Vertical Extensions: Stakeholder Perspectives on Development Decisions and Construction Strategies

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Abstract: A vertical extension (VE) involves the construction of additional floor space on top of an existing base building. With growing urban populations and an urgency to reduce building-related carbon emissions, VEs might have the potential to be a sustainable and innovative solution to overcome the shortage of urban spaces. However, despite the growing number of projects and the emerging academic literature, limited research has documented the decisions that inform the development of VE projects or the lessons learned from stakeholders that were involved in their creation. This paper presents the early decision-making processes that are undertaken to select a VE as an appropriate development type to construct in practice, and the common challenges and solutions during its realization, through semistructured interviews with a broad range of stakeholders, including developers, contractors, architects, and structural engineers that have been involved in recently completed VE projects. The results identify that the main driver of VEs is economic profit, followed by sustainability goals and the desire to stay on the same site. The challenges are related to the complex design and coordination of VE projects, and onsite construction challenges. In addition, this paper identifies the diverse structural support and reinforcement strategies that are used in VEs and contributes to the knowledge by capturing the different aesthetic and construction approaches that are used in practice. **DOI:** 10.1061/JAEIED.AEENG-1474. *© 2023 American Society of Civil Engineers.*

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Introduction

The increase in the world's urban population has contributed to the shortage of space in many cities. As the world's population is predicted to reach 9.8 billion by 2050, the percentage of the urban population is estimated to reach 60% and 68% in 2030 and 2050, respectively, which is an increase from 55% (UN 2019). An additional 230 billion m^2 of floor area might be required to satisfy future space demand by 2060 (Ness 2020; Schmidt et al. 2020). Urban sprawl has contributed to measurable negative impacts, socially and environmentally (Burchell et al. 1998; Newman and Kenworthy 2015), with urban densification promoted as a more sustainable model (UN 2017), which could preserve green areas, minimize costs, energy, and greenhouse gas emissions (Fatone et al. 2012; Hernandez-Palacio 2014; Neuman 2005; Oldfield 2019; Resch et al. 2016), and improve social satisfaction and physical health (Mouratidis 2019; Stevenson et al. 2016). However, the construction of additional floor space in urban areas can be challenging due to the scarcity of undeveloped sites and the complexities that are related to brownfield redevelopment (Cappai et al. 2019; Dulić and Krklješ 2014).

At the same time, the whole lifecycle carbon of buildings needs to be reduced (which includes embodied and operational emissions). Reducing building emissions is crucial to meet global climate targets (IEA and UNEP 2019) since the construction industry accounts for 37% of energy and process-related carbon emissions (UNEP 2021). With increasing energy efficiency in the built environment and the decarbonization of electricity supplies, embodied carbon becomes more significant (Ness 2020; Robati et al. 2021; Schmidt et al. 2020). It could account for 27%–58% of whole lifecycle emissions in newly constructed buildings (Robati et al. 2021) and even more in highly energy-efficient buildings (Chastas et al. 2016). Therefore, there is a considerable focus in the built environment on strategies to reduce embodied emissions, such as the use of low carbon and biomaterials, adaptive reuse, and the retrofit of existing buildings (Kumari et al. 2020; Mishra et al. 2022; Pomponi and Moncaster 2016; Robati and Oldfield 2022).

Based on this, vertical extensions (VEs) are emerging as a new type, where additional space is constructed on top of an existing base building to respond to increasing space demand in dense urban areas. Defined as building additional stories over an existing building (Amer et al. 2017; Floerke et al. 2014; Hermens et al. 2014), VEs are known as *aufstockung* in Germany (Eliason 2014; Floerke et al. 2014), vertical expansion (Jellen and Memari 2018), roof stacking (Amer et al. 2019; Amer and Attia 2019; Amer et al. 2017), rooftop extension (Aparicio-Gonzalez et al. 2020; Wijnants et al. 2019), and upward extension (Morris 2021). In Europe, VEs have been constructed for generations (Eliason 2014), some as early as the late eighteenth (González-Redondo 2022) or mid-nineteenth century (Artés et al. 2017) as many industrialized cities began to lack vacant sites. However, the trend has gained momentum in the last two decades (Horsley 2008; Inertia 2017). Similarly, academic studies on this topic are mostly available from 2000 onward. Fig. 1 shows two examples of VE projects: (1) De Karel Doorman

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Fig. 1. (a and b) De Karel Doorman in Rotterdam; and (c and d) Blue Cross Blue Shield in Chicago. [Images courtesy of (a) © Ibelings van Tilburg architecten, Marc Ibelings; (b) © Ibelings van Tilburg architecten, Ossip van Duivenbode; (c) © Marshall Gerometta for Goettsch Partners; and (d) © James Steinkamp Photography for Goettsch Partners.]

in Rotterdam, where 16 stories were built on top of an existing shopping center; and (2) the Blue Cross Blue Shield in Chicago, in which 24 stories were added on top of a 30-story building. In this latter case, the VE was part of the initial design; however, the additional floors were built 13 years later (which is termed a *planned VE*).

VEs provide a potential solution to the challenges outlined previously. The literature has suggested that VEs could create additional floor space in dense urban areas without requiring an empty site, therefore, supporting urban densification when preserving green areas (Amer et al. 2017; Eliason 2014; Hermens et al. 2014). By avoiding the demolition of existing buildings, VEs could preserve resources and the historical characteristics of cities (Eliason 2014; Jellen and Memari 2014). In addition, they could improve the performance of their base buildings since income from new floor areas could finance the refurbishment of the floors below (Lešnik et al. 2020; Soikkeli 2016). Environmental performance improvements at the building scale have been studied (Artés et al. 2017; Dind et al. 2018), as well as energy savings after VE implementation on a neighborhood scale (Aparicio-Gonzalez et al. 2020).

Several opportunities for VEs have been identified. One of the most significant suggestions was extra structural capacity in existing buildings to support the weight of additional stories (Jellen and Memari 2014; Thornton et al. 1991). Further opportunities are unused development rights and changes in building regulations over time. If a building has unused air rights, this can be developed or transferred to an adjacent plot (Jellen and Memari 2014), with developers using this to realize VE projects (Hevesi 1999; Kussin 2016).

Despite studies on the benefits and prospects of VEs, there remain unanswered questions related to the drivers and decision-making processes that inform why VEs are chosen as a building solution. Most existing research on VEs is set within the European context and frames the sustainable potential of VEs to improve existing buildings and support urban densification (Aparicio-Gonzalez et al. 2020; Artés et al. 2017; Dind et al. 2018; Hermens et al. 2014; Soikkeli 2016). Others discuss procedures related to VEs, including a methodology to assess the potential of VE for urban densification (Amer et al. 2017), a decision-making framework to select offsite construction for VE (Amer et al. 2019), and a feasibility analysis for VE with modular construction (Jellen and Memari 2014, 2018). However, there is limited research that documents the empirical early decision-making processes that influence the selection of VEs drawn from the experience of practitioners that are involved in their realization. This is the first gap addressed in this research. Understanding the decision-making processes undertaken in the early stages of building development is vital, as these often have the most significant impact on building cost and carbon reduction potential (WorldGBC 2019; Østergård et al. 2016).

A further research gap relates to the challenges and solutions implemented in built VE projects. For the challenges, the existing literature highlights that understanding the base buildings' condition and structural capacity is crucial (Artés et al. 2017; Jellen and Memari 2018; Norell et al. 2020). Some gray literature (i.e., newspaper articles) noted that some VE projects in New York provoked controversy and objections from occupants, neighbors, and the community due to the direct construction impacts and visual appearance (Hevesi 1999; Horsley 2008; Kussin 2016). However, a comprehensive understanding of the challenges faced in the realization of VE across planning, design, and construction is lacking. For VE solutions, advanced construction techniques and logistic planning have been promoted to solve inherent construction complexities (Dow 2017; Logan 2019), with the use of offsite construction and lightweight solutions repeatedly highlighted (Bergsten 2005; Dind et al. 2018; Hermens et al. 2014; Jellen and Memari 2018; Soikkeli 2016). In addition, construction methods and structural strategies for VEs have been studied and classified (Amer et al. 2019; Hermens et al. 2014). These show a series of technical approaches for VEs; however, an understanding of both the architectural and technical approaches to a VE based on multiple projects is limited. Most studies either focused on one technical aspect (i.e., the construction method) or drew findings from a single project.

Primary knowledge about VEs from stakeholders is valuable to address the previous research gaps. Some studies have used interviews with VE stakeholders (Amer et al. 2019; Amer and Attia 2019; Bergsten 2005; Norell et al. 2020; Sundling 2019), but most are limited to building engineers and architects in the European context. For instance, Norell et al. (2020) interviewed architects that were involved in eight VE projects in Sweden,

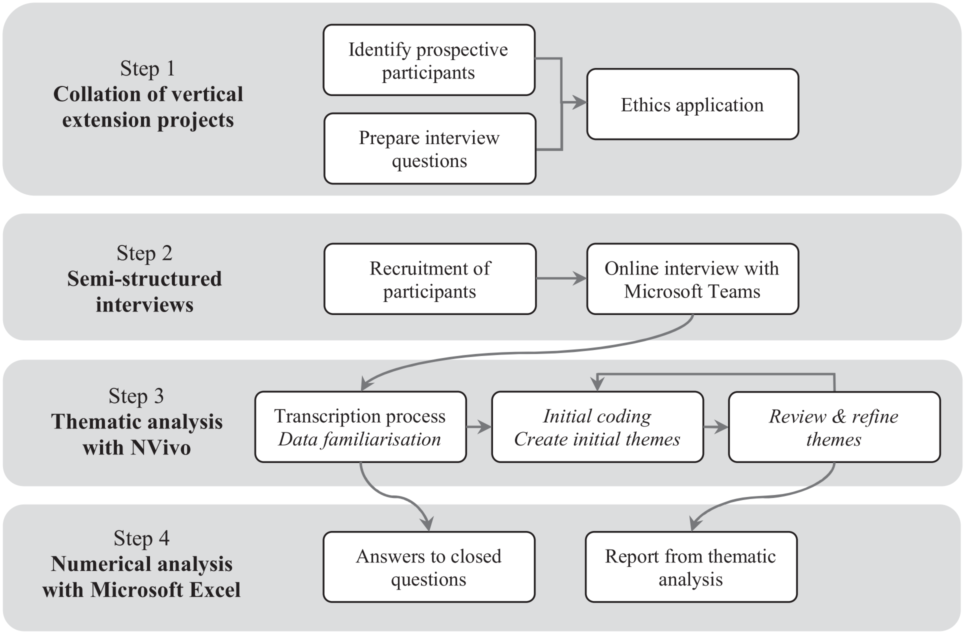

Fig. 2. Research methodology and procedures.

with a particular focus on the interface between the base building and the VE. Knowledge from architects and engineers is important since they play key roles in the design of VEs. However, to the best of the authors' knowledge, no research has interviewed a broad range of stakeholders including developers and contractors, who play an integral role in the early decision-making on whether to proceed with a VE and resolve the construction challenges faced during development.

This paper will address the previous research gaps by gaining insight from a broader array of VE stakeholders than the current literature, including those who drive much of the early decision-making and VE realization (developers, architects, engineers, and contractors), and from wider contexts allowing knowledge to be drawn from projects worldwide that include Europe, the US, and Australia. Therefore, the following research questions (RQs) are answered:

1. What are the drivers and decision-making processes that inform the development of VEs?
2. What are the architectural and technical challenges, and solutions of VEs in practice?

For the first RQ, this paper identifies an empirical decision-making process that is based on real VE projects with influential procedures and activities that are used to inform the decision as to whether to proceed with a VE or not. This includes identifying stakeholders' perceptions of VE benefits compared with conventional development options as a valuable insight for future project decision-making. For the second question, this paper presents lessons learned from real projects on the challenges to be expected in VE realization alongside the architectural and technical solutions that have been applied. Decision-making in the design and construction of buildings is complex, with multiple stakeholders engaged with a large number of interacting issues and priorities. Because decision-makers in the industry tend to follow established concepts from previous projects (Criado-Perez et al. 2020), this research could provide value for future design teams that are pursuing potential VE projects by defining established decision-making processes and identifying real-life challenges and solutions in the realization of VEs in practice.

Research Methodology

Semistructured interviews with open and closed questions and purposive sampling were utilized in this paper. Interviews are a powerful tool when deriving new knowledge from experts (Gillham 2000; Given 2008; Opoku et al. 2016). The data collected was analyzed qualitatively and quantitatively. Thematic analysis was utilized to analyze qualitative interview responses by identifying, organizing, and reporting patterns and themes (Braun and Clarke 2006; King and Brooks 2018; Nowell et al. 2017). Numerical analysis was used for closed questions and to complement the thematic analysis by providing a degree of magnitude in the results and data to support the potential replicability of this paper (Maxwell 2010). The complete methodology and procedures are shown in Fig. 2.

First, completed and ongoing VE projects located worldwide were collated. In total, 50 projects were identified, which were then reduced to 31 projects that were completed in the last 15 years to ensure that the stakeholders had a reasonable level of recollection of the projects and the decisions undertaken that informed them. Developers, architects, structural engineers, and contractors that were involved in these projects were identified as prospective participants. The interview questions were designed to answer the specific RQs in this paper (Table 1).

- For RQ 1, there were two open questions (Questions 1 and 2) and two closed questions (Questions 6 and 7 with yes or no answers). The closed questions were designed to capture interviewees' reflections (after project completion) on the VE benefits compared with conventional development options.
- For RQ 2, three open questions were related to the challenges faced and solutions developed when realizing VEs (Questions 3–5).

Ethics approval for this research was granted by the University of New South Wales (UNSW) Human Research Ethics Advisory Panel E: Built Environment (ethics application number: HC200904) in December 2020.

During data collection, semistructured interviews were undertaken. From the 31 projects that were screened, 68 stakeholders were identified and invited to take part in the interviews. The

Table 1. Interview guiding questions that corresponded to the RQs

RQs	Interview guiding questions
RQ1: Drivers and decision-making process that informed VE development	Q1. Decision-making processes of why VE was chosen (open question) Q2. Feasibility studies in deciding VE (open question) Q6. Comparing VE with building on the ground [closed question (yes or no)] Q7. Comparing VE with demolish and rebuild [closed question (yes or no)]
RQ2: Challenges and solutions in VE realization	Q3. Challenges faced (open question) Q4. Strategies at design stage (open question) Q5. Strategies at construction stage (open question)

Note: Full interview questions are available in Appendix S1.

Table 2. Profile of interviewees

Location	Architects	Developers	Structural engineers	Contractors	Total
Australia	3	2	3	3	11
Europe	6	1	3	0	10
US	4	1	2	2	9
Total	13	4	8	5	30

selection of participants was driven by the desire to include developers and contractors that were central to key decisions on building development and realization, and the availability of stakeholders to conduct an interview. Online interviews with Microsoft Teams were performed with 30 stakeholders that agreed to participate, as outlined in Table 2. These interviews relate to 18 distinct VE projects (Table 3).

The final stage was data analysis. For open questions, thematic analysis with NVivo was utilized to analyze and synthesize the data collected. The analysis process flowed from data familiarization, initial coding, generating initial themes, developing and reviewing themes, refining themes, and writing the report (Braun and Clarke 2006, 2021; Nowell et al. 2017). The thematic analysis could be inductive or deductive. In this paper, the initial coding process was mostly inductive (bottom-up), which allowed themes to emerge from the data (data-driven) without a predefined coding frame (Braun and Clarke 2006). First, interview recordings were transcribed by the researchers, reread, and some notes were taken as part of data familiarization. For each RQ, the interview transcripts were highlighted during the initial coding process and grouped to create initial themes. These themes were grouped, reviewed, and refined to answer the RQs. Table 4 lists some examples of the coding process. To understand the degree of magnitude of the themes, numerical data were included in the results in terms of the numbers or percentages of interviewees who mentioned specific responses or the number of projects a particular solution was utilized in. For the closed questions, interviewees' responses were analyzed directly in an Excel spreadsheet.

Results

Decision-Making Processes

Through thematic analysis, a pattern of common decision-making processes that interviewees undertook to proceed with a VE was developed (Fig. 3). Apart from the drivers (i.e., motivations behind the decision to choose a VE), direct pressures, which were conditions or problems that had to be met or anticipated during project development, were identified as additional factors that informed the decision-making. By considering the drivers, pressures faced, or both, the developers or owners investigated opportunities for VE. Then, with the assistance of technical experts, a feasibility study was performed. In the feasibility study, a VE concept was developed based on studies or due diligence and compared with other development options for their potential benefits. When these

Table 3. List of VE projects interviewees were involved in

	Base building			VE			
Project location	Year built	Number of stories	Function	Year built	Number of stories	Function	VE planned/unplanned[a]
Australia							
Sydney	1939	8	industrial	2014	3	office	unplanned
Melbourne	1989	7	office	2019	10	hotel	planned
Melbourne	1967	4	retail	2019	5	office	unplanned
Sydney	1930	6	industrial	2020	7	office	unplanned
Brisbane	1980s	20	office	2021	7 ($1D$)[b]	office	unplanned
Europe							
Rotterdam	19th century	3	house and office	2006	1	house	unplanned
Rotterdam	1951	5	retail	2015	16 ($2D$)[b]	apartment	unplanned
Berlin	1987	4-6	school	2019	1–2	school	unplanned
Hammarby Sjostad	1929	4	office	2019	5 ($1D$)[b]	office	unplanned
Stockholm	1901	5	office	2020	3 ($1D$)[b]	office	unplanned
London	1930s	3	school	2016	1	school	unplanned
London	1998	9	office	2021	3 ($2D$)[b]	office	unplanned
US							
Seattle	1904	3	industrial	2006	1	office	unplanned
Chicago	1997	30	office	2010	24	office	planned
Missouri	1986	2	hospital	2016	3	hospital	planned
New York	1857	5	office	2016	2	apartment	unplanned
New York	1926	3	office	2017	3 ($1D$)[b]	apartment	unplanned
New York	19th century	4	school	2018	2 ($1D$)[b]	sport	unplanned

[a] Planned or unplanned denotes whether the VE was planned as part of the initial building design (planned) or not (unplanned).

[b] x (yD) = y stories were demolished when an x-story VE was built.

Table 4. Examples of coding cycles

RQs	Interview topics	Coding cycle	Examples of codes identified
1. What are the drivers and decision-making processes that inform the development of VEs?	Drivers	First cycle: identify initial codes (inductive)	*Commercial profit, best return on investment, base building can't be demolished, reducing energy and emissions, urban densification, no other option to extend, and limited space in site* were highlighted as motivations behind VEs
		Second cycle: collating codes into themes	*Economic profit, heritage preservation, sustainability, and limited site space for extension* were defined as themes (first level codes)
		Third cycle: grouping, reviewing, refining themes	*Drivers and pressures* were defined as parent themes (first level codes) *Economic profit, heritage preservation, sustainability, and limited site space for extension* were defined as subthemes (second level codes)
2. What are the architectural and technical challenges and solutions of VEs in practice?	Challenges faced	First cycle: identify initial codes (inductive)	*Satisfy current building requirements, restricted construction site, minimize disruptions to the occupants, adapt the old building, poor structural integrity of the base building, and short floor-to-floor height in the base building* were highlighted as some challenges in VE realization
		Second cycle: collating codes into themes	*Building and service requirements compliance, logistics, minimize disruptions, and unfavorable condition of the base building* were defined as themes (first level codes)
		Third cycle: grouping, reviewing, and refining themes	*Design and coordination challenges, construction challenges, and base building challenges* were defined as parent themes (first level codes) *Building and service requirements compliance, logistics, minimize disruptions, and unfavorable condition of the base building* were defined as subthemes (second level codes)

Note: Final results of the thematic analysis and their numerical counts are available in Appendix S2.

benefits met the drivers and direct pressures, the VE could be considered as a feasible or best solution.

This pattern of decision-making was utilized in most of the VE projects that were included in this paper. For three projects with planned VEs (out of 18 projects), this process was repeated twice as: (1) an initial decision and feasibility study; and (2) a decision-making process and feasibility study when the VE was about to be constructed, which was often many years later. This is explained in more detail in the section "Feasibility Studies."

Drivers and Pressures

Economic profit was the main driver of VEs, as identified by 28 interviewees (93%), followed by sustainability goals [identified by eight interviewees (27%)], and a desire to stay on the same site [six interviewees (20%)]. The two direct pressures that encouraged VEs to be chosen were heritage preservation of the base building, and limited space onsite for conventional extensions, as noted by nine (30%) and eight (27%) interviewees, respectively.

Of the 18 projects the interviewees were involved with, 14 (78%) were commercial; therefore, economic profit was the main driver. However, in some cases, heritage preservation or limited space onsite became an inevitable pressure that had a significant influence. A contractor stated, "It could go higher, but couldn't be demolished. So, they had to find the balance between maintaining the heritage building and getting a few more floors in to make it commercially viable." An architect noted, "Because Manhattan is so heavily built, unless you have free land or you demolish existing buildings, you cannot expand anything."

For the four noncommercial projects, the common driver was different and was informed mainly by the desire to stay onsite. For the VE of a private house and office, the architect revealed, "They needed more private space, but also their business, which was in the same building, was growing. People would often move to the edge of the city or to the suburbs where there's more space. But they did not want to move, because they were very attached to the building and the city." The main driver of a school VE project was keeping the students together on the same site. In addition, sustainability and economics were considered, as stated by the architect, "There is no real need to demolish to make space for a new building, it was just not a sustainable way to go and not a cost-effective way to go."

Opportunities

The decisions to build a VE were often influenced by opportunities that were provided by the site and base building.

Opportunities Offered by the Base Building [Noted by 28 Interviewees (93%)]. The structural capacity to support additional floors on top of an existing base building was crucial in most cases [noted by 23 interviewees (77%)]. This could be either an excess capacity from the existing structure [$n = 17$ (57%)], a capacity that was purposely planned in the initial design of the base building (i.e., planned VE projects) [$n = 8$ (27%)], or due to the generally good condition of the existing structure [$n = 4$ (13%)]. Interviewees noted that excess capacity in an existing structure (of the base building) was found to be mostly caused by:

1. An oversized structure of an older building with a conventional structural design [$n = 14$ (47%)].
2. Higher design loadings of the original building function compared with the redeveloped function, which provided additional capacity [$n = 4$ (13%)].
3. The use of uniform component sizes in the base building meant the perimeter components were effectively oversized [$n = 2$ (7%)].

A developer shared, "There's often a structural capacity in those buildings, and that's generally a product of better modeling with modern technology that structural engineers can do now, which

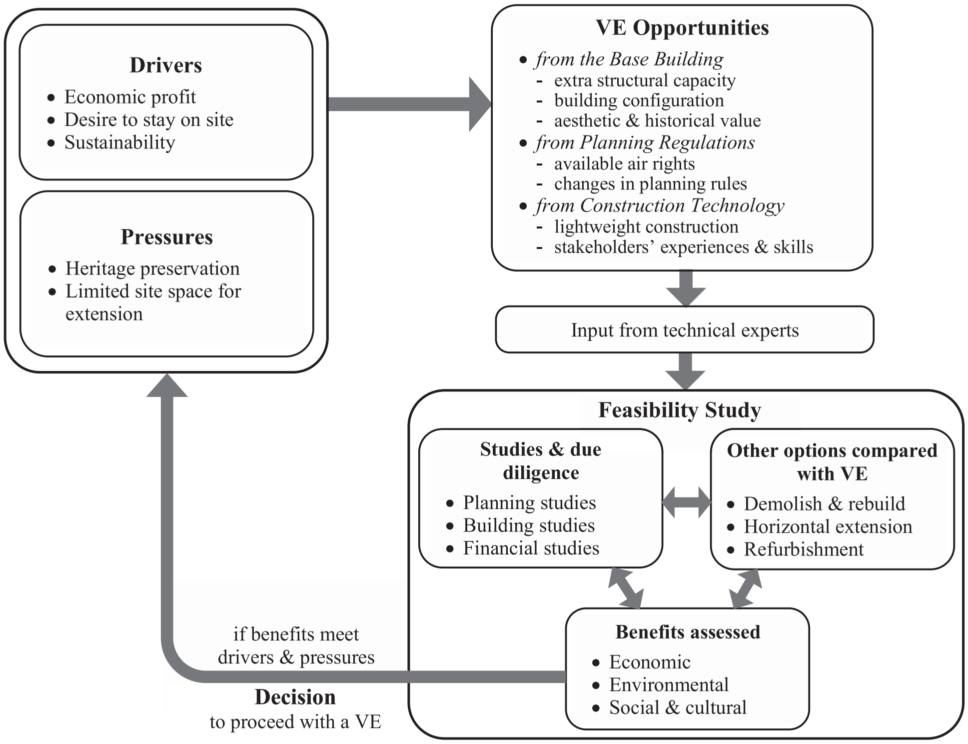

Fig. 3. Decision making processes in selecting a VE as a development strategy. Note: Numerical evidence is provided in Appendix S2.

means that they can often justify squeezing an extra bit of height on top." A structural engineer revealed, "Some buildings in London are Georgian or Victorian buildings, and originally, they were warehouses, so the floor loadings were very generous. Hence, they have a residual capacity that allows VEs, especially where there is a change of use." Another engineer disclosed, "The columns around the perimeter were the same size as the columns internally. So, although the columns internally were pushed to capacity, the ones around the perimeter had a fair bit of capacity still left in them."

Beyond this, base building configurations were identified as opportunities that informed VE development [16 interviewees (53%)]. Factors included the spatial arrangement of base buildings [$n = 12$ (40%)], buildings with flat roofs [$n = 5$ (17%)], and adequate floor-to-floor heights [$n = 2$ (7%)]. Base building value was another opportunity for VEs [noted by eight interviewees (27%)], either the aesthetic quality of the building [$n = 5$ (17%)] or the historical value that made the building preservation important [$n = 5$ (17%)].

Opportunities Offered by Planning Regulations [Noted by 10 Interviewees (33%)]. Planning opportunities for VEs included available air rights and changes to local planning rules. For example, an architect shared, "Under the latest zoning regulations, a lot of older buildings haven't built out all the available area that they are allowed to build, so they have leftover floor area or air rights that they can build on top of."

Construction Technology Opportunities [Noted by 10 Interviewees (33%)]. Advanced construction technology, knowledge, and skills provided an opportunity for VEs. An architect shared the use of lightweight materials "If we make a light building, five times as light as a concrete building with bricks, we can build it on top of the existing structure." While an engineer identified opportunities from the experiences of the people involved in the project, "We had 20–25 years of experience in reusing buildings or road tunnels as a foundation for new buildings. So, we already had the mindset of VE."

Feasibility Studies and Development Options

In most projects, a feasibility study was performed before the decision to proceed with a VE; 27 interviewees suggested this was the case (90%). Several development options were typically compared in the feasibility study. An architect revealed, "There was a series of options that were studied, at least 20 to 30 seriously studied, and that was predominantly going back to the financial feasibility." In total, 13 interviewees (43%) shared that VEs were compared with other options, which included demolish and rebuild, a horizontal extension, and refurbishment alternatives. Interestingly, eight (27%) mentioned that a VE was the only option considered due to restrictions to demolish the base building or since there was no space for a horizontal extension.

Three types of feasibility studies were identified in the interviews.

1. Planning studies [noted by 20 interviewees (67%)] involved analyzing local master plans, planning regulations, and heritage restrictions. These included building shape boundaries (e.g., setbacks, height limit, and site coverage), zoning, land use, and floor space ratio. From these studies, a rough building boundary for VE development could be identified.
2. Building studies (noted by all interviewees) included structural simulation [$n = 30$ (100%)], base building investigation [$n = 26$ (87%)] mainly focusing on existing structural capacity, and architectural conceptual studies [$n = 19$ (63%)]. Structural simulations based on an appraisal of the existing structure were imperative to determine the VE strategies and capacity to be built.
3. Financial studies [noted by 26 interviewees (87%)] were mostly cost and benefit analyses that compared the proposed design

cost with income or profit from the total floor area that was simulated to assess the return on investment.

An important aspect of the feasibility of VEs was the decision on how many floors would be built on top of the base building. This depended on various factors. Planning regulations often limited the height of the building, especially in heritage buildings and conservation areas, which was mentioned by 20 interviewees (67%). An engineer shared, "The building is in a landmark district, so they have extremely tight restrictions on the height and visibility from the street." In addition, structural considerations informed the number of additional floors [noted by 17 interviewees (57%)], with the structural capacity of the base building, the complexity of any necessary structural reinforcement, and lateral load resistance highlighted as key factors. A contractor shared, "It was the maximum that could be gained on the structural capacity, and there were cases where the stability rather than vertical load became the driver." Other determining factors were the floor area obtained [$n = 13$ (43%)], economic considerations [$n = 10$ (33%)], and building or services requirements compliance [$n = 8$ (27%)]. When discussing a planned VE project, the engineer said, "To achieve at least 200 hotel rooms, they needed to have 10 stories." The architect added, "The decision to go with timber was based on the economics, and the fact that the project wouldn't have gone ahead if we only build six levels because the economics wouldn't have made sense."

For planned VE projects, feasibility studies were often performed twice. First, a feasibility study of the base building was undertaken with preplanning for a future VE. Then, several years later, when the VE was about to be built, studies were performed to ensure the feasibility of the extension plan, and sometimes adjustments were made. An architect of a planned VE shared, "There were premiums paid to get the building ready to expand, like stronger foundations, electrical power that can handle the full building. All those things were planned in the early days…." Then, 10 years later, when the extension was about to be built, he confirmed that additional studies were undertaken, "Yes, check the foundations, did they indeed have the capacity and that there hadn't been any unexpected settlements; check the existing structure, because now the columns are going to have a lot more load." In another planned VE, some reinforcements were added, as shared by the contractor, "Originally, it was designed to support the future floors. However, the structural engineer had decided that it was not designed correctly. This resulted in an additional scope… we had to install bracings on four corners of the building."

Benefits of VEs

Economic benefits were the most common benefits that were identified from the interviews [noted by 28 interviewees (93%)]. VEs could add value and finance the refurbishment of their base buildings [$n = 14$ (47%)]. In a dense neighborhood, VEs could create high-rate and marketable space [$n = 10$ (33%)]. In addition, it was suggested that VEs could reduce development costs and time [$n = 15$ (50%)] compared with conventional approaches. A developer disclosed, "If we demolish the building and start it again, we would be behind 18 months. The statutory charges being our rates and land tax run at $10,000 a day. So, not even turning a light on and paying electricity, we're paying just under $4 million a year to hold that site." Compared with a demolish and rebuild, the same developer continued, "It's cheaper, $1,500 per square meter of GBA (gross building area) cheaper, significantly cheaper."

Environmental benefits were suggested by 27 interviewees (90%). By reusing existing buildings and materials, VEs could extend building life and avoid demolition [$n = 24$ (80%)]. Thirteen interviewees (43%) suggested that VEs supported urban densification and helped to preserve green areas; seven (23%) said that they could improve the performance of existing buildings. An architect said, "To demolish the building, all concrete and bricks have to be taken away, 15,000 tonnes of concrete they calculated. Keeping this building here and using it again, that's environmentally very sustainable." Similarly, a developer noted, "Without removing the two most heavy carbon-producing products–steel and concrete, in doing this repurposing and extension, we are 231% more environmental-friendly than a knock-down and rebuild, that equates to 11,000 tonnes of saved carbon."

Social and cultural benefits [noted by 11 interviewees (37%)] were less frequently identified by interviewees; however, it was still suggested that VEs could preserve the historical character of the city or neighborhood [$n = 8$ (27%)] and improve livability [$n = 3$ (10%)].

Comparing VEs with Conventional Developments

The interviewees were asked to compare VEs with two conventional building scenarios (Fig. 4): (1) constructing the same size of the building on the ground (i.e., horizontal extension); and (2) demolish and rebuild the entire building on the same site.

Responses from the two comparisons are shown in Fig. 5. Compared with a building that was constructed on the ground, most interviewees believed that a VE was more sustainable [27 interviewees (90%)]. However, the design process took longer [21 interviewees (70%)], and it was considered more expensive [19 interviewees (63%)]. For the construction process, there were split responses; 17 interviewees (57%) suggested that a VE took longer to construct, and 12 (40%) said the opposite. Compared with a demolish and rebuild approach, almost all interviewees felt that a VE was more sustainable [29 interviewees (97%)], with split responses on the design process (17 considered that it took longer, and 12 said the opposite). In addition, most believed that a VE was quicker to build [$n = 21$ (70%)] and less expensive [$n = 20$ (67%)].

Challenges in VEs

Design and Coordination Challenges

Building or Service Requirements Compliance [Noted by 20 Interviewees (67%)]. When VEs were constructed alongside the refurbishment of their base buildings (as in eight of the 18 projects), adapting the base building to meet current building or service requirements was considered challenging [$n = 13$ (43%)]. Complexity often arose when modern systems were installed in old buildings, which was confirmed by an engineer, "The existing HVAC solution was from the 70s, they were quite small. The new system requires bigger sizes and there would be bigger holes in the structure. A lot of brick walls were meant to be solid, so we had to do a lot of reinforcing."

Designing VEs that maximized space and met current building standards was identified as challenging [$n = 9$ (30%)]. For instance, an increased height of the building or the use of lightweight materials could be an issue for fire regulations. An architect shared, "We had to anticipate fire in terms of the design for final use with cross-laminated timber (CLT), we also had issues of the fire risk during construction…."

For a planned VE, anticipating future building regulations entailed detailed planning and uncertainties. An architect shared, "We had to anticipate building code changes [to accommodate the future VE]. We met with the city, and we agreed that the building would be grandfathered in, and we managed risks to be sure the building could be built in the future."

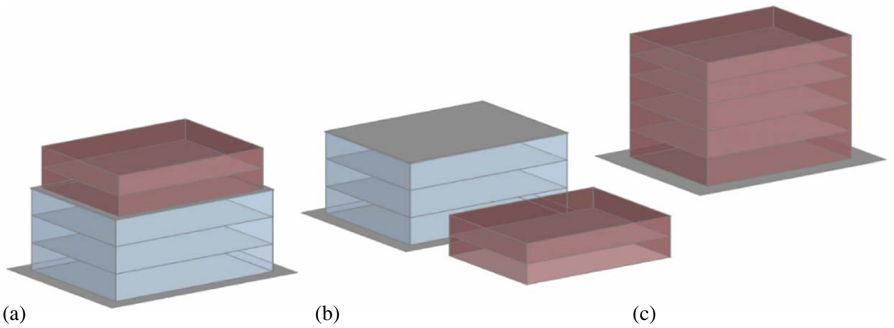

Fig. 4. Comparisons between (a) a VE; with two conventional building scenarios; (b) building on the ground; and (c) demolish and rebuild.

Structural Design Challenges [Noted by 17 Interviewees (57%)]. Choosing an appropriate reinforcement strategy that was related to the conditions of the existing structure was identified as a significant challenge [$n = 12$ (40%)], along with finding the best extension solution and ensuring structural stability [$n = 10$ (33%)]. An engineer noted, "We need to make sure the building had adequate stiffness. The lateral system is always the tricky part, making sure that people are comfortable, and the building drifts are within industry standards." Details on structural strategies used will be discussed in the following sections.

Design Integration or Detailing [Noted by 14 Interviewees (47%)]. In VEs, construction from two eras is combined; therefore, design integration is crucial. "The interface between the new and the existing, assembling a new building that doesn't have the same load path or structural arrangement as the building below is a real challenge," shared an engineer. The architect of a planned VE revealed, "The curtain wall, a company from Canada built Phase 1, but another company did Phase 2, so two different companies, but they had to look like a [single] wall. That was challenging."

Working with Timber and Lightweight Construction [Noted by Eight Interviewees (27%)]. Timber and lightweight construction provided opportunities for VE; however, due to their novelty, they contributed to certain challenges, such as the changing perception of the materials, coordination and accuracy requirements, fire resistance, acoustic, and vibration issues. An architect shared, "We had this vibration problem because we're building so light. The problem can be solved easily if we pour 3–5 cm of concrete on top of the wooden floors, but then we'll have to take off 3–4 floors because it will be too much weight."

Construction Challenges

Construction logistics were identified as a major challenge [noted by 20 interviewees (67%)] due to restricted work zones (since most VEs were built in the central business district (CBD) or

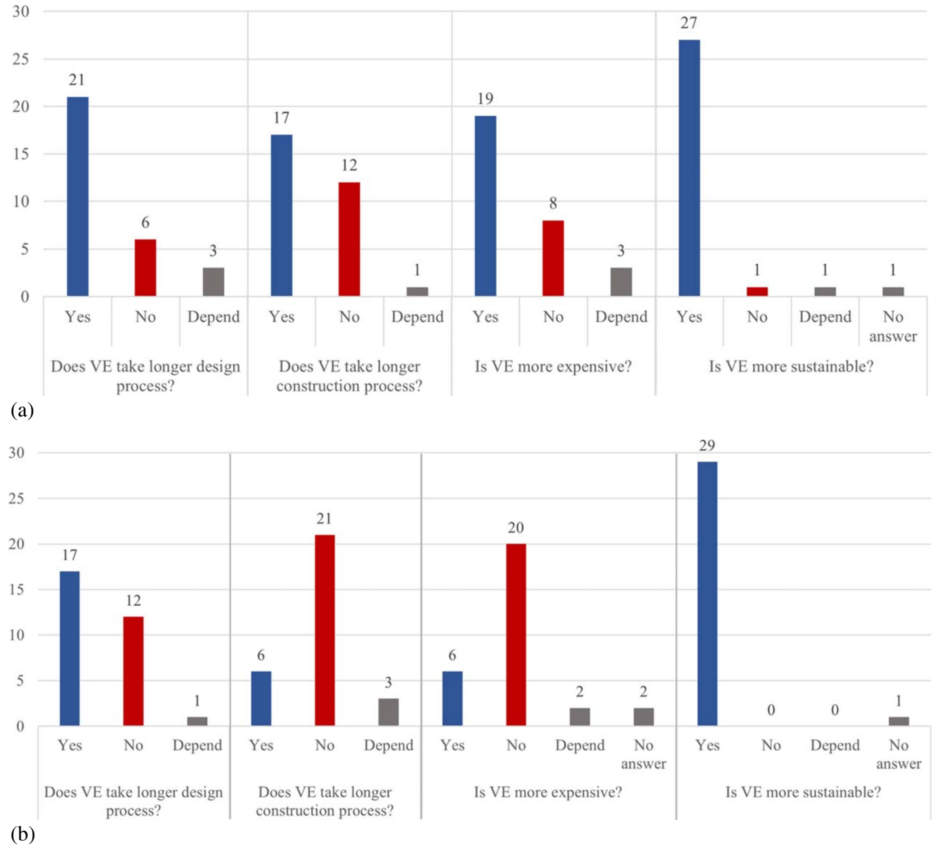

Fig. 5. Interviewees' responses that compared: (a) a VE with building on the ground; and (b) a VE with demolish and rebuild.

dense neighborhoods), difficulties when building on top of other buildings, and the added complexity if the existing structure required strengthening. In addition, minimizing disturbance to the occupants and neighbors was challenging [noted by 17 interviewees (57%)], especially if the base building was occupied. An engineer shared, "There's always a million challenges when your job site starts 500 feet up in the air. You just got to find a way to get the construction workers up, when you've got 4,000 employees working below you." Time constraints and unexpected issues that cause time delay [$n = 13$ (43%)] were other hurdles that were shared in the interviews, alongside the importance of appropriate construction sequences and workflow [$n = 7$ (23%)].

Base Building Challenges

Unfavorable conditions in the base building have caused challenges in VE realization [noted by 17 participants (57%)]. These included structural issues [$n = 14$ (47%)], such as weak, deteriorated, sunk, damaged parts of the building structure or low construction quality. An engineer revealed, "Latent defects in the existing structure that weren't identified during the feasibility process have caused the biggest problem."

Initial investigations [$n = 14$ (47%)] and existing information [$n = 11$ (37%)] were other challenges. Some difficulties were constraints when surveying the existing structure, especially when the base building was occupied, limited information on the base building, and issues in the accuracy and interpretation of the information. "We were missing information because the original drawings were not matching with reality, we had to draw as the building was occupied and not having so much access. Then, once the building was empty, we had access, but the drawings needed to be ready," an architect shared.

Other Challenges

Obtaining approval for VE could be challenging [noted by 17 interviewees (57%)], either official approval from the city council and landmark preservation committee, or support from the neighbors or community, union trades, and people involved. VEs were often considered a novel idea; therefore, ensuring that the right people were on board was vital, and ensuring coordination between various stakeholders [noted by 15 interviewees (50%)]. An engineer commented, "During the construction, one contractor did the reinforcement in the basement, while another company did the renovation and the extension, so there was a lot of coordination required."

VE Solutions

Architectural Strategies

Plan Organization [Discussed by 20 Interviewees (67%)]. Determining an optimum grid arrangement for the new extension floors that satisfied architectural, functional, and structural requirements was crucial. In six of the 18 projects (33%), a different grid was used in the VE due to the specific functional requirements of the extension space, setback consequences, different structural systems employed, or to make the extension lighter. An architect shared, "On the extension, we have a smaller grid for apartments, and hence we can keep the construction light." In comparison, a longer grid was applied to the extension levels in another project, as noted by the engineer, "The existing column grid was too close for a modern form, they wanted more open space. Also, we needed to step the facade in by a couple of meters, so the only logical thing to do was to have a different layout and then transfer it." In 12 projects (67%), the grid of the VE followed that of the base building to simplify the load transfer mechanism. An architect revealed, "We put load-bearing walls and the extension structure following the basic skeleton of the existing building, to make it as efficient as possible and to avoid additional structural work."

Facade and Visual Appearance [Discussed by 23 Interviewees (77%)]. Several different approaches were identified for the visual appearance of VEs compared with the base buildings.

1. A distinct or contrasting appearance between the new and existing was applied in 13 projects (72%), either by designing the VE's facade or form as a contemporary addition, applying a setback, or making the VE invisible to respect a historic base building. An architect shared, "Being a historic building, we needed to let this be what it was and created an architecture of today… We weren't going to mimic this at all, we did study the existing building and drew inspiration from it." Likewise, a contrasting appearance was shared by a contractor, "The additional levels look like a bubble floating above the heritage building, that when you're walking along the footpath, it's not drawing attention away from the heritage, instead it's looking like its own kind of building sitting in the background."
2. For four projects (22%), a similar appearance of the VE was created by adopting characteristics of the base building's facade into the extension. An architect shared, "We wanted a building which was contextually appropriate. We have these horizontal bands in the building that relate to the horizontal bands in the existing…."
3. A unified appearance, in which the extension facade was designed to be the same as the base building, was found in one project with a planned VE. The architect noted, "We wanted them to look the same, the glass and the aluminum colors. So, a lot of time was spent studying materials that would not show their age and would be available in 10 years. The idea was people should not be able to tell where Phase 1 and Phase 2 meet."

Structural Strategies

Structural Support Strategies [Discussed by 29 Interviewees (97%)]. Three strategies to support the weight of the VE were identified (Fig. 6):

1. The existing structure (of the base building) fully supported the VE in six projects (33%) because the structure was either robust and oversized or predesigned (in the case of a planned VE). Therefore, in most cases VEs could be constructed when the base building was occupied.
2. The existing structure supported the VE with additional reinforcement in 11 projects (61%).
3. For one project, an entirely separate structure supported the VE due to the limited capacity of the existing structure and the consideration that the extension could be demolished later without disturbing the heritage building.

For Point 2, several methods were used to strengthen the base building structure. Additional lateral reinforcement was applied in nine projects (50%), because the existing structure was adequate to support additional vertical loads but not for lateral stability. This included adding new structural core or shear walls, strengthening the existing core, or extending it into the extension levels. Other methods were adding steel bracings or strengthening the floor diaphragm. An engineer shared, "A common strategy is to build a new lift core to deal with the lateral loads. In terms of vertical loads, the strategy is to justify strength gain in the existing structure." Reinforcing existing columns or walls was required in nine projects (50%). Methods to strengthen existing columns included increasing column dimensions by carbon wrapping or jacketing with concrete, employing additional steel-plated members, or strengthening

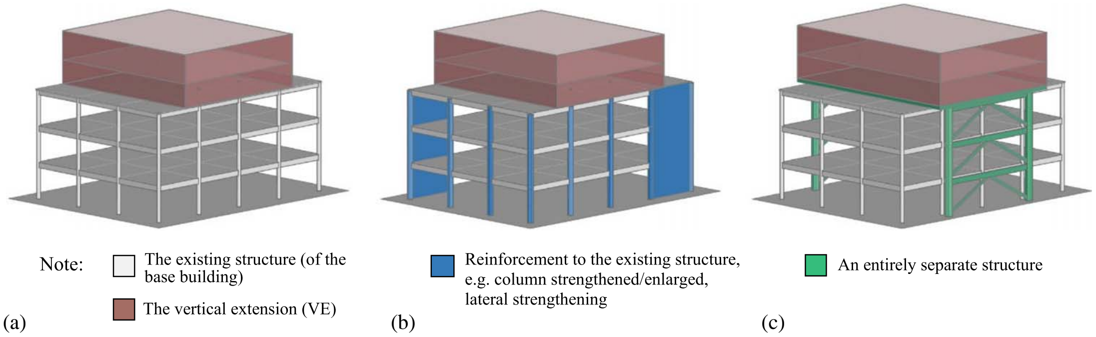

Fig. 6. Three identified structural support strategies for VEs: (a) fully supported by existing structure; (b) supported by existing structure with additional reinforcement; and (c) supported by an entirely separate structure.

connections. In some cases, new columns were built to reinforce the existing structure and existing masonry walls were repaired or strengthened. In addition, foundation reinforcement was necessary for eight projects (44%). Specific strategies included increasing their size, seismic upgrades, building new foundations for new structural components, or replacing unfitted foundations.

Transfer structures were applied in 10 projects (56%) to anticipate different grids, materials, or both between the VE and its base. An engineer revealed, "The structure below is load-bearing walls, and this extension has a pillar structure, so there are beams to take the loads from the new columns and distribute them to the existing structure."

VE Solutions and Materials (Discussed by all Interviewees). To maximize the number of extension floors, lightweight construction was employed in 16 projects (89%). In addition, trade-off or partial demolition was applied in seven projects (39%). An engineer revealed, "What you might do is to allow a trade-off, taking down one floor of heavier construction and then adding on two floors of lighter construction, such like a load trade-off where you can justify the existing foundations."

The optimum selection of structural materials was widely discussed in the interviews. Steel was used in seven projects (39%), timber was used in seven projects (39%), and a combination of steel and timber was used in two projects (11%). The main reason was the lightweight potential of steel and timber to maximize the extension size, constructability and the potential for offsite construction benefits, or cost and time benefits. In addition, timber was considered to have benefits for environmental sustainability and aesthetic appearance. Concrete was only used in two projects (11%). The reasons were that it was considered the most common material and simplest construction method, the same material as the base building, a cheaper price, great strength, and durability. Although concrete is heavier, interviewees said that it was used because it was within the existing structure's capacity.

Building Service Strategies

In eight projects (44%), the VE was constructed simultaneously with the base building's refurbishment; therefore, new services were installed for the whole, as an architect shared, "All new services, the original building was stripped back to just its facades and its structural frame, and everything else is new in there." In 10 projects (56%), the base building was occupied during the construction of the VE; therefore, new services were only installed for the extension levels, either the existing services were retained or partially modified. The modifications varied from replacing a building plant, cooling tower, or water tank with a bigger capacity or more efficient system, removing utilities on the building roof, expanding the existing system, or swapping utility locations. When discussing a planned VE project, the architect revealed, "The existing cooling towers were on top of the existing building. Originally, we thought we would move the cooling towers. But after 10 years, we could buy a more efficient system, so new equipment was put in, and the old towers were dismantled." New core, lifts, and stairs were added in nine projects (50%). In others, the existing core or lift shafts were extended into the extension levels.

Construction Strategies

Two occupancy strategies were identified. In 10 projects (56%), the base buildings were occupied during construction; this occurred when the base building was not being refurbished, when both the extension and base building had the same function or owner, and the required structural changes in the existing structure were minimal. In eight projects (44%), the base buildings were unoccupied due to refurbishment, extensive construction, or both at these levels.

Offsite construction was the preferred construction method for VEs [identified by 22 interviewees (73%)] to overcome onsite logistical challenges and restricted work zones, and reduce construction time and disturbances to the occupants or neighbors when ensuring construction quality. Other strategies that were revealed were propping the base building [noted by seven interviewees (23%)], either to temporarily brace the existing structure when a permanent reinforcement was built, to anticipate a weak existing structure, or to assist with restoration work. VE constructions could be performed in multiple areas simultaneously to speed up the process by utilizing the base building as a platform [noted by two interviewees (7%)]. A developer claimed, "One of the benefits, the existing structure enabled us to work on many fronts, which accelerated the construction program."

Working in occupied contexts escalated the construction complexities. Therefore, specific strategies were used to minimize disruptions [as noted by 15 interviewees (50%)], which included protection works to protect occupants from construction debris [$n = 10$ (33%)], phasing the construction works or carrying out heavy work out-of-hours [$n = 10$ (33%)], and separate access [$n = 8$ (27%)]. Separate access was designed to differentiate workers' circulation with the occupants to minimize interactions, such as designing different entrances or construction hoists to take the workers up from outside. In a planned VE, separate access was provided by preparing space for future elevators through a predesigned atrium in the base building. "We designed an atrium, so that the shafts for the future phase would be just large atriums on day one. So, during construction, they [construction workers] would have separate elevators," noted the architect. In addition, the engineer shared, "They put a cafeteria on the 30th floor, so that people [the workers] didn't need to leave the building to get their meals."

This reduced the energy or the cost of the elevators and prevented the workers' circulation from disturbing the occupants.

Discussion and Conclusions

This paper presented a pattern of decision-making in VE development globally. In addition, it documented the challenges and solutions in VE projects across architectural, planning, economic, constructional, and structural fields. By including developers and contractors in the interviews, a detailed understanding of early development decisions, economic considerations, and studies on VE (i.e., typically led by developers), and construction challenges and solutions (i.e., typically led by contractors) were identified, drawn out and analyzed. Since practitioners tended to be guided by evidence found from previous projects (Criado-Perez et al. 2020), this paper provided a pathway for future design teams that pursue potential VE projects by framing the common decision-making processes and practices that were typically followed to select a VE as an appropriate type in the early development phase, and the frequent challenges that were faced by design teams along with the solutions that overcame these during design and construction. In addition, it could contribute to the academic fields of architectural engineering, construction management, and city planning.

Drivers and Decision-Making Processes that Inform the Development of VEs

The results revealed that economic profit was the main driver in commercial VE projects, which aligned with newspaper articles on this subject (Hevesi 1999; Kussin 2016), but was rarely reported in the research literature. However, remaining on the same site was the main driver for noncommercial projects, which had not previously been identified in existing studies. The existing research highlighted the sustainability potential of VEs; however, in this paper, the findings showed sustainability could be a driver, but it was not the most influential. This could change in the future, considering the vast majority of stakeholders felt that VEs were more sustainable than conventional approaches. Although most interviewees believed that VEs had more benefits compared with demolish and rebuild (Fig. 5); some of them noted that VEs had some limitations compared with building on the ground (e.g., more expensive and longer construction time). However, given the land scarcity in dense urban locations, building on the ground was often not feasible without some level of demolition of existing buildings, which made the VE the only option available to add more floor space. Stakeholder opinions here align with a growing awareness that the demolish and rebuild paradigm that was prevalent in the construction industry was suboptimal for the necessary carbon reductions that are needed to avoid climate change and jeopardized global ambitions of net zero by 2050 (Ness 2020). Instead, growing campaigns were emerging that supported more widespread retrofit and adaptive reuse to reduce embodied carbon and demolition waste (Hurst 2019; WorldGBC 2019), with VEs providing a particularly novel approach where this could be achieved alongside adding floor area and subsequently generating profit.

The extra structural capacity in base buildings, changes in planning regulations, and the application of advanced construction technologies and materials were prevalent opportunities for VEs. Base building configurations, aesthetics, and historical value were unveiled as other opportunities. The interviews suggested that the main reason for excess capacity in existing structures was oversizing in structural design, which was informed by conventional design methods. Reductions in design loading requirements that were due to functional changes and uniform component sizes in base buildings were identified in this paper as additional causes of this excess capacity. Orr et al. (2019) suggested that uniformity in component sizes was due to a culture in structural design that prioritized construction simplicity over structural efficiency, a practice that was criticized for contributing to increased material usage and embodied carbon emissions. However, this uniformity could be harnessed to VE development and subsequently reduce demolition and waste in the future.

Key characteristics and parameters that were used for VE feasibility studies included planning, building, and financial studies. The most references coded in the thematic analysis were on feasibility studies with 379 references. This reinforced the importance of feasibility studies in VE projects, which was identified in the existing literature (Artés et al. 2017; Jellen and Memari 2014, 2018).

Challenges and Solutions in VE Realization

The existing literature noted the challenges that were related to information on the base building and its structural capacity (Jellen and Memari 2018; Norell et al. 2020) and direct construction impacts (Hevesi 1999; Kussin 2016), which were also found in this paper. However, this paper identified the comprehensive challenges in VE realization, which included design and coordination (e.g., building and service requirements compliance and design integration), construction logistics, and unfavorable conditions in the base buildings. Limited strength in existing structures, obtaining accurate drawings, and accessing the base building to investigate the existing structure (especially when the building was occupied) were some barriers to VE identified in the interviews.

A wide range of solutions to overcome these challenges were identified.

- Some gray literature addressed the visual appearance of VEs that was related to heritage preservation (Horsley 2008) and community responses (Hevesi 1999); however, architectural and aesthetic approaches to the realizations of VE remain a gap in the knowledge base. This paper identified three visual appearance strategies that stakeholders could consider: (1) a facade and form of VE to look the same as its base building; (2) to look comparable; and (3) to look distinct or in contrast. In most cases, a distinct architectural approach was followed to provide a visual contrast between the existing and the new.
- Three structural support strategies were identified: (1) a VE that was fully supported by the existing structure; (2) a VE that was supported by the existing structure with some additional reinforcement; and (3) a VE that was supported by an entirely separate structure. These were similar to the structural strategies identified by Hermens et al. (2014). However, the results in this paper provided additional detail about Point 2 and the various methods and approaches used to provide additional reinforcement in practice. This included lateral reinforcement, strengthening columns or walls, and foundation reinforcement. A key finding was that the existing structure could often support additional floors for the vertical loads, but required greater strengthening specifically for lateral stability, which could be achieved by adding, strengthening, or extending the core or shear walls, or adding steel bracings.
- As outlined previously (Amer et al. 2019), steel and timber were the most frequently used structural materials for VEs, due to their lightness and potential for prefabrication. However, concrete was used as the primary structural material in some projects due to its ubiquity.
- The existing literature revealed complaints from occupants and neighbors about the direct construction impacts of VEs

(Hevesi 1999; Kussin 2016). However, this paper identified various construction strategies to minimize disruptions in occupied contexts, which included protection works, adjusting construction time, and separate access.

Limitations and Future Research

Some limitations were acknowledged in this paper. The results could be influenced by selection bias since it was probable that stakeholders who had completed VE projects would believe they were more sustainable than other development options. However, the closed questions presented a diversity in the results for the benefits and disadvantages of VEs, which acknowledged that VEs could be more expensive and often took longer to design than conventional approaches. In addition, there were geographical limitations, with interviewees based on projects in Australia, Europe, and the US due to a lack of data on projects in other regions and language barriers. Therefore, additional drivers, decision-making factors, and VE solutions might be prevalent in other regions and were missed in this paper. This paper provided one of the broadest overviews of VEs by geographical location; however, future studies should be developed to review VE trends across Asia, Africa, and South America. In addition, different locations were influenced by differences in local bylaws, planning policies, and regulatory frameworks. How these impact, promote, or stifle VE construction would be beneficial for future research.

The potential of VEs to meet future space demand sustainably has been widely discussed in the literature (Amer et al. 2017; Aparicio-Gonzalez et al. 2020; Artés et al. 2017; Dind et al. 2018). VEs support building retrofits or adaptive reuse and allow additional floor space to be created in dense urban areas. A body of evidence has documented how retrofits, in general, reduced building whole lifecycle emissions (Adlerstein 2016; Frey et al. 2011; Marique and Rossi 2018; Shirazi and Ashuri 2020); however, there is limited quantitative data that compares the environmental performance of VEs with conventional development approaches, and to what extent VEs could reduce embodied carbon. Therefore, further research here is essential.

Data Availability Statement

Some or all data, models, or codes generated or used during the study are proprietary or confidential and may only be provided with restrictions. The interview transcripts are stored as confidential data in the UNSW cloud system. They cannot be shared with other researchers according to ethics approval granted by UNSW HREAP E: Built Environment (ethics application number: HC200904).

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Supplemental Materials

Appendixes S1 and S2 are available online in the ASCE Library (www.ascelibrary.org).

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