment of VE (Amer et al. 2017; Argenziano et al. 2021; C. Gillott, J. B. Davison, and D. Densley Tingley 2022; Guma et al. 2009; Napieralska and Attia 2023; Vuckovic et al. 2019), indicating a necessity for urban policy revision that aligns with densification objectives.

Alternatively, categories such as “Utilities and Technical Infrastructure” (6 mentions), “Natural Hazards Vulnerability” (8 mentions), and “Planning and Stakeholder Involvement” (13 mentions) are among the least discussed. This indicates major research gaps. The insufficient focus on infrastructure compatibility (e.g., sewage or HVAC systems) may result in neglecting operational practicality. In a similar vein, the lack of emphasis on stakeholder participation raises the possibility that the sociopolitical complexity of implementation is underestimated. These gaps underscore the necessity for more multidisciplinary research that integrates engineering, urban governance, and social sciences.

At the individual factor level, some frequently mentioned factors, like “Material properties” and “Structural/foundation capabilities”, are featured in numerous categories, highlighting their cross-cutting significance. On the other hand, critical urban characteristics such as “Neighborhood/area capacity for densification” and “Accessibility of VE” only received nominal attention (12 and 15 mentions, respectively), despite their importance in determining VE sustainability and livability (Schuetze, Amoruso, and Sonn 2020; Semprini et al. 2017; Sundling 2019).

In summary, the majority of the literature focuses on technical viability, including structure, materials, and construction, with economic and environmental considerations receiving less attention but still being significant. While legal frameworks are acknowledged, they have not been thoroughly examined, and the human-centric and infrastructural dimensions are being underexplored. Several considerations appear notably neglected in this regard. Social and participatory elements such as “Effective flow of information between residents and stakeholders” (1 mention) and “Participation of architects/engineers/homeowners/stakeholders” (3 mentions) are minimally referenced. This implies a substantial research gap in the comprehension of the socio-political dynamics and collaborative processes that influence the feasibility and adoption of VE (Julistiono, Oldfield, and Cardelicchio 2023b; Mouna and Drias 2024; Schuetze, Amoruso, and Sonn 2020; Semprini et al. 2017; Sundling 2019). Likewise, factors such as “Fire safety measures/restrictions”, “Accessibility of VE”, and “Parking area/rules” receive moderate attention, even though they are essential for practical applications.

These disparities indicate a technically driven yet fragmented approach that has long characterized VE research. The dominance of engineering-oriented studies reflects not only disciplinary traditions but also risk-averse regulatory settings and funding schemes that tend to privilege quantifiable, standardized, and compliance-based criteria over qualitative or contextual factors. In such environments, issues of structural integrity, load capacity, and material

optimization are more easily framed within codified standards, while social, cultural, and governance-related aspects resist simplification and are consequently underrepresented. This technocratic bias, while ensuring that physical feasibility is well documented, inadvertently narrows the conceptual and methodological scope of VE research, restricting the capacity of existing studies to address real-world complexity or to guide socially responsive implementation strategies.

The underrepresentation of social and participatory dimensions carries important implications. Without adequate attention to resident engagement, community acceptance, and stakeholder collaboration, VE initiatives risk encountering resistance in planning approval processes, diminished user satisfaction, and inequitable outcomes in urban densification efforts. Moreover, the neglect of site-specific and infrastructural interdependencies limits the transferability of technical solutions across differing urban fabrics, particularly in contexts with variable regulatory maturity, socio-economic conditions, or heritage constraints.

Although a limited number of studies have begun to pursue integrated perspectives – for example, Soikkeli (2016) linking timber-based vertical additions to fire regulations and energy performance, or Amer and Attia (2019) combining sustainability indicators with spatial and structural analysis – the overall literature remains fragmented and siloed. Such fragmentation underscores the need for holistic frameworks that can simultaneously evaluate technical, environmental, economic, legal, and social dimensions of VE. Future research should thus aim to bridge these divides through interdisciplinary and context-sensitive approaches, integrating engineering rigor with urban governance, policy analysis, and participatory design. Only through such comprehensive evaluation can VE solutions evolve from technically feasible prototypes into socially inclusive, economically viable, environmentally resilient, and legally enforceable pathways for vertical urban growth.

### 3.2. VE suitability factors and levels

The analysis of VE suitability criteria indicates a clear priority pattern across the three suitability levels: “Building”, “Design”, and “Site” (Table 2). The “Building” level prevails in the literature with 706 citations, succeeded by “Design” with 665, and “Site” with a comparatively smaller count of 386 mentions. This distribution highlights a dominant trend in VE studies to emphasize the inherent features of current buildings and their physical feasibility for vertical expansion. This choice presumably arises from the structural and functional characteristics of VE, where the fundamental stability and flexibility of the base structure are key factors of viability. However, to better understand

how this focus is operationalized within the literature, it is necessary to examine which specific factors are most frequently addressed within the dominant suitability levels.

Among the highly cited factors, “Structural/foundation capabilities of the building” (91 mentions) is identified as the most frequent on the building level, underscoring its status as a non-negotiable requirement for any VE intervention. The “(Estimated) VE additional weight/load” (83) is closely linked and underscores the significance of structural resilience on the design level. A cross-cutting factor that is frequently brought up in both design and building levels is “Materials properties” (76 occurrences), which highlights how important material performance is to accomplishing safe and effective vertical expansions.

Additionally, regulatory and efficiency considerations are frequently addressed throughout the levels. For example, “VE-related regulations/guidelines” are mentioned consistently (46 times), showing a common concern with legal and planning frameworks irrespective of context and suitability level. Similarly, “Energy-saving demand/efficiency/potential of the building” (41 occurrences) encompasses both building and design levels, indicating that environmental performance is not only an aspirational concept but a pragmatic one integrated with feasibility evaluations.

At the site level, the comparatively lower frequency points to a peripheral role in VE discussions. Nevertheless, certain facets persist in being relevant in the literature, such as “Soil/ground conditions” (36 references) and “Natural light/solar gain/shading” (25 mentions). The lower focus on site factors may indicate a prevailing view that VE projects are intrinsically urban and hence subjected to relatively uniform external circumstances. This assumption, however, may oversimplify the intricate heterogeneity in urban shape, infrastructure limitations, and regulatory frameworks. This is particularly concerning if vertical extension transitions from an infrequent infill strategy to a systematic approach for managing urban densification on a broader scale, especially in areas where densification is more necessary or advisable (based on specific requirements, such as housing demands or urban constraints).

The underrepresentation of site-level factors reveals a deeper structural bias in how VE research conceptualizes context. By treating the city as a static backdrop rather than an active variable, much of the existing literature abstracts VE from its lived environment – the streetscapes, communities, and infrastructural systems that ultimately mediate its success. This technocratic framing reinforces a view of VE as a primarily building-centric intervention, rather than an urban strategy

**Table 2.** VE suitability factors and levels.

Suitability Level	Freq.	VE Suitability Factors	Freq.
Building	706	(Adequate) floor-to-floor/ceiling height	6
		(Prior) Industrial/retail/office function	7
		Actual height of the base building (e.g., number of existing floors)	18
		Air rights	2
		Architectural plan/layout/geometry of the building (rectangular plan, service shaft, elevator/staircase, orientation, etc.)	21
		Availability of original design data	21
		Base building's/VE's functions (e.g., adjusting additional functional requirements)	15
		Building age/year of construction/service or design life of the building	20
		Building occupation	1
		Carbon footprint of the building/extendable area	13
		Corporate/personal values or desires for the same site	1
		Energy-saving demand/efficiency/potential of the building	41
		Existing rooftop unit/equipment	3
		Feasibility of the residents' relocation	15
		Fire safety measures/restrictions	21
		Floor/surface area	7
		High/low level of construction (which floor)	1
		Historical/aesthetic values of the base building	1
		Level of comfort/wellbeing (living, thermal, visual, etc.)	7
		Market value/price for apartments/units (e.g., rent, sale)	24
		Materials properties (e.g., mechanical properties, high tensile strength, light weight, manufacturing adaptability, corrosive environment resistance, etc.)	76
		Natural light/solar gain/shading	25
		Need for additional space/unit (for family members, users, furniture, parking, etc.)	28
		Need/opportunity for renovation/refurbishment/remodeling	38
		No need for structural reinforcement especially when occupied	31
		Non-restrictive/regular (structural) grid	5
		Parking area/rules (demand, access, distance, etc.)	11
		Roof geometry (flat roof, etc.)	13
		Seismic behavior of the structure	37
		Sewage/sanitation capacity	1
		Social/residents' acceptance/disturbance/complaint	34
		Structural/foundation capabilities of the building (including originally designed extra capacity for VE)	91
		Technical system capacity (e.g., heating system)	5
		Type of ownership (private/public)	2
		VE-related regulations/guidelines (e.g., setbacks, height limit, etc.)	46
		Vertical circulation/elevator/lift (conditions, need for addition, etc.)	18

(Continued)

Table 2. (Continued).

Suitability Level	Freq.	VE Suitability Factors	Freq.
Design	665	(Estimated) VE additional weight/load (e.g., per square meter)	83
		Architectural/Facade design (compatibility of materials, comfort, harmony with surroundings, etc.)	24
		Building prototypes in the city	3
		Carbon footprint of the building/extendable area	13
		Compatibility of materials	12
		Compatibility/distinguishability with respect to the existing building (architecture, structure, typology, etc.)	20
		Construction convenience/difficulties (noise, dust, obstruction of roads, etc.)	10
		Construction/assembly safety	11
		Cost efficiency/benefit (materials, construction, labor, rent, environmental costs, etc.)	67
		Degree of adaptability/repeatability/reversibility/flexibility	15
		Ease of Maintenance	9
		Ease of management and supervision	2
		Effective flow of information between residents and stakeholders	1
		Energy-saving demand/efficiency/potential of the building	41
		Lightweight structure (steel, timber, membrane, etc.)	47
		Market value/price for apartments/units (e.g., rent, sale)	24
		Materials properties (e.g., mechanical properties, high tensile strength, light weight, manufacturing adaptability, corrosive environment resistance, etc.)	76
		Maximum allowed height	18
		Modular design	19
		Nice view/visual connection to outside	3
		Offsite construction/Prefabrication (including semi-prefabrication and dry construction)	33
		Parking area/rules (demand, access, distance, etc.)	11
		Participation of architects/engineers/homeowners/stakeholders	3
		Participation/coordination in planning	7
		Real estate/market value valorization	1
		Size of the extension (e.g., number of added floors)	17
		Sky line/view preservation	5
		Sound/noise insulation or control	8
		VE design/assembly/construction time (daily schedule, total time, etc.)	36
		VE-related regulations/guidelines (e.g., setbacks, height limit, etc.)	46

(Continued)

Table 2. (Continued).

Suitability Level	Freq.	VE Suitability Factors	Freq.
Site	386	(Micro)climatic conditions	12
		Ability of the community to cope with natural/man-made disasters	1
		Accessibility of VE (e.g., distance to public transportation/facilities/roads/green areas)	15
		Air flow/circulation condition	5
		Availability of skilled labor/designers	4
		Construction logistics (generally mentioned)	1
		Distance between buildings	3
		Distance to an aerodrome	1
		Distance to prefabrication/material plant or accessibility and transport of the (preassembled) components	6
		Government/Municipal support/plan (e.g., for densification)	23
		Groundwater level (high/low)	1
		Height of the surrounding buildings	6
		Heritage/protected areas restrictions (e.g., national parks or reserves)	10
		Individual requests for rooftop extensions	1
		Land price (high/low)	4
		Market demand/drivers for real estate/housing/penthouse	15
		Market value/price for apartments/units (e.g., rent, sale)	24
		Maximum allowed height	18
		Maximum permitted building density	4
		Natural light/solar gain/shading	25
		Neighborhood/area capacity for densification (urban services, infrastructure, etc.)	12
		Nice view/visual connection to outside	3
		Parking area/rules (demand, access, distance, etc.)	11
		Population density/growth or shortage in housing or workplace	24
		Protection/safety from hazards (flooding, hurricanes, high breezes, tremors, earthquakes, chemical degradation, etc.)	7
		Reform of the neighborhood	1
		Road/street/outdoor space width/size	5
		Site density (e.g., city center, suburbs)	12
		Site with/without traffic	4
		Social vulnerability (of the region)	1
		Social/residents' acceptance/disturbance/complaint	34
		Soil/ground conditions (type, bearing capacity)	36
		Space for on-site construction	10
		Urban sprawl and containment strategies	1
		VE-related regulations/guidelines (e.g., setbacks, height limit, etc.)	46

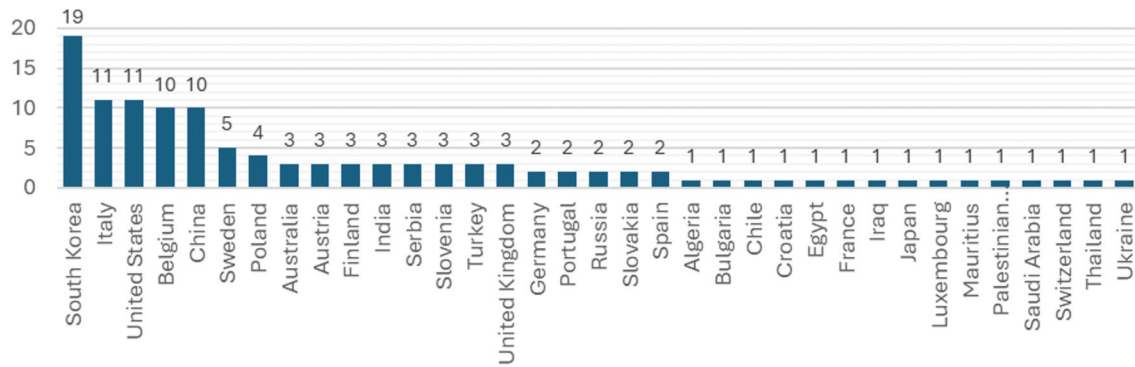


Figure 5. Countries producing research on the VE of buildings.

embedded within complex socio-spatial systems. As a result, discussions of how vertical extensions interact with surrounding morphology, mobility networks, or environmental microconditions remain limited. Such omissions risk overlooking critical issues such as the cumulative load on utilities, shadowing impacts on neighboring buildings, or equitable access to amenities and open space.

These tendencies are not merely academic oversights; they carry tangible consequences for cities. When VE is conceptualized primarily through structural or architectural feasibility, urban diversity and local constraints become invisible, leading to one-size-fits-all solutions that may perform well in theory but poorly in practice. The lack of attention to site specificity also constrains the transferability of successful VE models across different urban contexts – what works in a dense, well-served European city block may fail in a suburban or infrastructure-deficient setting. This gap becomes even more pressing as vertical extension transitions from a sporadic infill practice to a mainstream urban densification strategy, expected to contribute to housing provision and sustainability goals.

Ultimately, these statistical patterns expose a disciplinary and conceptual imbalance: VE research continues to privilege structural and building-level feasibility while marginalizing socio-political, spatial, and contextual dimensions. By framing VE primarily as an engineering problem, much of the literature underestimates its dependence on urban governance, land-use compatibility, demographic pressures, and social acceptance. Future research should therefore move toward a more spatially and socially grounded understanding of site conditions, integrating urban morphology, infrastructure resilience, and community dynamics into VE assessment frameworks. Such a shift would humanize VE research – acknowledging that the success of building upward is as much about the people, places, and policies beneath as it is about the structures themselves.

### 3.3. Geographic and temporal trends in factor category emphasis

#### 3.3.1. Geographic trends

Figure 6 shows how the VE suitability factor categories and publishing countries co-occur. The degree of involvement in each area varies greatly between countries, indicating national research objectives and maybe underlying academic traditions or built environment interests.

Among the countries, South Korea (as the most publishing country in VE research) stands out with a highly concentrated focus on technical and operational aspects of VE, with high references in categories such as “Structural Capacity and Safety” and “Construction Logistics and Feasibility”. This orientation reflects the country’s urban development context – dominated by high-density cities and a strong engineering sector (Cheng-Can and Jin-Tae 2017; Mun, Lee, and Kim 2024).

Belgium is also distinguished by its consistently high frequencies in a variety of categories – most notably “Construction Logistics and Feasibility” (46 mentions), “Environmental/Climatic and Comfort Conditions” (33), and “Structural Capacity and Safety” (29). This implies that Belgian research has a broad and pragmatic focus, which is consistent with the country’s congested urban settings and the intricate regulatory and infrastructural requirements that these contexts impose (Amer et al. 2017; The Brussels Morning Newspaper 2025; Roisin 2024). Similarly, Italy demonstrates significant involvement, particularly in “Construction Logistics and Feasibility” (28) and “Structural Capacity and Safety” (42), underscoring a trend of heightened focus on feasibility and technical performance in structurally and historically mature urban areas (Argenziano et al. 2021).

Notably, countries such as Finland, Australia, the UK, Spain, and Sweden have varied yet moderate levels of participation. For example, in Finland and Australia, “Building Geometry and Design” and

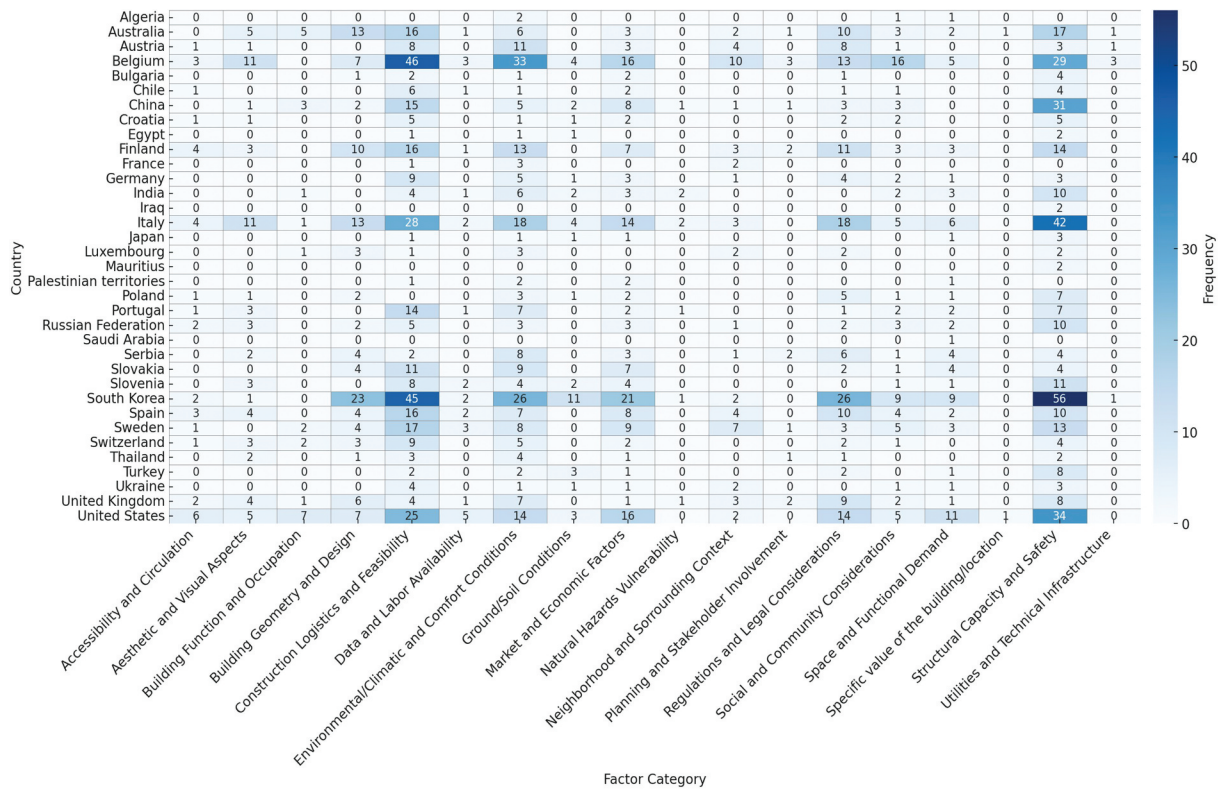


Figure 6. Co-occurrence analysis of the publishing countries and suitability factor categories.

“Environmental/Climatic and Comfort Conditions” are frequently discussed, which is likely due to the robust environmental performance standards and sustainable design imperatives that exist in both countries.

In the United States, greater emphasis is placed on technically focused categories. U.S.-based research identifies “Structural Capacity and Safety”, “Construction Logistics and Feasibility”, and “Market and Economic Factors” as pivotal to VE feasibility. This demonstrates a pragmatic strategy focused on performance enhancement and economic feasibility, aligned with a regulatory framework that favors densification and redevelopment rather than contextual preservation (as in Italy, for instance).

In contrast, several countries, including Egypt, Iraq, Mauritius, and Saudi Arabia, have little to absent involvement in the majority of categories. This absence may indicate restricted research outputs, varying (lower) urban growth pressures, or the emphasis on alternative forms of vertical development, such as new high-rise buildings, over vertical extension.

3.3.2. Temporal evolution

The second heatmap (Figure 7) illustrates the temporal evolution of academic attention to several categories of VE suitability factors. A significant increase in research effort is seen beginning in 2014, with a particularly steep ascent from 2017 onwards. This increase

corresponds with overarching trends in urban sustainability discussions and policies that prioritize densification, the repurposing of existing structures, and sustainable retrofitting, such as the UN Sustainable Development Goals, specifically goals 11 and 12 (United Nations Department of Economic and Social Affairs 2015), New Urban Agenda (UN-Habitat 2022), and the European Green Deal (European Commission 2021).

The categories of “Construction Logistics and Feasibility” and “Structural Capacity and Safety” prominently feature in recent literature, reaching a zenith in 2019 with 61 citations apiece. This highlights the increasing significance of actual implementation issues as VE evolves from a theoretical concept to a more operational realm in urban planning and architecture. It similarly indicates a persistent necessity to evaluate the physical integrity and structural viability of extending current buildings.

“Environmental/Climatic and Comfort Conditions”, “Regulations and Legal Considerations”, and “Market and Economic Factors” consistently exhibit elevated rates, reflecting an increasing interest in interior convenience, thermal regulations, and climate resilience – particularly pertinent to the retrofitting of older buildings – alongside the regulations and governance mechanisms that either facilitate or impede VE projects, as well as the cost-effectiveness and market valuation of such initiatives. Conversely, categories like “Utilities and Technical Infrastructure” and Natural

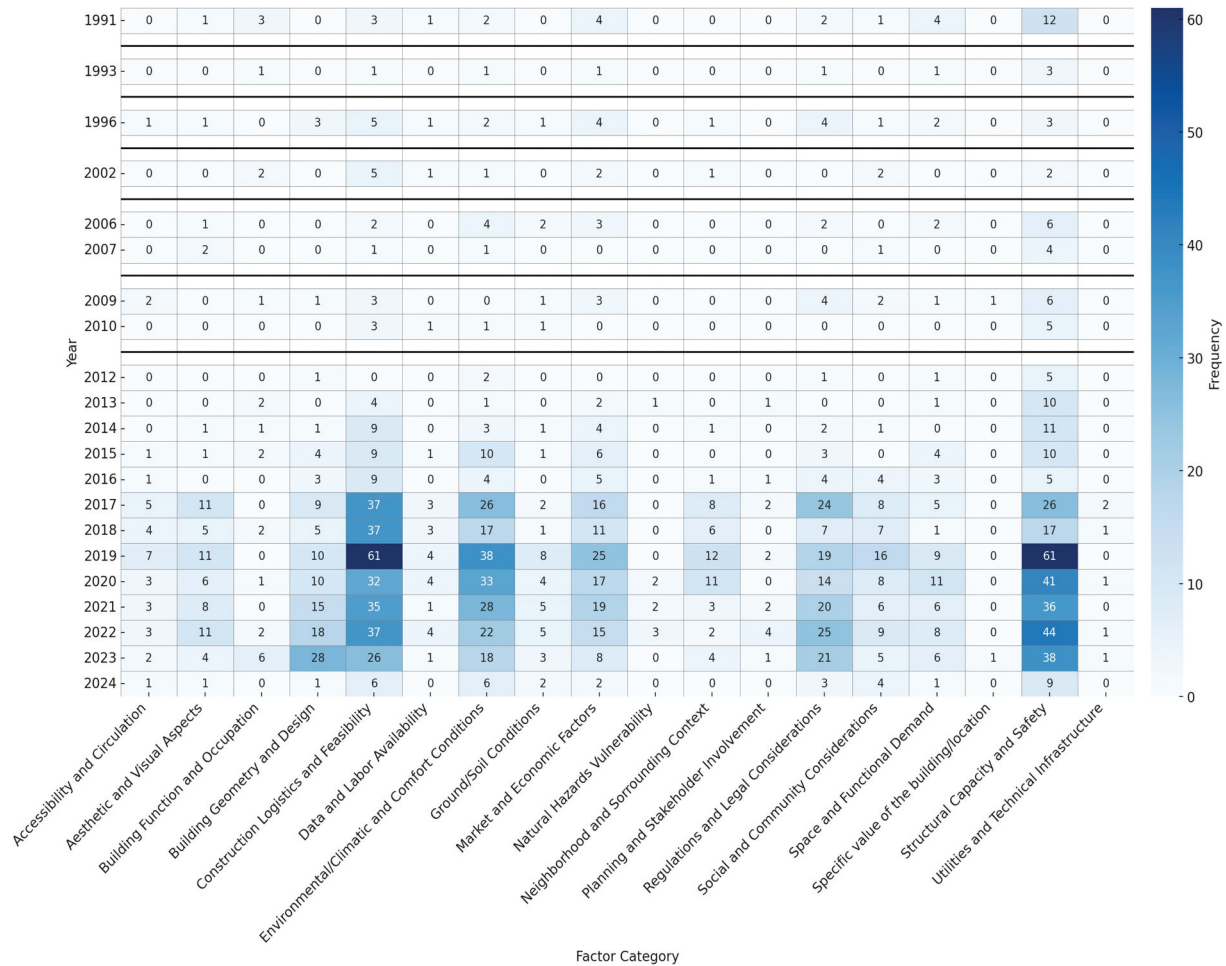


Figure 7. Co-occurrence analysis of the publication years and suitability factor categories.

Hazards vulnerability” are underrepresented, indicating potential gaps in the literature or a scarcity of available data and information in these areas of study.

The visual representation distinctly illustrates temporal gaps, notably the lack of publications in 1992, 1994–1995, 1997–2001, and some other early years. These gaps illustrate the fledgling condition of the VE issue in previous decades and substantiate the view of VE as an emerging area that only achieved prominence in studies around the mid-2010s.

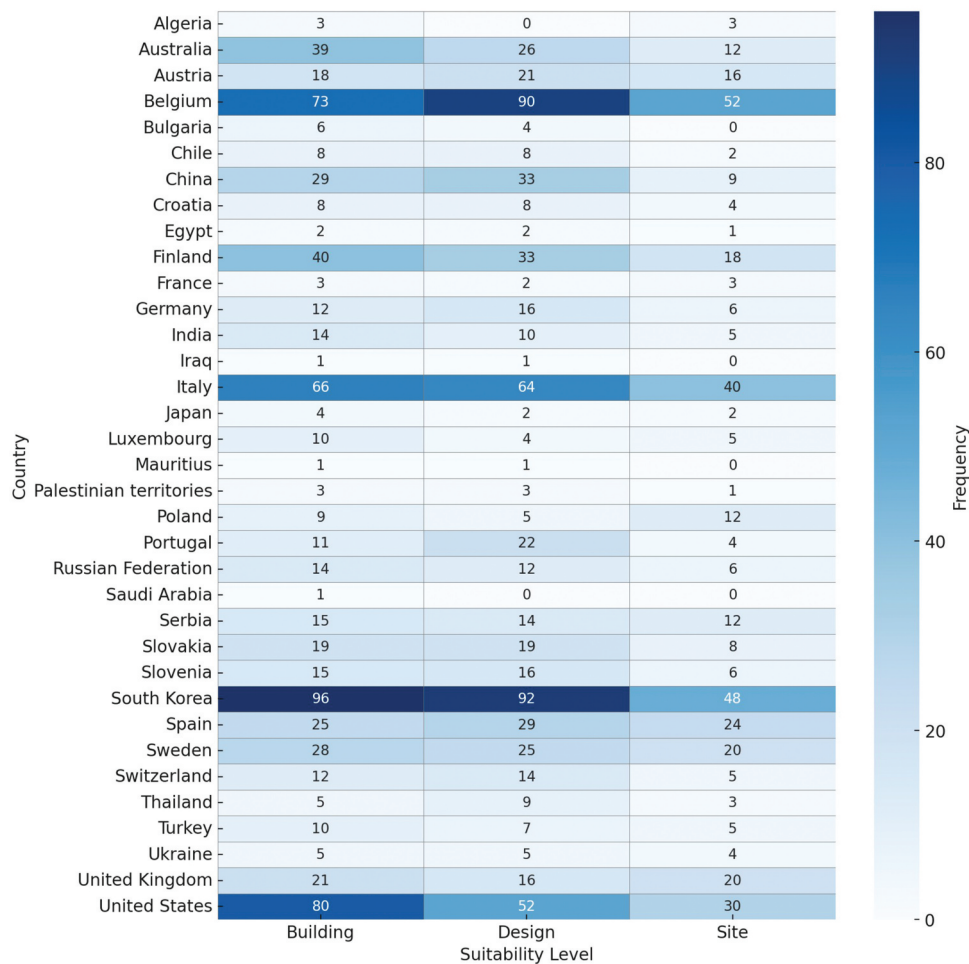
### 3.4. Geographic and temporal distribution of VE suitability levels

#### 3.4.1. Geographic distribution

Figure 8 illustrates the varying priorities assigned by countries to the three VE suitability levels – building, design, and site – in their research endeavors. As seen in the heatmap, South Korea, as a major publishing country, places significant importance on the building and design levels, with 96 and 92 mentions, respectively. This underscores the country’s commitment to structural feasibility and architectural integration, likely influenced by its dense urban settings and

sophisticated construction technologies, as mentioned earlier. Site-level variables are mentioned less frequently (48 times), implying that larger contextual factors take a back seat to technical and design imperatives in Korean literature. Belgium demonstrates a relatively more balanced distribution throughout all three classifications, with a notable emphasis on design suitability (90 citations for design, in contrast to 73 and 52 references for building and site levels, respectively). This may indicate the country’s need to harmonize VE initiatives with stringent heritage rules and intricate, compact urban fabrics.

Likewise, Italy demonstrates elevated frequency in building, design, and site categories (66, 64, and 40 occurrences, respectively), underscoring the significance of incorporating contextual sensitivity, architectural aesthetics, and structural integrity. This aligns with the complexity of Italian urban settings, where site-specific limitations – such as cultural conservation and visual impact – must be considered alongside technical specifications. Conversely, the United States emphasizes building-level assessments significantly (80 instances, in comparison to 52 and 30 instances for Building and Site levels), highlighting structural capacity and feasibility, whereas design-related and



**Figure 8.** Co-occurrence analysis of the publishing countries and suitability levels.

contextual factors are somewhat constrained. The country's contemporary building stock, standardized construction methods, and practical emphasis on cost-effectiveness and structural viability are probably the causes of this tendency. Flexible zoning and diminished historical and architectural continuity restrictions lower the need for comprehensive design integration or site-specific contextual study, prioritizing technological optimization as the primary focus.

Countries such as Finland, Australia, and China exhibit significant engagement, particularly in building and design, but to a lesser extent than the previously stated countries. Moreover, Sweden and Spain offer substantial contributions across all three levels with a more equitable approach. This may indicate these countries' commitment to integrated design methodologies and sustainable retrofitting regulations, necessitating cross-level evaluation frameworks. For instance, Sweden has launched the Viable Cities program since 2017, which promotes systemic urban change by funding cross-level projects – from urban frameworks to building-level renovation pilots – and demands integrated evaluation and stakeholder co-design (Viable Cities 2024). A similar approach can be seen in Spain, where the National Recovery and Resilience Plan (2021) allocated

€6.8 billion for green renovation and integrated energy, social, and accessibility goals at both neighborhood (site) and building scales (Feás and Steinberg 2021).

Overall, building and design suitability levels are regularly evaluated in almost all countries publishing on VE suitability, indicating a significant interest in incorporating vertical extensions into existing structures. This presents a substantial opportunity for future research on site suitability across countries to achieve a more equitable approach to varying suitability levels.

### 3.4.2. Temporal trends in VE suitability levels

Ultimately, Figure 9 provides a longitudinal analysis of the focus assigned to each VE suitability level over the years. The temporal trend indicates a gradual increase in academic participation during the 1990s and early 2000s, succeeded by a rapid escalation beginning in 2014 and reaching its top in 2019–2022.

Design and building levels have been the primary focus of literature in the past decade, with building typically surpassing design in terms of frequency, except for a few years. For instance, in 2019, design level is mentioned 116 times, while building is mentioned 108 times. This is indicative of a scholarly shift

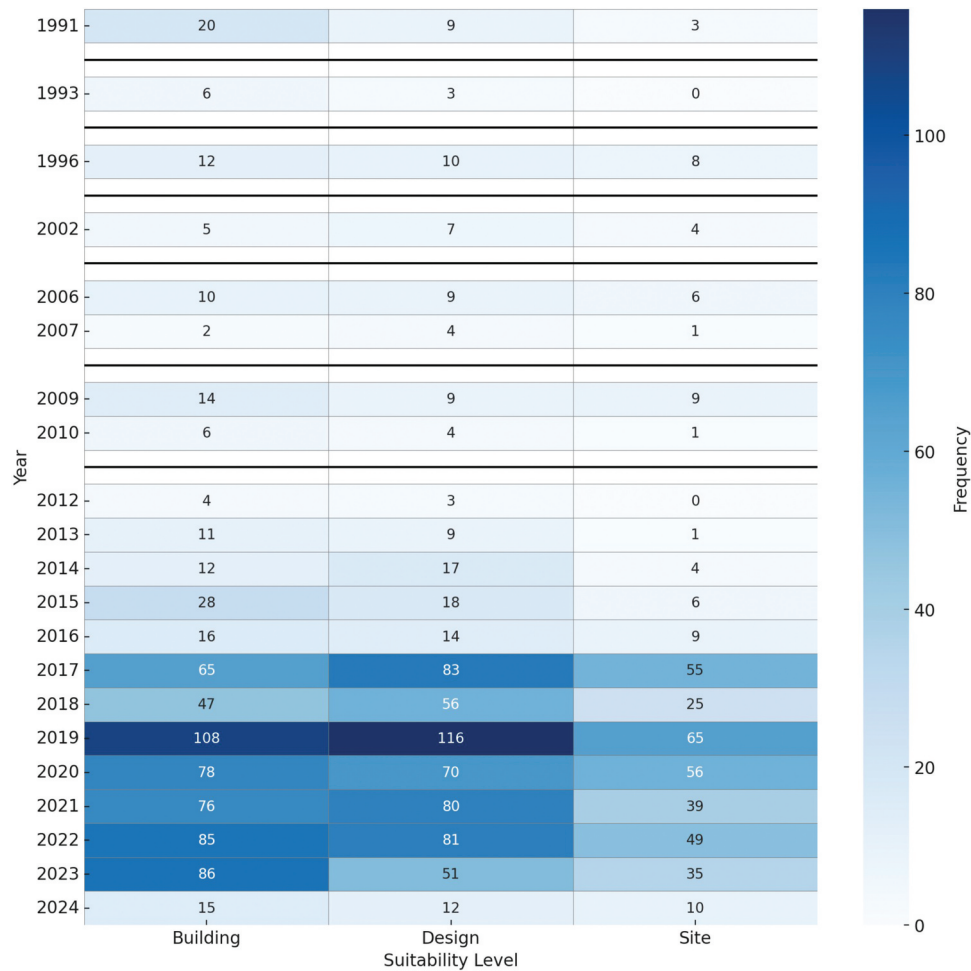


Figure 9. Co-occurrence analysis of the publication years and suitability levels.

toward human-centered and integrative design considerations, which may be incited by the advancement of urban design approaches, architectural innovations, and stakeholder collaboration practices. Building-level analysis is prevalent in the literature owing to its technical, quantifiable, and regulatory-compliant characteristics (e.g., energy efficiency, structural integrity, code adherence). Conversely, contemporary techniques, like generative design, parametric tools, and data-driven simulations, have facilitated novel approaches to design optimization that integrate evaluations at both the building and design levels.

Despite being consistently the least discussed level, the site level has experienced substantial growth, increasing from single-digit mentions in 1991–2016 to 55 in 2017. The elevated rate persisted almost consistently in subsequent years, with 25 to 65 mentions across several years. This increase may result from heightened knowledge of contextual limitations, like accessibility, zoning, environmental conditions, and infrastructural capacity, which are essential for the viability of VE in densely populated urban areas.

The uneven evolution of VE suitability research is highlighted by the gaps between publication years,

which are clearly shown by visual breaks that have been put into the heatmap (for example, between 1991 and 1993, and between 2002 and 2006). These disruptions are likely a result of the historically fragmented character of VE discourse, which has only recently unified into a coherent domain during the past 10 to 15 years (Sanei et al., 2025; see Figure 4).

### 3.5. What can be understood? Towards a more holistic framework

The statistics presented should not be read in isolation. Their uneven distribution demonstrates privileging some VE aspects while underrepresenting others. Recognizing this pattern offers a novel critical approach: rather than treating indicators and statistics as neutral descriptors, they can be understood as evidence of disciplinary blind spots and opportunities for rebalancing future research agendas, shaping more holistic frameworks.

Toward this end, the unequal distribution of research focus reflects a deeper theoretical imbalance inherent in the discipline, revealing not merely empirical variation but the structural orientation of

knowledge production itself. The current literature operates largely within a technocratic paradigm, wherein VE viability is defined primarily in terms of engineering capabilities and cost-effectiveness. This paradigm reinforces a reductionist framing of VE as a technical optimization problem, privileging quantifiable structural and economic parameters while marginalizing relational, contextual, and governance-related dimensions. This perspective, while comprehensible due to the technical hazards linked to vertical loading, overlooks the wider urban, social, and environmental factors that ultimately influence the long-term effectiveness of VE measures. By prioritizing technical determinism, the prevailing paradigm inadvertently suppresses the “urban metabolism” dimensions of VE, specifically the socio-political, regulatory, and site-specific interactions through which buildings are embedded in and co-evolve with their urban environments. As a result, VE remains conceptually confined to the domain of construction feasibility, rather than advancing toward its full potential as a holistic urban densification strategy.

This bias implies that the suitability of VE is still regarded as a building-scale intervention rather than an urban-level strategy. The assumption that site conditions are static constraints rather than adjustable parameters is one possible explanation. Soil bearing capacity, for example, may be assessed but seldom changed without incurring high costs, and zoning restrictions are typically rigid. Consequently, scholars and practitioners may perceive site circumstances as binary feasibility determinants, resulting in less scholarly focus compared to more adaptable and designable variables such as structural reinforcement or material selection. Within the technocratic paradigm, such factors are treated as exogenous boundary conditions rather than endogenous components of urban transformation processes, further reinforcing their marginalization in feasibility discourse.

Another potential explanation for the underrepresentation of site-level factors is the context-specific character of urban planning and regulatory environments. In contrast to structural principles, which are predominantly universal, zoning restrictions, infrastructural limitations, and neighborhood effects may differ significantly among cities and countries. This variety complicates the development of generalizable findings, thereby restricting the scope of cross-contextual research on site-related issues. However, this methodological challenge also reflects a deeper epistemological tendency to prioritize universally applicable technical solutions over context-sensitive urban integration, thereby perpetuating the theoretical imbalance identified in this study.

This lack of representation in research indicates a disparity between technical feasibility analyses and

urban-scale policy dialogues that necessitates additional investigation. In reality, VE influences beyond the singular structure; it affects urban shape, infrastructural requirements, environmental quality, and social dynamics. As a result, a restricted focus on a few variables, such as structural feasibility, yields solutions that are technically possible but poorly integrated into the urban setting. Consequently, the statistical dominance of building-level factors observed in this study should not be interpreted merely as a disciplinary preference but rather as evidence of a structural mechanism within the knowledge system that constrains the conceptualization and scalability of VE solutions. This mechanism limits the evolution of VE from a discrete construction technique into a systemic urban densification strategy capable of addressing broader spatial, governance, and sustainability objectives. Thus, the results indicate that forthcoming VE research and practice should embrace a more cohesive and integrative method. Specifically, the pronounced marginalization of social, governance, and site-level factors signifies a critical misalignment between current VE research and established theoretical discussions on urban densification strategies, multi-scalar governance, and equitable housing transformation. Building-level feasibility will consistently be a necessity; nevertheless, it must be supplemented by site-sensitive urban planning considerations and design approaches that improve usability, aesthetics, and sustainability.

The novelty of this study lies in providing a multi-level clustering framework that not only synthesizes and maps the distribution of suitability factors but also critically interprets biases and gaps in the literature. The analysis moves beyond simple frequency reporting by synthesizing these patterns to identify systemic theoretical imbalances and functional interdependencies inherent in the existing literature, thereby setting a critical agenda for future VE research. While our analysis is based solely on literature review, it establishes a transparent and reproducible foundation. Future work should validate these findings through empirical case studies and multi-criteria decision-making frameworks, enabling more holistic and practice-oriented assessments of VE feasibility.

The factor hierarchy identified in this study could serve as a multi-layered inventory for researchers, practitioners, and policymakers, ensuring that feasibility assessments are not restricted to structural and economic calculations but also include contextual and long-term factors. This inventory specifically provides the foundational variables and hierarchical structure necessary for the development of multi-criteria decision-support systems, urban simulation tools, and robust spatial feasibility models. For instance, site-related characteristics, including zoning flexibility, accessibility for construction equipment, and proximity to public infrastructure, which are frequently

regarded as external constraints, could be incorporated into project planning as active design parameters at the outset.

Moreover, in order to establish the foundation for smaller- or building-scale analyses in cities, it may be necessary to conduct more frequent larger-scale suitability/feasibility studies (e.g., urban scale). By actively addressing these contextual factors and establishing the requisite foundations, practitioners can identify possibilities to optimize approval processes, mitigate logistical challenges, and synchronize VE interventions with overarching urban development objectives, thus converting possible challenges into strategic advantages that improve project viability and public endorsement.

From a research perspective, the findings emphasize the necessity for comprehensive multi-criteria decision-making models that extend beyond quantitative analysis to include expert involvement, stakeholder preferences, and case-based validation across diverse scales. This will facilitate the alignment of technical feasibility with holistic value creation in VE projects.

#### 4. Conclusions

Existing literature was synthesized in this study to identify and analyze the primary factors that influence the suitability of vertical extension in buildings. Through a thematic classification of these factors, their alignment across the three levels of suitability (site, building, and design), and an analysis of their regional and temporal patterns, we have offered a systematic knowledge of the multidimensional considerations involved in VE implementation.

Collectively, the identified trends reveal that existing research on VE is heavily concentrated on the technical and structural dimensions, as issues like load-bearing capacity, material performance, and construction feasibility are well-documented and dominate the scholarly discourse. In contrast, the softer and more qualitative dimensions, such as community participation, societal acceptance, and multi-level governance, remain underdeveloped and often treated as peripheral considerations. This imbalance suggests that while VE is now well understood as an engineering possibility, it is still insufficiently explored as a social and urban practice. The lack of attention to participatory processes, human-scale design, and policy coordination limits the capacity of VE to evolve from an isolated architectural solution into a truly integrative strategy for sustainable urban transformation.

Furthermore, the study reveals that site-level factors are disproportionately overlooked, implying a recurring assumption that VE operates within

uniform urban contexts. In reality, every city, and indeed every neighborhood, presents unique morphological, infrastructural, and cultural conditions that profoundly shape the success or failure of upward extensions. The omission of these contextual variables constrains the adaptability and transferability of VE strategies, particularly in cities with varying regulatory maturity, heritage sensitivities, or infrastructural limitations. Recognizing and incorporating this local heterogeneity is therefore essential if VE is to become a practical and equitable component of urban densification policies.

Ultimately, the study underscores that the future of VE depends on a more comprehensive and human-centered paradigm; one that aligns engineering reliability with socio-spatial awareness, policy integration, and community engagement. Advancing VE as a viable urban strategy, therefore, requires collaboration across disciplines and scales, bridging the technical with the societal, and the measurable with the experiential. By reframing VE as both a technological innovation and a collective urban project, this research invites a shift from feasibility-focused analysis toward more contextually sensitive and socially attuned pathways for vertical urban growth.

The unique contribution of this study is the development of a conceptually grounded multi-level clustering framework. Rather than functioning solely as a static inventory, this framework functionally deconstructs the complexity of VE implementation, identifying the precise intersections where technical feasibility diverges from urban reality. By classifying factors into site, building, and design hierarchies, the study provides the ontological structure necessary for future scholars to move from descriptive case studies to explanatory theoretical models. This taxonomy bridges the gap between isolated engineering studies and the broader theoretical discourse on sustainable urban densification.

Although the analysis relied on literature without direct empirical validation, it provided a reproducible foundation for subsequent studies. Future research should combine literature-based insights with external validation through case studies and multi-criteria decision models to ensure robust and applicable outcomes. Also, given the global scope of the review and the extensive range of factors examined, it was not feasible to explore each individual factor or national context in depth. Instead, the analysis focused on cross-cutting trends and research gaps observable across the literature, acknowledging the value of detailed analysis of factors and related contexts for future research.

This study followed the PRISMA protocol and is therefore limited to literature-based evidence. While no external empirical validation was conducted – consistent with the objectives of a systematic review –

methodological validity was ensured through multi-database searches, clearly defined inclusion/exclusion criteria, and inter-coder consistency checks during the coding process. Future research is encouraged to empirically test and refine the developed suitability framework through case studies, expert validation, and quantitative assessment of real VE projects.

Additionally, while this study is effective in identifying trends and gaps, and provides a novel factor taxonomy, it does not evaluate the relative importance or interdependence of the factors, as it is based on a frequency-based literature review. Therefore, forthcoming research is required to construct a formal logic framework or causal network model to investigate the complex interdependencies between factors, such as the impact of regulatory frameworks on economic feasibility and the impact of structural constraints on design solutions. Furthermore, it is recommended that future study quantitatively assesses the relative weight or effect of various suitability parameters using realistic case studies or multi-criteria decision analysis. The scope and availability of extant studies, which may differ in regional focus, methodology, and profundity, also constrain our analysis. Also, the qualitative character of certain factors presents difficulties in terms of consistent categorization and comparison across various studies. Despite these constraints, this investigation offers valuable insights that can be used as a reference by urban planners, engineers, researchers, and policymakers to evaluate the VE suitability in particular contexts, thereby facilitating more informed decision-making during the initial phases of project evaluation and planning.

### Author contributions

*Mohsen Sanei*: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. *Mina Khodadad*: Formal analysis, Investigation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. *Hüseyin Emre Iğın*: Writing – review & editing. *Shady Attia*: Writing – review & editing. *Agatino Rizzo*: Writing – review & editing, Project administration. *Kevin Lau*: Writing – review & editing, Project administration, Supervision.

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### Data availability statement

The data that support the findings of this study are available from the corresponding author, [MS], upon reasonable request.

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