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Drivers, barriers and enablers: construction sector views on vertical extensions

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ABSTRACT

Buildings and construction are responsible for 38% of global greenhouse gas (GHG) emissions, making decarbonisation of the construction sector essential in combatting climate change. Limiting resource consumption and waste generation by transitioning to a circular economy (CE) is key to reducing emissions. The adaptive reuse of existing buildings, such as through their vertical extension, represents one of the most effective ways in which this can be done. Despite this, and although existing work has been completed in surrounding contexts, understanding of factors influencing the uptake of vertical extensions remains limited. Through a survey and follow-up interviews, this paper investigates construction sector professionals' current awareness, uptake and experience of vertical extensions, as well as the key drivers, barriers and enablers affecting implementation. Economic factors are revealed to be the primary driver for extension projects, though case-by-case variability results in commercial risk in some instances. Other barriers include difficulty appraising existing structures, resistance within the construction sector and unfavourable tax regimes. Mandatory whole-life carbon assessments and adjustment of tax regimes are recommended to increase uptake of vertical extensions, as well as enhanced education of engineers and greater consideration of CE amongst stakeholders.

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Built environment; circular economy; embodied carbon; adaptability; reuse; demolition

Introduction

Fulfilling the Paris agreement (United Nations Framework Convention on Climate Change, 2015) requires a drastic reduction in global energy consumption and associated greenhouse gas (GHG) emissions, of which the built environment is responsible for 35% and 38% respectively (United Nations Environment Programme, 2020). This has led to industry-wide declarations of climate emergency (Built Environment Declares, 2021) and increasing recognition of the need to reduce GHG emissions in construction.

The UK has typically focussed on reducing GHG emissions from the operation (e.g. heating, cooling, lighting and ventilation) of buildings. More recently, however, following improvements in operational efficiency and decarbonisation of the electricity grid, the importance of embodied carbon has come to the fore (World Green Building Council, 2019). This comprises emissions from the extraction, manufacture and transport of materials; construction, repair and deconstruction of buildings; and processing and disposal of waste (British Standards Institution, 2012). Embodied carbon currently makes up 18% of the whole life emissions of buildings in the UK, with this expected to grow to 38% by 2030 (UKGBC, 2021). Despite this, and unlike operational emissions, embodied carbon remains unregulated in the UK.

Embodied carbon can be reduced by transition to a circular economy (CE), which minimizes the linear flow of materials by retaining them at their highest level of usefulness, for as long as possible. This includes *slowing* resource flows through product life extension; *narrowing* resource flows through efficient design; and *closing* resource flows through reuse and recycling (Bocken et al., 2016). In the built environment this translates as: the reuse of buildings and their design for longevity, adaptability and deconstructability; the optimization of structures and components; and the specification of reused/reusable and recycled/recyclable materials with maximum recoverability.

Adapting and reusing buildings – rather than demolishing and replacing them – is one of the most effective CE strategies as it ensures a maximum amount of material is retained in its most useful form. Vertical extension refers to the adaptation of an existing building through the addition of new storeys, realizing the embodied carbon savings of building reuse whilst also generating new useable floorspace. In England, the

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opportunities and multiple benefits of vertical extension have been recognized by the introduction of a streamlined permitted development (PD) planning route for certain extension types (HM Government, 2020). Despite this, and notwithstanding the numerous cases seen in the UK to date (Gillott et al., 2022), uptake remains limited (Department for Levelling Up Housing and Communities, 2021). A greater understanding of the key drivers, barriers and enablers influencing the adoption of vertical extension is therefore required.

State of the art

Approaches to understanding factors influencing engagement in sustainable construction practices are varied across existing literature, including theoretical reasoning and first-hand experience (Pattison, 2021; Sundling, 2019), consideration of case-study projects (Gillott et al., 2022; Manewa et al., 2016; Pattison, 2021; Rizos et al., 2015; Rockow et al., 2019), stakeholder consultation (Adams et al., 2017; Du et al., 2014; Giesekam et al., 2016; Giorgi et al., 2022; Kershaw & Simm, 2014; Kirchherr et al., 2018; Manewa et al., 2016; Osmani & O'Reilly, 2009; Ross et al., 2016) and the systematic review of existing work (de Jesus & Mendonça, 2018; Giesekam et al., 2014; Gosling et al., 2013; Hart et al., 2019; Rockow et al., 2019). As the prevalence of influencing factors varies across contexts and stakeholder groups, the influence of subjectivity is present in all of these approaches. Stakeholder consultations attempt to mitigate this by considering the views of a wide range of stakeholders, typically through the employment of a survey (Adams et al., 2017; Du et al., 2014; Giesekam et al., 2016; Kershaw & Simm, 2014; Kirchherr et al., 2018; Ross et al., 2016). This approach also assists in capturing stakeholder perceptions, which can be equally as influential as evidence-based beliefs.

Studies focusing on factors influencing vertical extensions are limited in number and typically narrow in scope, comprising first-hand experiences (Pattison, 2021) and consideration of a small number of real-world (Artés et al., 2017; Gillott et al., 2022; Sundling, 2019; Sundling et al., 2019) or hypothetical (Pattison, 2021) case studies. By neglecting to consider a range of contexts and viewpoints, these studies also have an inherent focus on quantifiable technical factors and omit those rooted in stakeholder perception.

Related work considers more general contexts such as low-carbon design (Giesekam et al., 2014) and CE in construction (Adams et al., 2017; Hart et al., 2019; Kanters, 2020; Rizos et al., 2015), or focuses on adjacent decarbonisation strategies such as adaptable buildings (Gosling et al., 2013; Manewa et al., 2016; Rockow et al., 2019; Rockow et al., 2021; Ross et al., 2016) and low-carbon materials (Giesekam et al., 2016). Given the relevance of the employed methods and resultant findings, a review of this wider body of work is provided alongside extension-specific studies below.

Drivers of vertical extensions

The main drivers of vertical extension identified in the literature are environmental and economic, including carbon and CE benefits, and the ability to maximize refurbishment potential and thus asset value (Gillott et al., 2022; Pattison, 2021). Potential for reduced project costs and programme are also noted (Gillott et al., 2022), as well as the relaxation of planning requirements for some extension types (Gillott et al., 2022; Pattison, 2021).

Applying life cycle profit and carbon analyses to six case studies in Sweden, Sundling et al. (2019) show vertical extensions to have the lowest environmental impact and highest return on investment. The authors also highlight the ability of vertical extensions to finance environmental retrofit and increase the density of urban areas without enlarging their footprint (Sundling et al., 2019). In a subsequent study, the high demand for housing is also suggested to drive vertical extension projects in Sweden (Sundling, 2019).

Barriers to sustainable construction practice

Work by Pattison (2021) considers technical challenges of vertical extensions using first-hand experience and hypothetical case studies. The barriers identified are solely from a structural engineering perspective and include issues associated with increases in design loads; the reuse of foundations; structural appraisals; intrusive investigations; and structural robustness and fire (Pattison, 2021). Through consideration of real-world case studies, Sundling et al. (2019) identify a limited number of non-structural, yet-still-technical barriers to vertical extension, including site constraints (e.g. working at height and disruption to surrounding buildings) and the installation of building services. This work also outlines the need for further research on the barriers and enablers of vertical extensions and acknowledges the inefficacy of case studies in identifying non-technical factors (Sundling et al., 2019).

A systematic review by Giesekam et al. (2014) considers over 1000 publications to identify 30 barriers common across the uptake of low carbon construction technologies, practices and materials. These are categorized as economic, technical and performance-related, institutional and habitual, and knowledge and perception based. A complete summary of the barriers identified by this work can be found in Giesekam et al. (2014). Through a sequential explanatory mixed-methods approach, a subsequent study (Giesekam et al., 2016) aimed to understand the relative significance of these factors in the context of low carbon building materials. This places perceived high costs; a shortage of knowledge and skills; inadequate design time and an inability to establish responsibility among the most pertinent barriers.

Employing a similar mixed methods approach, Adams et al. (2017) identify 26 barriers to the implementation of CE in construction. Comparably to the work of Giesekam et al. (2014), these span three areas of technical concern ('manufacture of construction products', 'designing and operating buildings' and 'recovery of materials and products') as well as 'awareness and understanding', 'business and economics' and 'legislation and policy'. The most importantly viewed challenges are the complexity of buildings, insufficient consideration of their end of life, limited awareness and interest of stakeholders, an unclear financial case and a lack of market mechanisms (Adams et al., 2017). These factors are among the 18 cultural, regulatory, financial and sectoral barriers, identified by Hart et al. (2019) in a review of 21 existing studies. Their work concludes that whilst there are several technical and regulatory challenges to CE in construction, the primary barriers are cultural (e.g. lacking collaboration across supply chains) and financial (e.g. difficulty demonstrating a business case) (Hart et al., 2019). This is consistent with Kanters (2020), who finds the conservativeness of the construction sector to be one of the main barriers to CE at present through a series of semi-structured interviews.

Enablers of sustainable construction practice

In addition to the identified barriers to vertical extension, Sundling (2019) also suggests several high-level enablers. These too are derived from the consideration of real-world case studies and include the presence of reserve structural capacity, stakeholder engagement and collaboration, and early-stage option evaluation. No specific approaches to achieving these enabling conditions are suggested, however, as a result of the limited scope of this work (Sundling, 2019).

Using the same categorizations as for barriers, Adams et al. (2017) identify 15 enablers of CE in construction. These include best practice case studies to clarify the business case and end of life considerations such as material buy-back schemes (Adams et al., 2017). Similar recommendations are amongst the 20 cultural, regulatory, financial and sectoral enablers uncovered (Hart et al. 2019). In response to their identification of cultural and financial barriers, this work concludes that 'technological and regulatory developments alone will not suffice, and a shift is required in business models and stakeholder behaviours and attitudes' (Hart et al., 2019).

Giesekam et al. (2016) reveal that the need for best practice case studies identified by Adams et al. (2017) is also relevant in the context of low-carbon materials. Additionally identified enablers include early engagement of construction professionals; whole-life costing; changes to contract and tender documents; the provision of training and guidance; and unspecified regulatory drivers (Giesekam et al., 2016).

Through a review of existing literature, Gosling et al. (2013) identify key enablers of adaptable building design, categorizing these as either design- (e.g. layering of building elements) or process based (e.g. flexibility of planning practices). Subsequent work by Ross et al. (2016) considers the perceived effectiveness of 11 design-based enablers through a preliminary expert survey. This identifies the most important to be clear and accurate building records; the presence of reserve capacity; separation of buildings into layers and open-plan layouts (Ross et al., 2016). Rockow et al. (2021) compare adaptability strategies from the literature with empirical data from 89 case study projects, concluding that the most important enablers are quality design documentation and simple designs with open floor plans and large floor-to-floor heights.

Aims and objectives

Despite previous consideration of factors influencing the uptake of vertical extensions, and the likely relevance of those for other sustainable construction practices, understanding remains limited. This is a result of extension-specific work being limited in scope, identifying only high-level technical considerations, and because the transferability of factors from other contexts is unknown.

The primary aim of this study is thus to identify the key drivers, barriers and enablers of vertical extension, and how these compare with those of other sustainable construction practices. A greater understanding of the causality, impact and interrelation of influencing factors is also sought, to identify those with greatest potential to enable future uptake. To aid in achieving these aims, stakeholders' awareness of, involvement in and first-hand experiences of vertical extension are also considered.

Methodology

To ensure the capture of perceptions and non-technical factors, a sequential, explanatory mixed methods approach (Creswell, 2018) is adopted. Similar to previous work (Du et al., 2014; Giesekam et al., 2016; Kirchherr et al., 2018), this comprises a survey and semi-structured interviews to consider a wide range of views whilst obtaining sufficient detail for the formation of justified conclusions (Knight & Ruddock, 2008; Saunders et al., 2016). To further promote the consideration of non-technical factors and minimize the influence of subjectivity, the construction sector in its entirety is taken as the target population. The study does not seek to recruit a statistically representative sample, however, with the influence of purposive sampling and self-selection bias (Bryman, 2016) being acknowledged. The vertical extension of all building typologies, by any height, is considered in this work.

Both elements of the study assess current awareness, uptake and experience of vertical extensions, as well as the drivers, barriers and enablers influencing adoption. The primary purpose of the survey is to provide a quantitative measure of this, with semi-structured interviews capturing any previously unidentified factors and generating a qualitative understanding of the themes identified within the survey.

Survey

The survey was hosted online using Qualtrics (Qualtrics, 2020) for a six-month period between 2020 and 2021. As suitable participants were defined as anyone working within the construction sector, this was openly accessible and a self-selective, non-probabilistic sampling process was adopted (Saunders et al., 2016). Invitation to participate was issued in The Structural Engineer (The Institution of Structural Engineers, 2020) and on The Urban Flows Observatory's news feed (Urban Flows Observatory, 2020), as well as at events held by the Association for Consultancy and Engineering (ACE) and Resource Efficiency in Construction and the Built Environment (RECBE) groups. Further requests for participation were made through social media and to established industry contracts via email. Upon recruitment, and following completion of the survey, a request for dissemination to potential respondents was made to increase the range and number of responses through snowball sampling (Saunders et al., 2016).

In addition to the collection of demographic information, the survey included sections collecting quantitative and qualitative data on respondents' awareness, involvement and experience of vertical extension projects, as well as their views on potential barriers and enablers. The barriers and enablers presented to respondents were derived from a formal review of existing studies considering the implementation of sustainable construction practices. This collated over 300 factors in total and resulted in the 19 influencing factors shown in Figure 3 through a process of duplicate deletion, merging and re-specialization. Similar to previous studies, these are disaggregated as technical, cultural, economic and legal.

A range of multiple-choice categorical, rating scale and free text entry questions were utilized in the survey. Branch- and show/hide-logic was implemented to tailor the experience to each participant based on previous inputs. This increased the ease of completion of the survey, ensured sufficient quantitative data was collected from each respondent and provided the opportunity for qualitative explanation where desired. Following completion of the survey, respondents were invited to provide contact details for further research. A copy of the survey is included as supplementary information.

Owing to the descriptive labelling of rating scale points (e.g. 'extremely negative'), resulting data is treated as ordinal. Mode and median are therefore used as measures of central tendency, rather than the mean as in some existing studies (Adams et al., 2017). This is also the case for responses to categorical multiple-choice questions. Qualitative free-text responses were thematically analysed in NVivo (QSR International, 2020) using an inductive process (Braun & Clarke, 2006) to allow the emergence of themes to be dictated by the data.

Interviews

In an attempt to ensure even representation of all stakeholder groups, invitation to interview was sent to 17 of 24 survey respondents willing to be contacted for further research. These were selected based upon their ability to provide further insight (indicated by survey responses) and to maximize the spread of considered demographics. Interviews were conducted via video call over a 2-month period in 2021, lasted between 30 and 60 min, and were recorded to enable transcription.

A semi-structured format was adopted, employing a consistent question guide across interviews (see supplementary information for details). This ensured all key themes were discussed by each interviewee, whilst encouraging the exploration of additional topics arising naturally in conversation. Occasionally guiding interviewees towards topics beyond their area of expertise (e.g. inviting engineers to discuss tax regimes) assisted in capturing stakeholder perceptions in addition to more justified beliefs. Prescribed discussion points were influenced by the findings of the survey, and included specific drivers, benefits and personal experiences, as well as barriers and enablers to uptake. Before the closure of each interview, opportunity was given for interviewees to raise any additional points not yet considered. As such, and because of the diverse

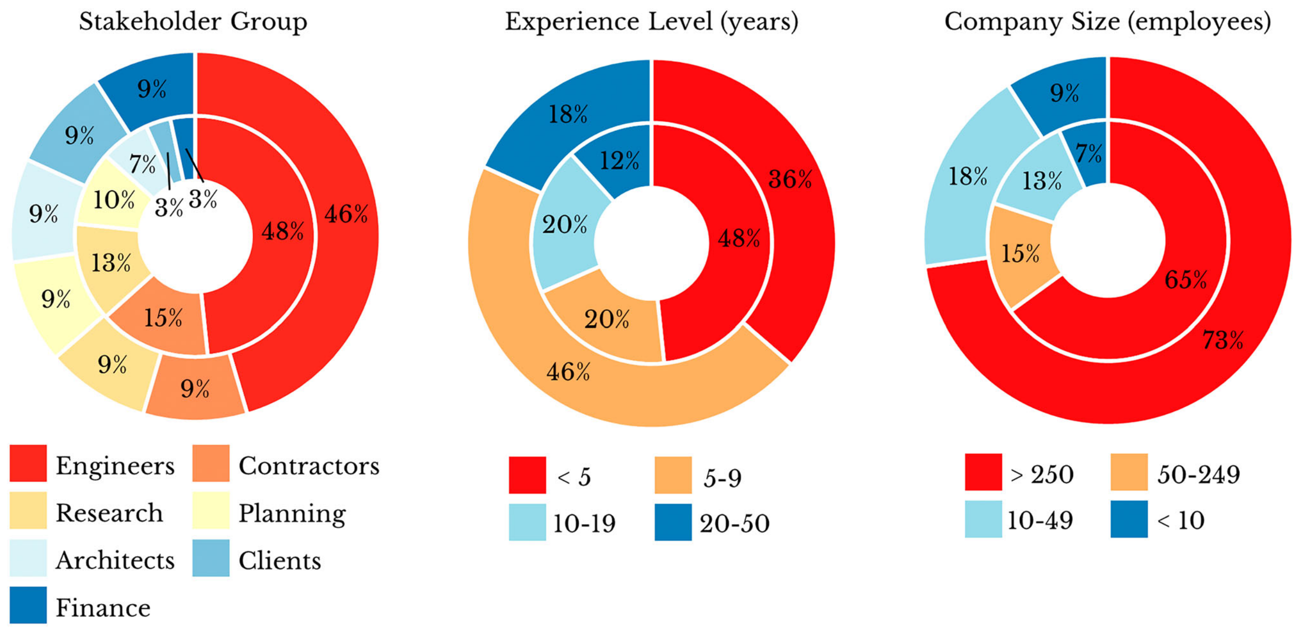

Figure 1. Proportion of survey respondents (inner ring) and interviewees (outer ring) belonging to each stakeholder group, experience level and company size.

expertise of the interviewees and the discursive nature of the semi-structured approach, the themes explored in each interview vary in both range and depth.

Following semi-automated transcription, an inductive thematic analysis (Braun & Clarke, 2006) was conducted in NVivo (QSR International, 2020). Data extracts assigned to each resulting theme were then reviewed in turn to build an explanatory discourse surrounding each.

Results

Demographics

The survey received 87 responses, 60 of which had a completion rate >90% and were carried forward for analysis. 11 interviews were held. A breakdown of respondent and interviewee demographics is given in Figure 1, detailing participants' stakeholder group, the number of years they have worked in the construction sector, and the size of their current company.

Awareness, uptake and experience

Prior awareness of vertical extension was shown by 54/59 of survey respondents, suggesting knowledge of this construction technique to be widespread across the sector. This is reinforced by general agreement that vertical extension refers to the addition of 'new storeys' to 'existing buildings', with these phrases gaining 37 and 33 explicit mentions in definitions provided across survey and interview responses.

This widespread awareness is not matched by current uptake, however, with 19/42 of survey respondents having never been involved in a project where vertical extension was considered at preliminary design stages (Figure 2). Similarly, 26/42 respondents have never been involved in a project in which vertical extension was selected as the preferred solution (Figure 2). Where respondents indicated that vertical extension has been considered as a preliminary design option but not selected as the preferred solution, project uncertainty and resulting commercial risk were the most commonly reported causes. This is consistent with interview findings, as discussed later.

Of the 23 respondents involved in project(s) where vertical extension has been considered, the largest number (7) have done so more than five times. Fewer respondents (6, 4 and 5 respectively) report being involved in one, two and three projects, with involvement four or five times being noted only once. A similar pattern is observed for projects where vertical extension was selected as the preferred solution (Figure 2). This suggests that some stakeholders have a greater-than-average appetite for vertical extensions and potentially indicates the emergence of specialists.

Of the 21 survey respondents who rated their experience being involved in vertical extension projects, 16 indicated this to be either somewhat (13) or extremely (3) positive, whilst three respondents stated this to be neither positive nor negative. Only two respondents indicated somewhat negative experiences and no extreme negative views were expressed. This suggests that negative perceptions held by stakeholders

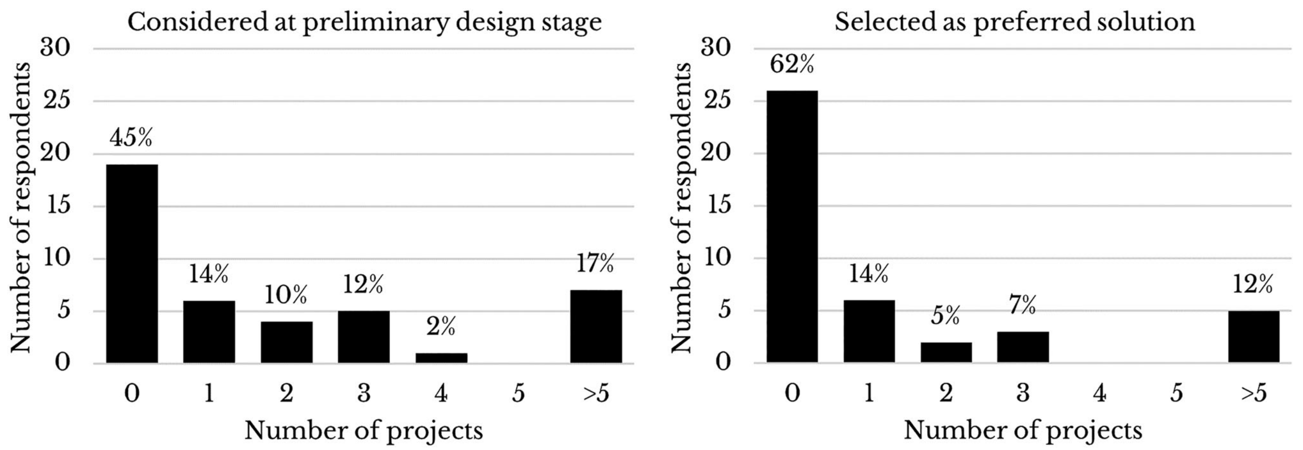

Figure 2. Survey respondent involvement in projects in which vertical extension was considered at preliminary design stages (left) and selected as the preferred solution (right).

perhaps represent a greater barrier to vertical extensions than negative views from first-hand experience. Disparity in respondents' desire to be involved in future extension projects corroborates this, with 20/22 and 3/6 of those with and without prior experience stating this to be the case.

Drivers

Interviewees reveal that the primary drivers of vertical extensions are economic. This is generally rooted in a desire to increase asset value and the potential to do so at a reduced cost. Possible savings are identified in the avoidance of land costs, a typically reduced material requirement and potential for a reduced programme in comparison with (demolition and) new build projects. Although the majority of survey respondents (32/50) believe that material costs will be lower for vertical extension schemes, there is disagreement regarding the influence of *total* project costs, with 22/50 and 20/50 believing this to be an enabler and barrier respectively. Despite being recognized by the majority of interviewees, embodied carbon savings are consistently viewed as a secondary benefit.

Barriers

Technical

Reserve structural capacity. All but two interviewees recognize existing structures' ability to resist increased loads as a key technical consideration for vertical extensions. Seven of these suggest a high likelihood of reserve structural capacity within existing buildings, with engineers claiming that 'you can find a […] lot of additional capacity in *any* structure' and that identifying 20–30% capacity 'isn't unusual'. In contrast, two further engineers argue that buildings are unlikely to be suitable for extension without strengthening works because the 'existing building stock has been efficiently designed with limited spare capacity'.

Structural appraisal and the ability of engineers. Interviewees reveal that 'the assessment of existing buildings is […] seen as […] a specialist discipline within structural engineering' and that this has resulted in 'a distinct split of experience' between 'those who understand how to assess existing structures […] and those who rely on outdated rules of thumb'. This is consistent with the split in opinion of survey respondents, with 26/41 believing engineers are equipped to design for extension projects whilst 15/41 believe this is not the case. Examples of such rules of thumb are discussed by four engineers, all of whom report assuming a permissible vertical load increase of up to 10%.

Availability of design information and structural surveys. Limited availability of original design information is noted by nine interviewees, with one stating that this is 'always the problem' on vertical extension projects. In combination with buildings' deviation from their original form, this typically necessitates a degree of structural investigation, at a time and cost expense to the project. Despite the general negative perception, two interviewees report being able to obtain sufficient information from as-built drawings and operation and maintenance manuals by working closely with asset and estate managers.

Design challenges and constraints. Several spatial constraints associated with reusing existing buildings are identified by interviewees. These include restrictive structural grids and floor-to-ceiling heights, as well as insufficient core and riser space for the flow of people and provision of services. Spatial constraints are revealed to represent a barrier because clients are effectively 'committing to the existing part of the building and making sure that fits [their] needs for the next 50 years', meaning they are often unwilling to compromise on perceived spatial requirements. Site constraints regarding access within and surrounding the existing building are also reported by interviewees as a barrier to vertical extension. These pose an issue during both investigation and construction stages and are most prevalent where a building is to remain operational throughout. Consistent with interviewees, six survey respondents report the unsuitability of existing buildings and inability to meet client requirements as reasons for non-involvement in vertical extension projects to date.

Cultural

Nature of the construction sector. The majority (28/42) of survey respondents believe the nature of the construction industry acts as a barrier to vertical extensions. This is discussed by five interviewees, who suggest that corporate inertia and individuals' aversion to change result in resistance to innovative techniques within the sector. A consequent difficulty in getting people 'on board' with extension schemes is reported by one interviewee, who adds that initial programme delays and investment in overcoming resistance are typically recouped in later project stages.

Economic

Uncertain business case and commercial risk. Despite the *potential* to increase asset value at a reduced project cost, interviewees reveal case-by-case variability to result in an uncertain business case for vertical extensions. This is because of variation in the form and condition of existing buildings, their ability to be extended and the need for structural alteration. The resultant requirement for upfront investment (e.g. in site investigations and structural appraisal) with no guarantee that extension will be possible poses a commercial risk to clients. Two interviewees report instances of clients' aversion to this risk resulting in them opting for (demolition and) new build without considering reuse.

Legal

Tax regimes. One interviewee discusses how current tax regimes 'fight against doing refurb[ishments]' and act as a barrier to vertical extension. This is because value-added tax (VAT) is currently zero-rated for the construction of new dwellings in the UK, whilst a rate of 5–20% is applied to the structural alteration of residential premises (HM Revenue and Customs, n.d.). It is argued that this can result in (demolition and) new build being financially favourable over building reuse, leading to a general preference for this amongst clients.

Planning permission. Difficulty obtaining planning permission for vertical extensions is reported by five interviewees, whilst 25/45 survey respondents believe that planning policy acts as a barrier to adoption. Although 'rights to light', 'visual pollution', 'materiality' and 'the nature of the design of the addition' are reported as potential reasons for non-approval, one interviewee states that they have 'hardly seen any […] that have been refused'. They do, however, report the planning process to be lengthier and more onerous for vertical extensions, representing a barrier through a prolonged project programme, and increased cost and uncertainty.

Enablers

As shown in Figure 3, all potential enablers are viewed as important to increasing the uptake of vertical extension. This also reveals technical enablers to be of greatest importance, with each of the eight considered factors being in the top nine most important. In contrast, all of the three least important enablers are cultural, with employers' corporate social responsibility and employees' personal moral obligation being viewed as least effective. Contradicting this trend of cultural unimportance is the formation of long-term partnerships, which is viewed as the seventh most important enabler overall.

Technical

Education of structural engineers. To overcome the aforementioned disparity in engineers' ability to appraise existing structures, five interviewees discuss the benefits of enhanced education of engineers on structural appraisal and adaptive reuse. This is rooted in an observed neglect of this at university, with the engineers interviewed suggesting they 'didn't really cover anything in relation to assessment [of existing buildings]', 'how buildings were built 100 years ago', or 'what you can think about doing to change those buildings'. Four interviewees also suggest educating engineers on 'the bigger picture' of adaptive reuse and CE in the context of climate change, in agreement with the 30/42 survey respondents who rate 'education and training on environmental issues in construction' as of above-average importance.

Design tools and guidance. Increased provision of tools, guidance and training for the design of vertical extensions was rated as the fifth most important enabler

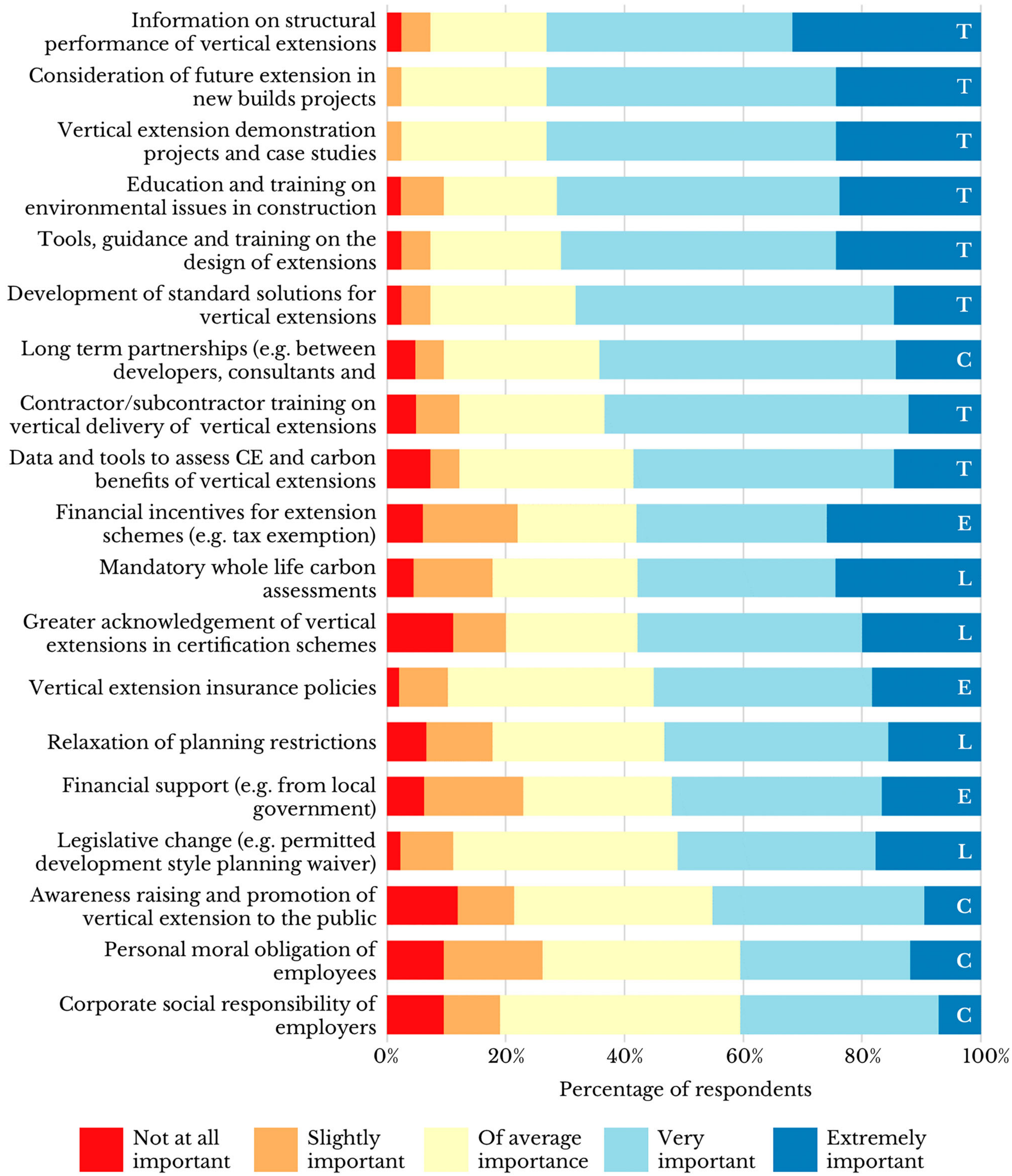

Figure 3. Importance of potential enablers (response to survey question 'Please rate the following in terms of their importance in increasing uptake of vertical extension'), sorted in order of most to least important (descending order of proportion of respondents indicating above-average importance). Lettering to the right of the figure indicates whether enablers are categorized as technical (T), cultural (C), economic (E) or legal (L).

(Figure 3), with 29/41 of survey respondents stating this to be of above-average importance. Four interviewees state that there 'isn't much guidance available' at present and that this typically focusses on 'workflows and diagrams' rather than decision making, as is suggested to be required for building reuse.

Demonstration projects and case studies. The provision of demonstration projects and case studies is noted by 30/41 of survey respondents to be of above-average importance in enabling vertical extensions. Interviewees suggest that these would be particularly beneficial in providing initial design guidance and an indication of viability at early project stages, where insufficient funds currently preclude the detailed exploration of innovative design options.

Consideration of future extension. Increased consideration of future extension in new-build projects is revealed by survey respondents to be the second most important factor in enabling uptake, with 30/41 stating this to be of above-average importance. This theme is discussed further by interviewees in terms of improved recording, storage and transfer of design and construction information, with one interviewee arguing that this would help to 'preserve the value of our assets […] rather than ending up in the same situation in 30–50 years'. As well as more general improvements, it is suggested that BIM models could be used for this purpose and extended to include as-built construction information (e.g. material test results) as well as pre-construction design details.

Greater integration of adaptability strategies in new build design is also suggested by interviewees as a means of enabling future extension. Rather than 'designing for all eventualities' and increasing the structural capacity of new buildings, which would increase upfront embodied carbon, recommendations typically relate to the generation of intervention plans for potential future adaptations. Interviewees perceive this to be 'a very small amount of work relative to the reward', giving examples such as column strengthening for vertical extensions.

Cultural

Questioning the brief. Despite personal moral obligation and corporate social responsibility being rated as comparatively unimportant in increasing uptake (Figure 3), the importance of challenging the brief is discussed by eight interviewees. These generally recognize their responsibility to do so and note a recent increase of this in the industry. In contrast, however, one junior structural engineer suggests that it is simply their task to fulfil the client's brief as received and that only more senior engineers 'would have a little bit more power' to ask questions. The likelihood of success when challenging a brief is also noted to be greatest at earlier project stages and where clients aren't 'looking for standard answers'.

Adaptive reuse specialists. Three interviewees discuss the need for vertical extension specialists to aid ease and speed of completion and reduce commercial risks. As well as the formation of specialists in existing roles (e.g. architects, engineers and contractors), the generation of new specialist roles is suggested. An example of this is given by one interviewee who describes an urban development company who 'help you figure out […] whether it [an extension] is viable or not' before 'connecting the whole process […] from design to supply chain'.

Economic

Costing of uncertainties. Two interviewees suggest that the assumption of a worst-case scenario when costing vertical extensions results in them erroneously being presented as economically unviable. They, therefore, propose a 'structured risk and uncertainty management approach' whereby multiple stakeholders work collaboratively in 'understanding all the uncertainties, listing them out, and pricing them'. This allows different scenarios (e.g. degrees of structural intervention) to be considered, offering a more accurate approach than 'using a percentage contingency' as is often seen at present.

Remuneration of additional works. Although design costs for vertical extensions are perceived to be higher than new build projects by 26/50 of survey respondents, interviewees reveal that consultants rarely receive increased fees to reflect this. Correct remuneration of stakeholders for additional works is therefore suggested as an enabler of vertical extension by three interviewees, with recommendations including additional fees for generating design options and quantifying their carbon impacts; appraising existing structures; and considering future extendibility in new build design.

Legal

Tax regimes. As present tax regimes 'fight against doing refurb[ishments]', interviewees suggest that adjusting these is key to incentivizing reuse. This is reinforced by survey respondents, 29/50 of which state financial incentives to be very or extremely important to increasing uptake of vertical extension. For housing, such an incentive may be achieved by increasing VAT for new build dwellings (such that they are treated equally to refurbishments) or by reversing the current imbalance to actively encourage reuse. Similar VAT incentivization is suggested by interviewees to be extended to all building use types.

Whole life carbon assessment, benchmarking and regulation. Promoting vertical extension through the consideration of whole-life carbon is discussed by five interviewees, with one suggesting that the key to encouraging reuse is 'how we […] drive the industry forward on valuing embodied carbon, and the decisions people make around that'. Considering the whole life carbon of different options at early project stages is suggested as one way of achieving this, with another interviewee calling for a 'cost-carbon exercise' considering the economic and environmental merits of building retention and replacement.

Interviewees generally suggest that, although 'some people will get on board with it [whole life carbon assessments]', most see time and cost constraints 'as a reason not to do it'. Four interviewees, therefore, argue for compulsory whole-life carbon assessments, in agreement with the 26/45 survey respondents who suggest this to be of above-average importance in increasing uptake of vertical extension (Figure 3). As well as requiring the measurement of whole-life carbon, one interviewee believes that future regulation 'should dictate targets for embodied carbon', which all developments would be required to meet.

Permitted development rights. Although specifically questioned on the matter, only one interviewee was aware of existing permitted development (PD) rights allowing for vertical extensions without planning permission. They believe that 'planning is probably the main barrier' at present and state that 'PD rights […] could play a massive role in opening up housing'. The limitations of PD rights are acknowledged, however, including their restriction to adding 'up to two floors on a post-war building' and the fact that formal planning is required where other alterations are to be made. Increased design guidance on 'what is and isn't acceptable' in PD-delivered extensions is suggested to increase uptake further, preventing 'bad examples' that could harm the perceptions of the construction sector and general public.

Local authority plans. Three interviewees suggest that the uptake of vertical extension could be increased by introducing CE considerations in local authority plans, similar to as seen in Greater London (The Greater London Authority, 2021). This is noted to be 'explicit about the consideration of the future of […] building [s]', enhancing both the reuse of current building stock and the future reusability of new builds. As a result of these requirements 'forcing clients to go outside the comfort zone', consideration of CE in local authority plans is seen as a potential mechanism to overcome the cultural barriers discussed previously.

Discussion

Drivers

Consistent with previous work (Gillott et al., 2022; Pattison, 2021; Sundling et al., 2019), this study identifies the main drivers of vertical extension to be economic and environmental. This includes the ability to maximize refurbishment potential and asset value (Pattison, 2021), as well as embodied carbon and CE benefits (Gillott et al., 2022; Pattison, 2021).

Unlike previous studies, however, it is suggested here that economic factors are significantly more influential than environmental considerations, which are instead considered a secondary benefit. Survey and interview participants also fail to recognize the demand for housing or benefits of increased density as drivers of vertical extension, as seen previously in other countries (Sundling, 2019).

Barriers

Technical

Although their importance is potentially exaggerated by the over-representation of engineers, identified technical barriers are in general agreement with those from existing literature. This includes the need to justify increased loads and resultant requirement for intrusive investigation (Pattison, 2021). Inexperience of engineers in appraising structures is revealed to represent a greater barrier than the technical infeasibility of extension, as a result of the likely presence of reserve capacity in existing buildings. Availability of design data and building occupancy are also shown to impact the requirement for, and difficulty completing, intrusive investigation and thus its representation as a barrier.

The barrier to CE posed by building complexity (Adams et al., 2017) is shown to apply to vertical extensions. Context-specific challenges include the provision of building services and sufficient space for ingress/egress, as well as the requirement to work within pre-determined spatial constraints (e.g. column spacing and floor-ceiling height). These challenges are likely to apply to adaptive reuse more widely, as alluded to by existing studies (Rockow et al., 2021; Ross et al., 2016). In further consistency with the work of Adams et al. (2017), barriers arising from the complexity of buildings are shown by this study to be exacerbated by limited consideration of a building's end of life in its original design and construction.

Cultural

Consideration of cultural barriers to vertical extension is limited in existing work, with this study revealing those from neighbouring contexts to be only somewhat applicable. For example, whilst a shortage of knowledge of CE and low-carbon materials is noted (Adams et al., 2017; Giesekam et al., 2016), vertical extensions are more widely known and understood. The potential influence of acquiescence and self-selection bias should be noted here, however. Supply chain issues and responsibility establishment also appear to be of lesser issue for vertical extensions than for CE (Adams et al., 2017) and low-carbon materials (Giesekam et al., 2016) respectively. In contrast, the conservativeness of the construction sector is shown to be comparatively impeding of vertical extension as it is CE more widely (Hart et al., 2019; Kanters, 2020).

Economic

Despite being identified as a primary driver in previous work (Gillott et al., 2022; Sundling, 2019; Sundling et al., 2019) and this study, economic factors surrounding vertical extension are reported as a potential barrier to adoption. This results from a high degree of case-by-case variability, which is reflected in survey respondents' uncertainty regarding whether this acts as a barrier or enabler of uptake. As suggested for low-carbon materials (Giesekam et al., 2016), this is potentially contributed to by stakeholders' *perception* of high costs rather than this being the case in reality. Case-by-case variability ultimately results in an unclear financial case for vertical extension schemes, representing a barrier to adoption as seen for CE more generally (Adams et al., 2017; Hart et al., 2019).

Legal

Difficulty obtaining planning permission is identified as one of two legal barriers to vertical extension, despite the 2020 introduction of PD rights being cited as a driver in previous work (Gillott et al., 2022; Pattison, 2021). This split perception may be a result of stakeholders' unawareness of PD rights at the time of investigation or because of differences between the traditional and PD planning routes. The representation of planning as a barrier to vertical extension contrasts with surrounding contexts, for which this is not revealed to be the case (Adams et al., 2017; Artés et al., 2017; de Jesus & Mendonça, 2018; Giesekam et al., 2016; Hart et al., 2019; Kershaw & Simm, 2014; Rockow et al., 2021; Ross et al., 2016).

Similarly, although only identified by a single interviewee in this study, VAT is not recognized as a barrier in the previous work. This is likely because of its focus on technical aspects (Pattison, 2021) and non-UK cases (Sundling, 2019; Sundling et al., 2019), as well as contexts to which building-level reuse does not apply (Giesekam et al., 2016; Hart et al., 2019; Rockow et al., 2021).

Enablers

Although potentially magnified by acquiescence bias, the favourable rating of all enablers in Figure 3 is to be expected because of their derivation, and thus likely transferability, from neighbouring sustainable construction practices. This result is similar to previous work which also experiences above-average rating of all considered enablers (Adams et al., 2017; Giesekam et al., 2016).

Technical

The most important rating of technical enablers (Figure 3), and their common discussion by interviewees, reinforces the findings of previous studies in the context of vertical extension (Pattison, 2021; Sundling, 2019). In wider contexts, however, although the importance of technical enablers is recognized, as below, cultural and legal factors are often reported to be of greater relevance (Giesekam et al., 2016; Hart et al., 2019). This may suggest that the over-representation of engineers in both the survey and interviews has resulted in exaggerated importance of technical factors in this work.

Overcoming technical barriers through greater consideration of future extension in new builds is identified as one of the most important enablers of vertical extension. As extendibility is a form of building adaptability, which itself is a CE design strategy, many identified considerations are consistent with the literature from these contexts (Adams et al., 2017; Rockow et al., 2021; Ross et al., 2016). This includes collection, storage and maintenance of design and construction data, as well as designing with key CE and adaptability concepts (e.g. reserve capacity and spatial flexibility) in mind.

Similarly as for promoting CE (Adams et al., 2017) and low-carbon material use (Giesekam et al., 2016), the introduction of demonstration projects and case studies is suggested to further enable vertical extensions. As well as exemplifying the potential benefits of adaptive reuse this would serve as early-stage design guidance, which is itself revealed as an enabler of vertical extension.

Cultural

The view of cultural enablers as least important to the uptake of vertical extensions (Figure 3) contradicts previous work in more general contexts (Giesekam et al., 2016; Hart et al., 2019). These typically take the view that technological and legal enablers are insufficient in isolation, and that shifts in stakeholder behaviour and attitude are also required. This disparity may be because of the specificity of vertical extensions (in comparison with CE and low-carbon design), resulting in a diminished recognition of the importance of more abstract enablers. Alternatively, differences in the perceived importance of cultural factors may result from the momentum gained by low-carbon design and CE between previous work and this study.

Interviewees offer greater recognition of the importance of cultural barriers and thus agreement with previous work, with questioning the brief being identified as a specific behaviour change to increase uptake. The suggestion of vertical extension specialists is also consistent with previous calls for early engagement of construction professionals (Giesekam et al., 2016) and stakeholder collaboration (Sundling et al., 2019).

Economic

Despite economic factors being a primary driver of vertical extensions, because of high case-by-case variability, a number of economic enablers are suggested. These are consistent with those identified for surrounding contexts, which generally view economic factors as more consistently inhibitive than is the case for vertical extensions. For example, the need for adjustments to uncertainty costing in extension projects is consistent with similar calls for whole-life costing (Giesekam et al., 2016; Hart et al., 2019) and adjustment of business models (Hart et al., 2019). Interviewees' call for correct remuneration of additional design works would also help to combat barriers identified in surrounding contexts, such as lower design fees and inadequate design time for low carbon material use (Giesekam et al., 2016).

Legal

The identification of several specific legal reforms to enhance the uptake of vertical extension is consistent with general calls for this in previous work (Adams et al., 2017; Giesekam et al., 2016; Hart et al., 2019). More specifically, interviewees' suggestion of mandatory whole life carbon assessment, benchmarking and regulation, echoes similar recommendations made in the context of low-carbon material use (Giesekam et al., 2016). This is also consistent with increasing advocacy for measurement and regulation of embodied carbon within the industry (Part Z, 2021) and the requirement of this by some local planning authorities (The Greater London Authority, 2021). Local authorities are also beginning to include consideration of CE as a planning requirement, such as in 'Circular Economy Statements' now required in Greater London (The Greater London Authority, 2021). The increased implementation of this across the UK is suggested as an enabler of vertical extension here, where this is not recognized by previous work.

In further contrast with existing work, which typically views PD rights as an enabler of vertical extension (Gillott et al., 2022; Pattison, 2021), a widespread unawareness of these is identified within the industry. This may result from the proximity of the introduction of PD rights and the completion of this study, or potentially indicates a preference for vertical extension through the traditional planning route. Considering that just 188 PD extensions have been approved to date (Department for Levelling Up Housing and Communities, 2021), promotion and/or further reform of PD rights may boost uptake in the future, with further research on this being required.

The adjustment of VAT tariffs for construction projects suggested in this work expands on previous suggestions of tax incentives to promote CE in construction (Hart et al., 2019) and low carbon material use (Giesekam et al., 2016). This would see VAT for new build dwellings raised, such that they are treated equally to refurbishments, or the current imbalance reversed to actively encourage reuse whilst decentivizing new developments.

Limitations and future work

Although not intended to be statistically representative, and despite efforts to ensure even consideration in the interviewee selection process, both elements of this study experience over-representation of engineers (Figure 1). This may result from self-selection bias (Bryman, 2016) and the surveys advertisement in The Structural Engineer (The Institution of Structural Engineers, 2020), with the effects of this being exacerbated by snowball sampling (Saunders et al., 2016). The over-representation of engineers may have contributed to the identified importance of technical considerations, with similar, yet less extreme, results potentially being present for imbalances in respondents' experience level and company size. As such, subsequent work specifically targeting under- or unrepresented stakeholder groups is suggested. Owing to the identified barriers and enablers, it is suggested that this should include building surveyors and architectural technologists as well as experts in real estate, construction finance and tax.

The study's capture of perceptions means it is unclear whether the factors identified are real or simply common misconceptions. This does not diminish their value however, with perceived factors being similarly capable of influencing adoption as those founded in reality. Notwithstanding this, further research on some themes is recommended, such as where conflicting project cost views are reported. Greater understanding could be achieved here by analysing real-world cost data for vertical extension projects in the UK, similarly to already completed for a small sample in Sweden (Sundling, 2019; Sundling et al., 2019).

Additional work is also recommended to better understand the presence of reserve structural capacity within existing buildings. This should build upon previous studies' identification of overdesign and reserve capacity (Moynihan & Allwood, 2014) to quantify this in terms of a potential load increase. The validity of commonly used rules of thumb, such as the aforementioned 10% permissible load increase, should also be considered here.

The introduction of PD rights shortly before this study, and unawareness of these amongst respondents, results in a further research gap. This may be addressed by future work considering the impact of PD rights on instances of vertical extension, as well as the potential for these if utilized more widely.

Conclusion and recommendations

Through a sequential explanatory mixed-methods study, this paper yields new insights on drivers, barriers and enablers of vertical extension. The conducted survey and interviews also, for the first time, assess stakeholders' awareness, uptake and experiences of this construction technique. This study addresses a previously limited understanding by considering a wide range of viewpoints to identify new influencing factors and assess the applicability of those from surrounding contexts. A further contribution to knowledge is made by this work's consideration of the causality, impact and interrelation of influencing factors, as well as their potential to enable uptake.

The ability of vertical extension to increase the value of buildings is revealed to be its primary driver at present. Despite this, high case-by-case variability and deficiencies in the costing of uncertainties result in an uncertain and unfavourable business case in some instances. This can create a barrier in the form of commercial risk, which is worsened by current tax regimes and conservativity of the construction sector. Although widely acknowledged, environmental benefits are viewed as a secondary benefit of vertical extension at present.

Technical considerations such as the justification of reserve capacity, working within spatial constraints and unavailability of design information are identified amongst the most inhibitive barriers to vertical extensions. This is not perceived to be an indication of technical infeasibility, however, with these barriers suggested to result from the inexperience of engineers, clients' unwillingness to compromise and limited consideration of future reuse in new build design.

In addition to the above suggestions for potential future research, four overarching recommendations are made based upon the findings of this study:

1. The content of undergraduate civil and structural engineering courses should be reviewed to ensure the appraisal of existing structures is adequately addressed. This would serve to combat the neglect of this reported by interviewees and thus the resultant disparity in engineers' ability to design for reuse. Such a review of course content is consistent with the Joint Board of Moderators' recognition of the need to increase focus on the climate crisis in civil and structural engineering degrees (Joint Board of Moderators, 2021).
2. VAT rates for refurbishments should be aligned with those for new build projects across all use types. This would provide a financial incentive for vertical extensions, countering the effects of project uncertainty. Improving the business case in this way would serve to allay concerns regarding commercial risk and mitigate the economic barrier this represents. As well as vertical extensions, realignment of VAT rates would serve to enhance the uptake of adaptive building reuse more generally.
3. Whole-life carbon assessments should be made mandatory for all construction projects. This would serve to more clearly articulate the embodied carbon savings associated with building reuse and elevate this from a secondary benefit to a primary driver of vertical extension. Building upon this with sequential benchmark targets and regulatory limits would further promote vertical extension, forcing clients to consider building reuse and encouraging associated design compromise.
4. Encouraging greater consideration of CE by all stakeholders is suggested as a final means of enhancing the uptake of vertical extension. This would counter the presently limited consideration of future reuse in the design and construction of new buildings, as well as the resultant barriers of poor availability of original design data and reduced technical feasibility. In addition to encouraging key CE strategies such as design for adaptability and longevity, and the proficient storage, management and transfer of design data, this would serve to promote the benefits of CE more widely. This may also enhance clients' willingness to compromise on perceived design requirements and provide consultants, architects,

engineers and contractors with greater grounds on which to challenge their brief. More widespread integration of CE considerations in local authority planning requirements is suggested as one way in which this enhanced engagement may be achieved.

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Ethical approval

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