New Angles for Adaptive Building Reuse Research

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Abstract. This paper seeks to establish the current state of research into adaptive building reuse with the view to highlighting new approaches and opportunities for expanding the collective knowledge on this subject. This approach focuses on appraisal and evaluation of current methods by looking through a structural engineering lens and considering the most beneficial options in terms of reducing additional embodied carbon intensity in our built environment.

Keywords. Suggesting new approaches for adaptive building reuse research through literature review and evaluation. Embodied carbon, Building lifespans, Sustainability.

1. Introduction
The objective of this paper is to describe and evaluate the current literature and research methodology around adaptive building reuse and identify areas that warrant further investigation or work.

1.1. Environmental Context and Sustainability
It is suggested that our concept of sustainable buildings is mainly focused on improving their energy efficiency with insufficient emphasis on the social [1,2] and economic [3] aspects. Aspects like the embodied CO2 of our buildings are often overlooked [4] in pursuit of more efficient building performance, as noted by Ibn-Mohammed et al. in their comparison of operational and embodied emissions [5].

The Happy Planet Index (HPI) measures the sustainable well-being of a nation, although the accuracy of the measure and its constraints are sometimes questioned. Abdul-Rahman et al. suggest, based on Campus et al.’s results, that it is difficult to score highly in both the overall HPI measure and economic growth due to the conflict between high living standards and sustainability [2,6]. In addition to the many existing reasons for adaptive reuse, explored in section 1.2, it is a built environment strategy which allows society to balance standards of living with environmental consequences.

1.2. Reasons for Adaptive Reuse
There are many reasons for adaptive reuse of buildings. Živković et al. [7] explain the benefits of utilizing existing buildings, made redundant due to social and societal change, to serve the current high residential housing demand. Xuereb et al. [8] describe the need for adaptations due to changing use and climate mitigation, though consideration should also be given to the continued introduction of new external factors and building requirements like resistance to terror threat or regulation changes.

Adaptive building reuse was recognized in 2018 as a successful intervention approach under the
European year of cultural heritage [9]. Some of the rationale discussed in the literature includes preserving heritage, urban regeneration, energy, pollution and carbon saving, performance upgrades, avoiding construction and demolition waste, economic savings, reduced construction times, added value, circularity principles and increased green space preservation [7–13]. These benefits are not confined to historical buildings, thus making the case for work to be done to facilitate adaptive reuse of any existing building [9].

2. Literature Review and Discussion

The papers discussed herein are varied in nature and a diverse range of literature is discussed in response to the scarcity of specific work looking at adaptive building reuse. A lack of clarity and consistent usage of potentially relevant search terms, along with a dearth of primary research currently available, hindered a systematic selection process. Rather, the approach was to utilise iterative search, evaluation, and selection rounds to explore refinement of the research questions related to the overall aims of the study.

For example, several works were emitted from the study where the content focussed purely on retrofitting and did not consider or mention any structural or use changes. This study examines 32 sources comprising of academic papers, articles, books, reports, guidance or proceedings documents.

2.1. Context

The volume of published research on building reuse has increased in the last 40 years. Shahi et al. say that this is due to a more favourable outlook on adaptive building reuse as ‘a sustainable approach to asset and urban management’ [14]. The idea that ‘building refurbishment’, ‘retrofitting’, ‘rehabilitation’ and ‘renovation’ are better established concepts than reuse is borne out with the discovery that these topics have 2.75 times more published articles, between 2010 and 2020, than those on ‘adaptive reuse’, ‘material reuse’ and ‘building conversion’. Different terminology in use within research around building reuse is identified, including but not limited to; ‘retrofitting’, ‘refurbishing’, ‘regeneration’ and ‘adaptive reuse’ with elements of disparity with geographic location. Shahi et al. [14] provide clear explanations and definitions of current terminology and suggest a framework to avoid additional cost arising from confusion of scope on projects due to overlapping terminologies. Indeed Wilkinson et al. [10] state that the term ‘building adaptation’ can be applied to an array of different alterations. Shahi et al. suggest a framework, see Figure 1, to determine which scope, either singular or multiple, a building adaptation project comes under. Any work with structural improvements as part of its remit would, according to the proposed framework, come under ‘building rehabilitation’ or ‘renovation’ under the category of ‘refurbishment’ or under ‘conversion’ or ‘material reuse’ within the category of ‘adaptive reuse’.

The structure, including both superstructure and substructure, is the most expensive part of a building to demolish and reconstruct financially and in terms of CO₂ [8], making their preservation a worthwhile priority. Xuereb et al. refer to the need to ‘unleash the building frame’s full potential in sustainable
design beyond the construction stage, which could also result in significant economic benefits.’ This reinforces other literature suggesting a high environmental and economic value in maintaining and reusing our current building structures.

Adaptive reuse has a big part to play in moving towards a more circular economy and reducing additional building materials required to meet the demands of society. Research finds that many capital cities (often in Western Europe) ranked highly in a proposed Adaptive Reuse of Cultural Heritage (ARCH) index and it is suggested that they act as a magnet for cultural and creative centres [11].

2.2. Adaptable buildings and futureproofing
Overdesigning structural capacity, open plans and the layering of multiple structural systems are often identified as the most effective methods for creating future adaptability [13–16]. These approaches could end up being costly [8], wasting resources and unnecessarily increasing embodied carbon. Nonetheless ‘loose fit’ and ‘over designing’ strategies are suggested in the guidelines for new buildings by several bodies [17,18] and researchers [19,20]. Though Black et al. [13] say that the recommendations lack the empirical data to confirm their efficacy, they conclude that their study data confirms that ‘loose fit’ and ‘over designing’ strategies facilitate building adaptation. There is no mention in this or similar work of the carbon cost of these strategies, they focus solely on ease of adaptation rather than how to tackle the more problematic characteristics. There is scope to reflect on the potential benefits of the ‘negative’ characteristics that are often but understandably overlooked. For example, in one study, a respondent’s reference to a dense column arrangement was, reasonably given the research remit, regarded as negative despite the expressed view that the columns aided in space definition. It would be wise to remember that as complicated and reliant on multiple different criteria as the decision to adapt a building is, the outcomes too are not singular. Taking a more holistic approach to the definition of a successful adaptation of a project may be more realistic and could perhaps yield different beneficial design strategies.

Xuereb et al. [8] propose adaptive reuse as a mechanism for future proofing in contrast to the popular but seemingly contradictory approach of overdesigning from the outset to provide additional capacity. They propose implementing data acquisition systems to increase our knowledge of the actual structural behaviour of buildings, as opposed to their theoretical behaviour, to facilitate building design and permit more optimal solutions. Potential barriers which may restrict the implementation of this method are the industry’s slow uptake of new technology, the need to future-proof data and the specific installation methods. The need for the structure to be in use to get data could be a problem for some reuse projects where conception may occur once a building is vacant. Xuereb et al. describe several of the options and benefits that using this tech-focused approach could have, including versatility, encouragement of long-term ownership and asset value and potential cost savings of any future works. The concept of moving to a culture where retaining and improving the value of an asset is seen as paramount, appears to synergize well with the idea of adaptive building reuse, as seen in Casablanca [21]. Investigation of this theory through data-based research would serve to validate or disprove this relationship.

2.3. Adaptive reuse factors
Multiple studies have ascertained factors influencing adaptive reuse, both positive and negative and have assigned importance to them to feed into models and increase our depth of understanding of the critical aspects. Tan et al. [12] looked at the adaptive reuse of industrial buildings in Hong Kong and consider 33 factors. Six, shown in Figure 2, are deemed Critical Success Factors (CSFs) based on analysis of questionnaire responses. Principal component analysis (PCA) is used to aggregate all the factors into 8 principal components. The average mean/factor in each principal component category can be used to suggest a relative order of importance of each component. Figure 2 shows the principal components listed in order of that inferred importance, demonstrating that the factors grouped into ‘sustainability’ and ‘physical condition of the building’ generally rank low in importance compared to those making up ‘the market’, ‘legal and regulatory’ and ‘economics and governance’.

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Ease of adaptation and the need for ‘substantial alterations’ are judged to be an important factor in whether a building is successfully redeveloped [12]. Tan et al. [10] find that the adaptive reuse of industrial buildings as commercial offices is more likely as most industrial buildings are in good or fair condition. It is stated that some conversion works would require substantial alterations to be suitable for residential purposes, suggesting a potential opportunity for facilitating this process. Poor physical condition of a building increases conversion costs but affects the project timeline, which can be key in itself [22], and can increase the risk for developers, preventing building reuse [12].

Zivković et al. [7] suggest five groups of evaluation criteria used to assess conversion quality (Figure 4). Some of these criteria are similar to those discussed by Tan et al. although they have not been ranked. Zivković et al. [7] suggest, echoing Kincaid [23], that to improve the quality of a reuse project it is essential to define: benefits, to maximise or exploit; negatives, to negate or remove; and any neutral aspects. A Serbian case study is used to demonstrate application of the model including the assignment of ‘asset’ or ‘challenge’ status to identified characteristics of the project, before using a simple ratio between the two to demonstrate the potential. The physical aspects of a building do not only influence adaptive reuse decisions; Živković et al. [7] state that building obsolescence can also be driven by physical elements of the building as well as due to changes in the wider environment.

Xuereb et al. [8] identify ‘future-proof characteristics’ of existing old buildings [4]; the building material and ‘resilience of their form’ are described as important to allow adaptation to fit buildings to their new requirements [24]. Hagia Sophia in Turkey and Victorian houses in the UK with their masonry walls and timber floors are given as examples. They argue that more optimised building construction reduces adaptability, and that any required changes will be expensive and disruptive. There is no mention of the difference in embodied CO2 with this approach. They continue that it can be hard to predict the changes that may be needed over the life span of a building which suggests that designing optimally and altering if needed would be the most prudent solution carbon wise.

Using interviews, Xuereb et al. [8] discovered that the factors affecting the use of structural sensors in order of decreasing importance, included: adaptability, added long-term value, legislation, return on
investment and sustainability. It would be informative to discover if a similar trend were to be observed with other novel suggestions which may assist with adaptive reuse.

In discussing key attributes determining building adaptability, Wilkinson et al. [5] list the ‘adaptive reuse criteria for existing buildings’ with references to relevant research studies with the most recent examples from 2007. The identified criteria are: age; condition; height; depth; envelope and cladding; structure; building services; internal layout; flexibility for a range of differing uses and functional equipment; purpose-built buildings (not speculative); location; perceived heritage value; size; accessibility; proactive policy making or legislation (planning and building codes including fire); acoustic separation; user demand; and site conditions. Adaptive reuse is complex, it is therefore necessary to consider many of these factors simultaneously and the authors suggest that a form of multi-criteria decision-making (MCDM) should be used to analyse all factors and provide weightings used to describe the adaptation potential for a building. The authors state that previous work has considered only relatively modest numbers of buildings to determine the relevance of the criteria to building adaptations.

Black et al.’s [13] study into features relating positively or negatively to building adaptation aimed to focus on just the physical features based on the phraseology of the questionnaire. Although physical related commentary was prompted, other factors were mentioned demonstrating that the physical factors are not the sole influencer. The most common features related to either ‘loose fit’ i.e. large open spaces or attributes deemed to help with ‘extending the building life’ - e.g. residual strength and maintenance. Of the nine factors identified, as seen in Figure 4, all but one unique factor, maintenance, match or fit within the terminology of the eleven factors proposed in a similar study by Ross et al. [16].

Figure 4. Factors positively and negatively influencing building adaptability, (Black et al. [13]).

The factors identified by Black et al. [13] can be seen, along with their frequency as having either a positive or negative impact on the 16 projects included in the study, in Figure 4. The authors also commented that there are often several options for building adaptation and that certain physical characteristics may enable different adaptation solutions. It is useful to identify factors which can assist or, potentially more importantly, impede an adaptation. Bearing in mind that the focus was on physical factors, other factors may have had a greater influence on final decision making.

2.4. Extending life span/redundancy
Obsolescence and redundancy in the built environment frequently lead to unnecessary demolition [16]. There are various reasons a building may become obsolete; economic, technological, social and
functional obsolescence are identified as key reasons driven by physical elements of the building or changes in the wider environment [7]. Increased adaptive building reuse can promote successful regeneration of an area [9,12] and is identified as an important factor in the adaptive reuse decisions in Hong Kong.

There are many examples of older historic buildings, like Hagia Sophia or the Eifel tower, which have long surpassed their intended design life through adaptation. Xuereb et al. [8] say that historic building construction using masonry and timber is easier to adapt than more contemporary construction using steel and concrete. This suggests that new approaches are needed [8].

50 years is regarded as the normal life span for most buildings in the UK and other countries. During this timescale, changes normally occur which necessitate adaptation [8]. Of the different layers of a building the structure has the longest potential age [16] whilst the design life is often surpassed by the real in-service life. The life of infrastructure in the UK is usually extended beyond the typical 100-year design life with remedial work, avoiding the huge financial, time, disruption, resource and business costs of renewal. With the now more apparent and widely accepted issues around climate change and resource scarcity it would seem prudent to take a similar approach to buildings. The idea of ‘banning’ demolition entirely has crept into the public domain over recent years with high profile supporters and various news articles on the topic [25,26]. It would mean that all current buildings need to last forever, an interesting perspective from which to view building adaptation research where buildings deemed ‘difficult to adapt’ could not be ignored.

The wealth of research and examples of building adaptation and re-purposing being successfully employed to extend the life span of historic buildings demonstrates the efficacy of this solution. This is further confirmed by the existence of research studies into future use decision-making models, like that of Radziszewska-Zielina et al. [27]. A logical progression could be to apply the decision-making concepts to obsolete buildings that haven’t been identified as culturally significant, to make best use of them as assets and preserve the value of the materials and carbon already invested within them.

2.5. Policy, codes and standards

Much of the work on adaptive reuse suggests potential impact for policy and standards, a common vehicle for change within the construction industry. There are calls for more standards, guidance, and tools as well as information to ensure that all stakeholders can fully interact with and understand the issues involved in project and planning decisions [12]. In Hong Kong, for example, there is a suggestion that government should be providing relevant consulting services for building owners who may be interested in adaptive reuse to encourage reuse of their industrial buildings [12]. The need for a decision-making tool to assist policymakers and city planners when prioritizing buildings is echoed in many studies [9,10] suggesting that although decision making has been researched for specific case studies, a satisfactory larger scale version is not currently available. The benefits of adaptive building reuse are seldom identified by sustainability reporting tools, a missed opportunity which would increase the attractiveness of proposals to investors, developers[8,28] and potentially designers alike.

The suggestion that adaptive reuse of buildings can drive urban regeneration is a key point for policy makers and planning authorities as ‘up and coming’ areas are seen as an attractive and lucrative option for developers and investors [29]. A large-scale example in the UK is Nine Elms in London where retention of the area’s heritage, including Battersea Power station is a key part of the strategy [30].

Specific policy can have a great effect. The high rate of adaptive reuse demonstrated in Hong Kong is driven in part by government initiatives. Foster et al. [11] suggest that EU policy should focus on bringing the circular economy and adaptive reuse of cultural heritage policies to all countries in Europe thus making it a more diverse and inclusive scheme. This research is on a larger scale than otherwise reviewed in this study as it suggests research that could be helpful to inform policy on a macro scale.

2.6. Finance

With any adaptive reuse case many factors come into play, for example tax incentives, town planning and building regulations which vary greatly across countries. Xuereb et al. [8] briefly discuss how
legislation and policy in the UK has recently changed to ‘encourage developers to retain ownership of the asset’ which could encourage more adaptive reuse of buildings seen through an investment lens.

Even where public authorities own or have rights to current unused buildings there is a lack of resources in this sector and it often falls to local authorities to pre-empt local development needs and seek the appropriate investors, private or otherwise [9].

Wilkinson et al. [10] discuss that in some circumstances it can be cheaper to build new rather than adapt, however there are many examples to the contrary. In the UK it was found that financial incentives and grants have the power to determine the success of a project, demonstrating how the influence of policy could effectively increase adaptive reuse opportunities. However, also in the UK, currently VAT acts as a disincentive as the rate for refurbishing works, including adaptive reuse, is 20% compared to 0% for new build [31]. Until this is addressed, as suggested by many including the Urban Task Force [32], it is unlikely that adaptive reuse will increase due to market forces alone.

Various work exists seeking to quantify the financial aspects and implications of adaptive reuse projects. Abdul-Rahman et al. [2] propose a methodology to ensure that the environmental considerations of housing do not eclipse the economic and social performance criteria included within sustainability. Often financial considerations are limited to single project research, although there are attempts to include the financial aspects in multi-project-applicable research models like Della Spina’s model to assess Financial Sustainability based on DCFA (Discounted Cash Flow Analysis) [9].

Work by Foster et al. [11] quantifying investment opportunities in different European Cities though an index to measure potential, comes under the CLIC (Circular models Leveraging Investments in Cultural heritage adaptive reuse) project framework. This is a clear demonstration of research establishing that there is a direct financial benefit to be gained from uptake of adaptive reuse as a form of investment in addition to those that come with urban regeneration.

2.7. Methodologies of previous research

Xuereb et al [8] discuss the need for data-acquiring systems in buildings to enable and inform adaptations in the future with evaluation of two case studies of successful implementation. Client and stakeholder interviews were used to examine the importance of factors affecting adoption.

Capozzoli et al. [33] look at energy performance certificates (EPCs) for flats from a domestic retrofitting point of view. A large data set is built up from the available EPC information and analysed, identifying representative samples through use of the classification tree methodology. Those properties with the highest energy demand were deemed to be the priority and investigated further to develop suitable retrofitting strategies and uncover hidden dependencies.

Abdul-Rahman et al. [2] use a ‘fuzzy analytic hierarchical process tool’ to establish priorities for the different factors involved in housing sustainability in an integrated way. They interviewed a range of experts, both industry and academic professionals, to establish their priorities in pair-wise comparisons of 52 identified factors across the three main categories. These responses were then converted to fuzzy numbers to account for any uncertainty and check for consistency.

Wilkinson et al. [10] adopt a retrospective approach to determining trigger points or characteristics of buildings that have undergone adaptation within the Melbourne central building district that render them apt for adaptation. They suggest a decision-making tool would help policy makers and city planners identify buildings to prioritise and when.

Black, et al. [13] investigate physical features of buildings which may aid or hamper adaptation through a survey to practising professionals based on their own project examples. Collating the results established common features. The study focused on physical attributes, despite this, other factors were brought up, thus demonstrating that sometimes the decision is made based on multiple criterion types.

A multi-criteria decision-making model approach is commonplace for historical or conservation buildings [34] though some of the current research adopts a strictly hierarchical approach which fails to acknowledge and adjust for the network type interface that is likely to be seen in practice [28]. Radziszewska-Zielina et al. summarise several analysis techniques then propose a new system, demonstrated with a case study of the great armoury in Poland in Gdansk [27]. The authors extend
current versions of multi-criteria-decision-making models, with specific reference to the Weighted Influence Non-linear Gauge System (WINGs), to represent the complicated interrelationships with a network model to deal with inconsistencies or unknowns in the data as well as determining a method to manage difficult decision making reflecting real-world complexity. A similar approach could be taken or at least evaluated in reference to structural adaptation of any existing buildings.

Śladowski et al. further extend the framework to increase the realism by including relationships between the multiple variant options [34]. Two different model types are investigated: the DEMATEL (Decision Making Trial and Evaluation Laboratory) and the ANP (Analytical Network Process). A hybridised version is created before the method is tested on the Boyen fortress, a case study based in Poland, to verify it. The authors comment that the ability for the method to deal with further unknowns could be extended. Della Spina [9] also explores a multi-criteria decision-making methodology model to examine the feasibility of different alternative use types (from multiple points of view) as well as the financial feasibility and model that can be expected from the project.

Foster et al. [11] seek to bring together principles of circular economy and adaptive reuse of cultural heritage buildings through an index looking at city level across Europe. The index serves as an indicator for how able a city is to increase its ARCH from a cultural stock, environmental, and socio-economic view, thus contributing to the circular economy of the city. Del et al. [36] investigate the importance of different architectural values in historical conservation of cultural buildings by a literature review based on a snowball sampling method of current research mentioning physical values in reference to conservation. The value mention frequencies are counted and recorded; the sampling stops once the most recent 10% of the sample size has not brought up any new values. An entropy method is used to feed in values derived from expert’s opinions. The certainty of the effect and importance of these values are then ordered to rank and categorise them. Foster et al. and Del et al.’s work are yet more examples of research attempting to draw together multiple complex inputs to convert them to a simplified process with ranked value-type answers.

Across the ten methodologies explored here there is a prevalence of multi-criteria decision-making research and a tendency to use questionnaires or interviews to gather data from experts and stakeholders to inform the new knowledge or models. Using a pre-existing database of building information is rare and analysis of any solutions to factors considered to be hindering adaptation is not found.

2.8. Data considerations
The detailed data on existing buildings in work by Tan et al [12] including building quantities, condition and age demonstrates the availability of data in Hong Kong. It would be pertinent to examine whether the availability of data in Hong Kong has directly contributed to more reuse, to establish potential benefits of developing databases for elsewhere. Xuereb et al.’s research [8] into data-acquiring systems in buildings demonstrates a lack of data in the area suggesting that better adaptive reuse may be possible with increased knowledge about a building structure’s real-life behaviour. They also state that owners and developers are demanding more information about buildings which further demonstrates the demand for building data and could suggest the need for a process that officially attributes a value to it.

The availability of data is likely to be one of the main challenges with investigating adaptive reuse in the UK as there is a lack of publicly available centralized building information. One method to obtain the data is to approach companies in the construction sector industry by way of questionnaires, workshops or focus groups, though this relies on companies being comfortable to share project data or insights and on that data being appropriate for the study. Though potentially challenging this option is utilized within the current literature on adaptive reuse of buildings. Of the papers’ methodologies considered in this study 30% involve some form of direct data capture from stakeholders within the construction industry.

3. Conclusions and Future Work Suggestions
This paper has shown that existing literature forms a strong basis for further research and activities to increase adaptive reuse of buildings. This will unlock a vital opportunity for the construction industry
and society to reduce the embodied carbon of our built environment.

Humanity will continue to change the demands on buildings before the end of their life, consequently we must repurpose and adapt them if we aim to be sustainable. Existing buildings should be adapted to exploit their potential carbon savings, whilst continuing to seek to adapt culturally or historically important buildings to preserve our heritage.

Most of the research into examining, changing, and extending multi-criteria decision-making models focusses on historic buildings. It would be helpful if such research were extended to all the exiting building stock, something that should be seen as a priority by researchers focusing on the construction industry. Furthermore, existing research work seems to indicate a low level of structural consideration for adapting a building to a new use. Does this demonstrate a gap in our knowledge and skills with the potential to improve the way we use our existing built environment? Perhaps structural engineers are succeeding in their work by advocating for minimal structural change requirements, negating the need for additional resources and associated emissions. There is certainly scope for further investigation of this topic examining the balance between different levels of intervention on the potential end results of a building adaptation.

Research into features or characteristics that enable adaptive building reuse often suggest guidelines for new build. Given the previously stated fluctuation in building requirements, it seems more prudent to suggest attributes that should be excluded for having adverse effects on adaptability than to try and determine future space requirements. This stance advocates optimisation for any new build deemed essential, rather than overdesigning or loose fit strategies, to minimise our resource consumption, with the knowledge that changing priorities in the future may call for unexpected future adaptation.

Whilst there is certainly value in identifying buildings which may be easier to adapt, it is vital that those deemed less suitable are not forgotten. There is a need for research focusing on these difficult-to-adapt buildings to ascertain the best strategies for reusing all current buildings to meet demand and to increase our current existing knowledge of how to deal with these buildings in a more environmentally conscious way. Mapping an existing building to a set of dynamic desired criteria, relating to the end use and success of adaptation, is an area of research with great potential. Research into the issue at different scales and across multiple disciplines should identify a greater number of routes to beneficial outcomes which could be influential for future policy and help maximise embodied CO2 reductions.

Current legislation and policy should be reviewed in the UK especially considering the successful impact that has been seen to increase adaptive reuse of buildings in other countries. Perhaps studies seeking to demonstrate the potential for similar approaches in the UK could help to push this further up the agenda.

With any adaptation project collaboration between the stakeholders is paramount to success, as is an understanding and commonality of the project aims and priorities. Strategies to limit embodied carbon in industry, like circularity, can have contradicting elements and complicated decisions will be made by stakeholders, highlighting the importance of a unified culture where buildings are recognised as assets. Increasingly, the value of building information must be seen to contribute to the value of the asset itself. There appears to be opportunity within this remit to extend the current research in this direction, with focus on the different stakeholders and the power they have to influence the current culture and expectations within the construction industry.

It is essential that engineering design and policy moves into a space where we are reducing the built environment’s embodied carbon. Allowing design to use the adaptability of humans may be one of the keys to unlocking this.

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