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A framework for sustainable adaptive reuse: understanding vacancy and underuse in existing urban buildings

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Cities have been built on the benefits of density, proximity, and connectivity. However, the recent COVID-19 pandemic, along with continuously evolving communication technologies, has seen an increase in vacancies and underuse of urban buildings, challenging the agglomeration benefits of cities and our understanding of business-as-usual. By reflecting on these continuous changes in our urban environment, we can better understand the dynamics in play, the various user needs, the temporary or permanent nature of these changes, and possible adaptive strategies to navigate our future toward a more sustainable and resilient state. This article, therefore, presents a systematic literature review, using PRISMA, to examine and map how vacancy intersects with adaptive reuse literature. This review examined 43 academic articles and revealed research predominately focusing on whole-building adaptive reuse of completely vacant buildings. This review highlighted that vacancy is mainly assumed in research, and both vacancy and adaptive reuse are insufficiently unpacked. A new adaptive reuse framework is proposed to address the misalignment between the realities of how a vacancy is distributed in building stocks and the focus on whole-building adaptive reuse. The framework is set to inform urban policy development supporting sustainable reuse. This article presents a point of departure to understand how adaptive planning approaches could be applied to enhance broader sustainability and resilience initiatives.

KEYWORDS

urban regeneration, adaptive reuse, vacancy, obsolescence, temporary

1. Introduction

Cities have always attracted population growth and economic agglomeration, building on the benefits of density, proximity, and connectivity (Burdett, 2022). As a result, cities have existed as epicenters of new capital, creativity, and innovation because proximity generates serendipity, a "spill over" effect, and connections from which new ideas and opportunities arise (Albizu and Estensoro, 2020). During the recent COVID-19 pandemic, this became more evident as lockdowns were imposed on the benefits of agglomeration economies, and at the same time provided evidence of how the agglomeration benefits of cities are eroded by better communication technologies (Voith and Wray, 2021). While many are now debating the life and death of the city as we know it, mainly related to increases in property vacancies across global cities, one thing is evident: the need for urban preparedness for future pandemics (Martínez and Short, 2021). Short-term implications might well spill over into the long-term implications for city design, resilience, and sustainability.

In addition, while the change in our cities and urban landscapes is continuous, the need to reflect on and understand these transformations is essential, in order to conform to the objectives of a sustainable and resilient future for all. Sustainable development stems from the triangulation of environmental (conservation), economic (growth), and social (equity) dimensions (Keiner, 2005). Sustainability, in the urban sense, refers to improved human wellbeing and quality of life, as well as the protection of the natural systems that support and enable this quality of life. Sustaining cities by ensuring that their functional integrity is maintained may well be a critical goal of urban sustainability (Peres et al., 2017). Resilience is closely tied to the qualities of a sustainable city in quest of an enhanced quality of life, drawing on the general agreement that health, safety and security, and mobility are key performance qualities of a sustainable city. As a result, sustainability is increasingly being recognized to include those qualities and relationships that give rise to a thriving and regenerative urban system in which the relationships within and between social and ecological systems are renewed (Peres et al., 2017). The permanent dynamic evolution of cities will always be a part of this urban landscape (Sassen and Kourtit, 2021), as cities and urban agglomerations have never been static.

At the same time, connecting high vacancy and urban revitalization through residential adaptive reuse is not new. Research has examined the role of policy and adaptive reuse to regenerate city centers since the late 1980s (Zukin, 1989; Heath, 2001), and more recently, the debate explored the tensions between the retention of heritage buildings and conformance with regulatory requirements and raised questions about whether regulatory systems can embrace both green building technologies and heritage conservation principles (Conejos et al., 2016). Adaptive reuse of all types of buildings and sites has become increasingly important as an urban, architectural, and conservational strategy (Plevoets and Van Cleempoel, 2019). However, few studies have considered the topic of vacancy in urban centers *per se*, despite several cycles of interest in adaptive reuse to mitigate economic downturns creating supply and demand mismatches in commercial building markets (Remøy, 2010; Wilkinson and Reed, 2011; Muldoon-Smith, 2016; Armstrong et al., 2021). The challenges of managing existing buildings are complex in mature urban environments, particularly when socioeconomic processes are at play in urban development (Muldoon-Smith, 2016). Various concepts and different interpretations come into play, which contributes to the complexity. Vacancy, in itself, can imply various scales and measurements of the inverse of occupied space. For purposes of this research, vacancy implies the amount of unoccupied space in the respective building in each calendar month in a specific year. The vacancy is measured by the total gross lettable floor area which is vacant on the first day of a respective calendar month (Law Insider, 2022). The vacancy rate is the amount of unoccupied gross lettable floor area expressed as a percentage of the building's, or city's, total gross lettable floor area (PCA, n.d.). Calculations, however, often involve an overly simplistic characterization of space as either "vacant" or "occupied" (Muldoon-Smith, 2016). Similarly, the concept of "adaptive reuse" holds various interpretations. Adaptive reuse is considered the short-term transformation of space to accommodate alternative uses and functions that will contribute to the overall social, economic, and environmental footprint of the building (and surrounding space). It aligns with the approaches to retrofit, refurbish, and renovate, the process of taking an existing structure and updating or adapting it for a new use or purpose, from the position of use and design solution.

Studies spanning 30 years, across different countries, have highlighted that while adaptive reuse could help create a vibrant mixed-use urban village, it should not be seen as a panacea to address vacancy (Barlow, 1993; Muldoon-Smith, 2016; Armstrong, 2020). The complexity of "vacancy" along with the benefits pertaining to "adaptive reuse options" should be understood and explored from a context-based approach in order to find plausible, sustainable solutions.

This is no new issue, but the recent COVID-19 pandemic and related social restrictions that resulted from the pandemic placed a renewed emphasis on understanding how we use urban centers for work, living, and recreation (Vigiola et al., 2022), especially in the light of making sense of the various underutilized and vacant buildings in urban areas globally. It is within this renewed understanding that the concept of "sustainable adaptive reuse" is explored in this article, as a use and design solution to address vacancy and broader resilience goals in urban buildings.

1.1. Unpacking the concept of "sustainable adaptive reuse"

Adaptive reuse is regarded as a form of sustainable development as it facilitates extending the building's life and encourages the reuse of embodied energy (Bullen and Love, 2010). Adaptive reuse is often considered the most environmentally sound approach for the conservation of historical buildings and urban regeneration. In this regard, and as argued by Fisher-Gewirtzman (2016), adaptive reuse is a valuable strategy that involves revitalizing post-industrial cities by creating density, retrofitting post-industrial landscapes, reframing the urban fabric of shrinking cities, and mitigating urban sprawl. The key driver for adaptive reuse in all of these examples is the solution to address vacancy or underuse.

Adaptive reuse and the environment are closely related to one another, which is why adaptive reuse approaches support urban planners to develop low-carbon cities (Aigwi et al., 2020). A study by Bullen (2007) shows that the built environment is the single largest energy consumer and acts as the largest source of carbon dioxide and other greenhouse gas emissions. It is estimated that the global built environment consumes as much as 40% of the total energy produced and is responsible for one-third of greenhouse gas emissions (Cutieru, 2021). Another study by Bullen and Love (2010) shows that the demolition of a building accounts for as much as 48% of solid waste generated from the lifecycle of a building. In this regard, the promotion of reusing existing buildings not only helps in avoiding demolition and reconstructing them but also helps in fulfilling the demands of present and future generations (Sugden, 2018).

On a city-wide scale, sustainable adaptive reuse would be connected to "reduce, reuse, recycle" initiatives in an attempt to enhance carbon-neutral cities, the circular economy, and broader

urban resilience. The circular economy, in this sense, implies an approach to economic growth that is in line with sustainable environmental and economic development (Korhonen et al., 2018). Reusing old buildings simply reflects fulfilling the demands of the present and future generations. Adaptive reuse of buildings avoids the requirement of building demolition and reduces solid waste dumping from old buildings while reusing leftover embedded energy in the old buildings. Similarly, avoidance of building demolition is regarded to be conserving significant heritage values, and therefore, contribute to achieving sociocultural sustainability.

However, adaptive reuse is still far from mainstream planning and thinking, and literature pertaining to reuse and adaptive spaces is limited. Similarly, understanding vacancy as part of urban research is not unpacked to the full extent it should be, to make a valuable contribution to the notion of sustainable and resilient cities. This research set out to explore the connection between sustainable adaptive reuse and vacancy as a precursor to obsolescence, rates of dilapidation of underused buildings, the impact on urban vibrancy, as well as types of building obsolescence, the chronic and acute stresses that lead to vacancy, and the overall impact of vacancy on cities, as explained in the next section.

2. Methodology

This research followed a systematic review to evaluate how adaptive reuse is reported in the literature to address vacancy. The review focused on two aspects of adaptive reuse; namely, (1) how a vacancy is framed in the literature and (2) how adaptive reuse is framed as a solution to address underuse and vacancy.

The purpose of reviewing the literature is to propose a framework that connects a more nuanced understanding of different adaptive reuse approaches and to argue for a more critical discussion of vacancy in adaptive reuse research. The framework proposed seeks to highlight the explicit connection between vacancy as a driver and adaptive reuse and suggests that a deeper understanding of vacancy can aid in the development of new tools to inform adaptive reuse approaches and decisions.

Systematic reviews are gaining importance as part of a qualitative inquiry to understand the dynamics of the built environment as it typically focuses on a well-defined question, and because it provides answers to questions from a relatively narrow range of quality assessed studies (Arksey and O'Malley, 2005). This review follows PRISMA (evidence-based minimum set of items for reporting in systematic reviews and meta-analyzes) and examined how a vacancy is framed in research articles. Scopus was chosen as the database for this systematic review as adaptive reuse research tends to be qualitative in methodology, and it is one of the largest databases of qualitative research literature and reliably produces replicable research, suitable for systematic literature reviews (Baas et al., 2020).

One criticism of literature reviews as research methods is that search constraints can limit and skew the findings of review studies (Snyder, 2019). Although the literature searches attempted different combinations of keywords, the range of literature found may be limited by the following factors: key terms chosen for keyword searches may differ between built environment disciplines. It was noted that each discipline had slightly different preferred terminologies. Adaptive reuse was chosen as the most commonly used term in recent literature in the last 5 years associated with a change of use development. However, this is a potential limitation. Screening criteria were established to reduce potential limitations of review decisions for the inclusion of articles in the review. The screening questions were only used to ascertain the relevance of the context of each article, for example, if vacancy was discussed in relation to the building occupancy, and whether the research primarily focused on adaptive reuse in architecture, planning, property, or construction research. A further limitation could be the timespan used for the articles, although 10 years is a reasonable timeframe to capture sufficient data for review. The systematic review was chosen in order to provide methodological transparency so that the review could be replicated at a later date, as this topic is highly relevant after the impact of the COVID-19 pandemic (Balemi et al., 2021).

The literature identified by the keyword search in Scopus (vacant AND adaptive reuse) is accordingly discussed in the body text. It was acknowledged that certain keywords used in the search could pose limitations, for example, potential bias with subjective terms such as "empty", "vacant", or "abandoned", and whether these terms related to a single floor plate within a whole building or pertained to wholly empty or vacant buildings. The term "vacan*" was used to capture vacancy and vacant. Figure 1 represents the flow diagram of the method employed for the systematic review.

3. Research results

The research examined to what extent vacancy is considered in the decision-making process and by the research design investigating adaptive reuse. The review examined the basis on which adaptive reuse is discussed, from whole building adaptive reuse on a permanent change of use to partial adaptive reuse temporarily. The purpose of understanding literature from these two perspectives (how a vacancy is factored into research and how adaptive reuse is conceived) is important to critically understand the complexity of adaptive reuse and its relationship to urban regeneration through mitigating vacancy. The thematic findings pertaining to the systematic review are presented below.

3.1. From singular to a holistic approach to evaluating adaptive reuse

The fascination of redeveloping old building forms for new novel experiences is growing (Lynch, 2016). Increasingly, non-heritage buildings, perceived to be obsolete, vacant, or underused, are connected with adaptive reuse, including commercial offices (Wilkinson and Reed, 2011; Remøy and van der Voordt, 2014; Hamida et al., 2020), industrial buildings (Petković-Grozdanovića et al., 2016; Tan et al., 2018; Vardopoulos, 2019), and retail (Lesneski, 2011; Roberts and Carter, 2020).

Two key motivators to address vacancy through adaptive reuse are: the fear that underutilized buildings dilapidate quickly, and that they become an eyesore or liability, are underlying motivators advocating for increased adaptive reuse uptake (Bullen and Love, 2011). This could be argued to impact the city's attractiveness

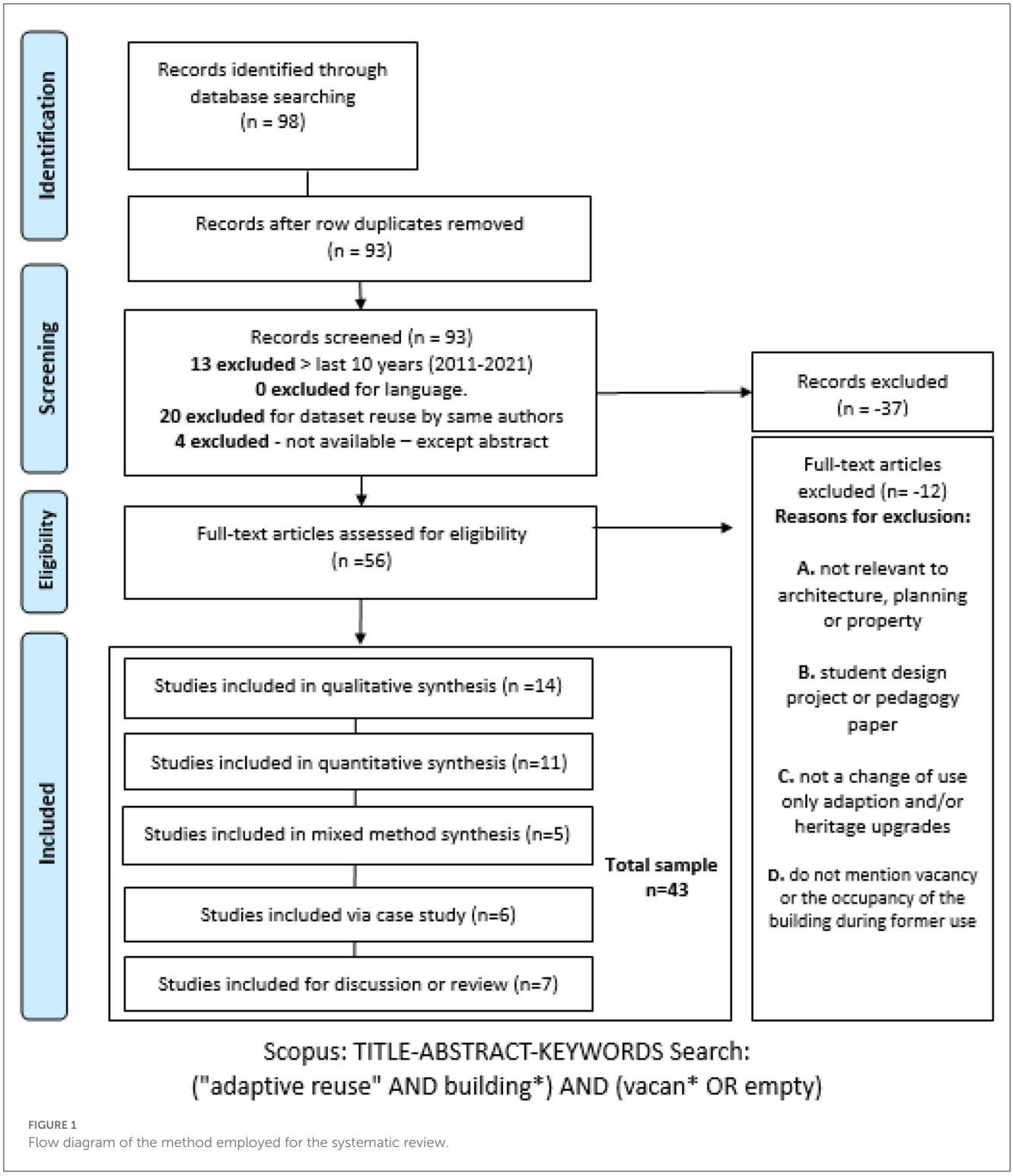

FIGURE 1
Flow diagram of the method employed for the systematic review.

as a whole as a place of investment and economic activity, not just the vacant building itself. This is particularly problematic for buildings of heritage value and the impact of the loss of heritage value on the character or economic value of an area or surrounding properties (Kee, 2019). A further argument advocating for reuse is through an environmental lens, arguing that a failure to optimize a building throughout its lifespan results in a building's residual lifecycle expectancy not being fully exploited (Sanchez et al., 2019). Riggs and Chamberlain (2018) are also critical of an unexpected environmental argument that vacant buildings use less energy and highlight that vacant buildings are not in themselves low energy consumers when city-wide sustainable growth standpoints are taken into consideration, as vacant buildings are inefficient users of the land. These three arguments are applied to single

TABLE 1 Comparing the focus of adaptive reuse literature, through the extent how much of the existing building is considered for adaptive reuse intervention.

Citation	Adaptive reuse extent			
	WBAR	MUML	PAR	TAR
Bullen and Love (2011), Ward (2013), Yap (2013), Remøy and van der Voordt (2014), Yung et al. (2014b), Conejos et al. (2016), Petković-Grozdanovića et al. (2016), Camocini and Nosova (2017), Fianchini (2017), Hong and Chen (2017), Mohamed et al. (2017), Giuliani et al. (2018), Plevoets and Sowińska-Heim (2018), Riggs and Chamberlain (2018), Tan et al. (2018), Bottero et al. (2019), Kee (2019), Turok et al. (2019), Vardopoulos (2019), Williams (2019), Abastante et al. (2020), Abdullah et al. (2020), Aigwi et al. (2020), Hamida et al. (2020), Paschoalin and Isaacs (2020), Roberts and Carter (2020), Vizzarri et al. (2020)	●			
Lesneski (2011), De Silva et al. (2019), Foster (2020)	●	●		●
Wilkinson and Reed (2011), Yung et al. (2014b), Misirlisoy (2020), Vehbi et al. (2021)	●	●	●	
Costa et al. (2019)				●

Extent of intervention: WBAR, whole building adaptive reuse; MUML, Mixed-Use Multiple Levels; PAR, pocket or partial adaptive reuse; TAR, temporary adaptive reuse. Source: Authors.

buildings, localized clusters of buildings, and building populations across cities.

Camocini and Nosova (2017) highlight that vacancy is a risk to all buildings throughout their lifetime. An underlying concern in the literature is the risk of poor economic returns, whereby the financial investment of an adaptive reuse development will be less than the returns post-completion, and consequently, buildings may remain in various states of underoccupancy for long periods (Remøy and van der Voordt, 2014; Riggs and Chamberlain, 2018). It could be suggested that adaptive reuse is an economic solution during periods of low market demand, to help reduce building surplus and transition buildings out of low-demand uses to markets of higher demand. Master planning, or curation of several land uses through adaptive reuse connects single building adaptive reuse to wider reactivation of an underutilized area or shrinking urban center to aid local employment opportunities (Giuliani et al., 2018); it creates tourism visitation (Camocini and Nosova, 2017; Bottero et al., 2019; De Silva et al., 2019; Vizzarri et al., 2020), provides improved health or education services through efficient reuse of public buildings (Juan et al., 2016), better utilizes underused buildings in developing countries (De Silva et al., 2019), develops urban resilience through boosting residential populations (Yap, 2013; Hamida et al., 2020), conserves religious landmarks in post-secular cities (Lynch, 2016), reunite communities through the reinterpretation of buildings' old meanings (Camocini and Nosova, 2017), can aid Transit Orientated Development growth (Riggs and Chamberlain, 2018), and can help transform whole areas into liveable environments (Petković-Grozdanovića et al., 2016; Misirlisoy, 2020). This can even include downtown areas that have vacant buildings being "held" until land values increase (Riggs and Chamberlain, 2018). Collectively, adaptive reuse events across a city can reduce construction's overall carbon consumption and waste compared with premature demolition and site redevelopment (Chan et al., 2020). A further emerging argument is the need to repurpose space to mitigate the sudden and dramatic economic and social shifts brought by social distancing restrictions during the global COVID-19 pandemic. The need for additional space through adaptive reuse in medical emergencies also needs to take account of patients' psychosocial needs on a day to day basis whilst receiving medical care (Roberts and Carter, 2020). More adaptive reuse cases and examples should be developed to show how care settings can improve, be inclusive, progressive, and convergent in the era of an aging population (Roberts and Carter, 2020).

Calls for adaptive reuse policy development argue for a holistic approach, rather than a piecemeal approach considering vacant properties separately, one at a time (Ren et al., 2014). Where there are several vacant buildings with similar land uses, location transformations are necessary, which may involve several buildings or a wider reactivation of an area, which may be accompanied by financial incentives to encourage reuse decisions (Remøy and van der Voordt, 2014). Financial incentives are also connected to developers' preference for the relaxation of regulatory requirements (Yap, 2013). Adaptive reuse becomes a central issue for urban policy when there are several abandoned buildings occupying large or prominent sites in cities (Vizzarri et al., 2020). Interestingly, an examination of eight case studies in Hong Kong identified that if a site is included in designated plans for urban renewal redevelopment, then it is more likely to undergo adaptive reuse. This research indicates that the biggest determiner of adaptive reuse decisions is planning overlays or regeneration plans led by local governments (Yung et al., 2014b).

3.2. Adaptive reuse timing and vacancy risk

Decisions to mitigate the risk of obsolescence can be taken throughout a building's lifecycle, not just at the end of its useful life (Hamida et al., 2020). Models exist to examine adaptive reuse intervention timing, such as Langston et al. (2013) Adaptive Reuse Potential ARP model (Yung et al., 2014b) and AdaptSTAR model to guide future adaptability at the initial stages of design for new construction (Conejos et al., 2016). While adaptive reuse is often described as a process (Douglas, 2006), it is also considered to be a "decision-making problem" (Abastante et al., 2020, p. 14). Adaptive reuse is described as a "looping action" in circular economy principles (reuse, recycle, and recovery) alongside other looping actions such as recycling of materials and waste, and energy recovery from sewage (Williams, 2019). The variables involved in adaptive reuse decisions, or "loops" are not yet clearly ordered in research (Costa et al., 2019). Multiple points of view need to be considered and conflicts of interest exist between various stakeholders involved in the decision-making process (Hong and

TABLE 2 Adaptive reuse decision tools and factors affecting decisions during the building lifecycle.

Citation	Decision making papers	
	Decision making tools	Identifying factors or building attributes
Abastante et al. (2020)	Evaluates MCDA tools, proposes SFR-II method for evaluating adaptive reuse options.	
Abdullah et al. (2020)		Sets out criteria for decision-making for reuse of Malaysian heritage listed pre-war shop houses.
Aigwi et al. (2020)		Identifies parameters for a a performance-based framework to identify underutilized buildings for adaptive reuse
Bottero et al. (2019)	Applies the Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE) to rank criteria for the success of adaptive reuse scenarios for 9 abandoned buildings	
Bullen and Love (2011)		Examines stakeholder views of adaptive reuse for identifying factors
Conejos et al. (2016)		Determines the various challenges encountered in undertaking adaptive reuse
Costa et al. (2019)	Introduces the CAT-SD method to help aid decision making	
De Silva et al. (2019)		Identify remedial actions that can overcome adaptive reuse barriers
Giuliani et al. (2018)	Multi-attribute decision analysis to selecting the best new use for reuse proposals.	
Hamida et al. (2020)		Identify factors influencing adaptive reuse of commercial projects, throughout their life cycle, but no vacancy
Hong and Chen (2017)	Establish evaluation model via Delphi method and analytic hierarchy process	
Misirlisoy (2020)		Identifies key considerations in decision-making process for continuity of traditional markets
Remøy and van der Voordt (2014)		A meta-study to reveal drivers for office-to-housing conversions
Tan et al. (2018)		Identifies critical success factors (CSFs) for adaptive reuse
Vehbi et al. (2021)	Multi-criteria assessment for defining compatible new use	
Vizzarri et al. (2020)		Identifies attributes for decision makers using a case study
Wilkinson and Reed (2011)		Identifies factors driving adaption using PCA analysis—Principal component analysis
Yap (2013)		Case study approach to identify hindrance factors affecting adaptive re-use
Yung et al. (2014b)		Examination of adaptive reuse case studies and decisions to reuse

Source: Authors.

Chen, 2017; Costa et al., 2019; Günçe and Misirlisoy, 2019). The different perspectives add complexity when attempting to rank and apply order to the adaptive reuse decision process.

The end cause(s) of obsolescence may be due to a combination of depreciation factors including their physical, economic, social, technological, legal, or functional performance (Hamida et al., 2020), not all of which require a change of use to remain useful (De Silva et al., 2019). Decisions to transition an existing building to a new market are dependent on a range of factors which have been identified by Wilkinson and Reed (2011), Conejos et al. (2016), Hong and Chen (2017), Aigwi et al. (2020), Hamida et al. (2020), and Vizzarri et al. (2020) (see Table 1). The complexity of factors to consider is wide-ranging, with 18 themes identified by qualitative methods in one article alone (Conejos et al., 2016). However, other than the presence of a vacancy, there is little discussion of vacancy in the wide range of factors. The range of factors suggested, however, appears to change depending on the building typology of the existing building function (e.g., office, industrial, agriculture, and religious buildings) and the proposed new use (affordable housing, health services, and touristic experience). These criteria or parameters for adaptive reuse can be contextualized in helpful frameworks to structure adaptive reuse decision-making, such as a performance-based framework (Aigwi et al., 2020), which poses the need for a framework that connects vacancy to adaptive reuse.

Discussions around underuse and vacancy are limited in available research studies, with many articles presenting a simplistic assumption that office buildings are standing empty in cities.

TABLE 3 Timing of adaptive reuse intervention.

Citation	Timing for adaptive reuse intervention		
	Through-out life cycle	During periods of underuse/increasing underuse	End of useful life or wholly vacant
Bullen and Love (2011), Lesneski (2011), Ward (2013), Yung et al. (2014a), Conejos et al. (2016), Petković-Grozdanovića et al. (2016), Fianchini (2017), Hong and Chen (2017), Mohamed et al. (2017), Giuliani et al. (2018), Plevoets and Sowińska-Heim (2018), Riggs and Chamberlain (2018), Tan et al. (2018), Bottero et al. (2019), Costa et al. (2019), Kee (2019), Turok et al. (2019), Vardopoulos (2019), Williams (2019), Abastante et al. (2020), Abdullah et al. (2020), Paschoalin and Isaacs (2020), Roberts and Carter (2020), Vizzarri et al. (2020)			●
Wilkinson and Reed (2011), Yap (2013), Camocini and Nosova (2017), Hamida et al. (2020), Misirlisoy (2020)	●		
De Silva et al. (2019), Aigwi et al. (2020), Foster (2020)		●	
Remøy and van der Voordt (2014), Vehbi et al. (2021)		●	●
Yung et al. (2014b)	●		●

Extent of intervention: WBAR, whole building adaptive reuse; MUML, Mixed-Use Multiple Levels; PAR, pocket or partial adaptive reuse; TAR, temporary adaptive reuse. Source: Authors.

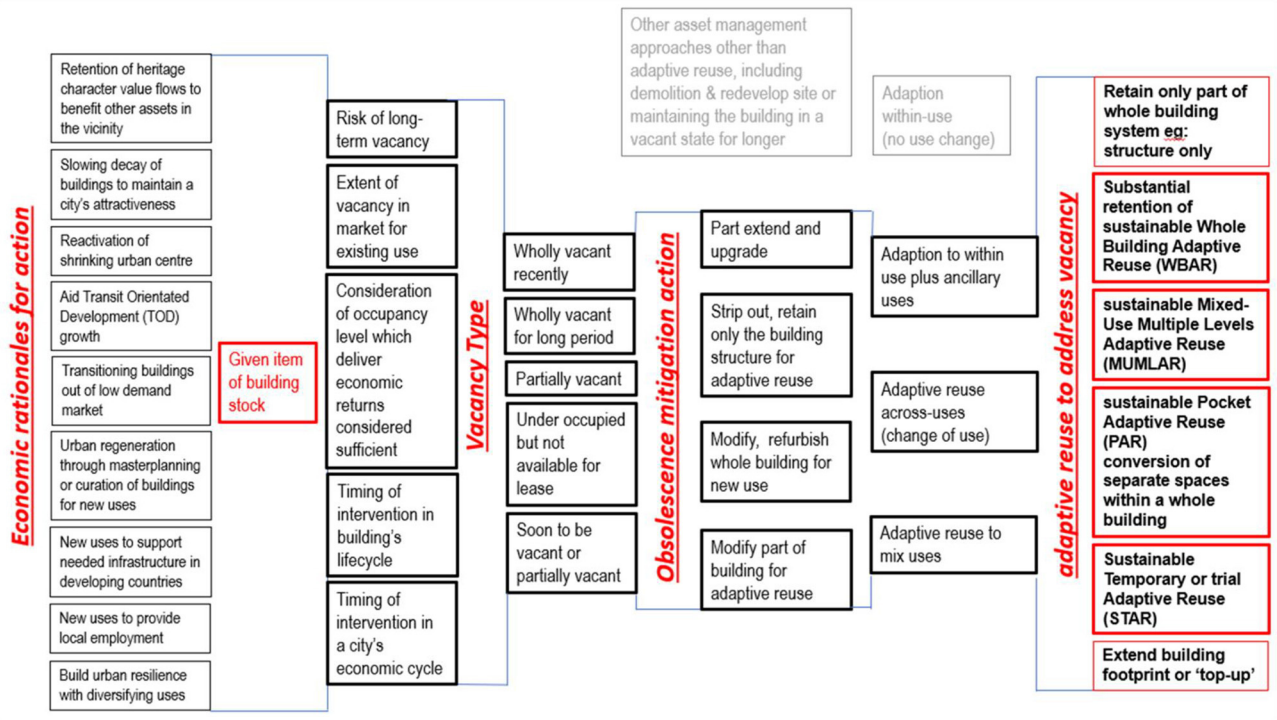

FIGURE 2
Framework for adaptive reuse of buildings.

Many articles in the review assumed buildings are wholly vacant or make no reference to the processes to ensure a property is vacant before adaptive reuse occurs. There is some recognition, however, that the process of obsolescence may occur over time. Sanchez et al. (2019) suggest that adaptive reuse is useful when buildings are "nearing the end of their disuse stage" (p. 422), but no in-depth research was found by this review that even begins to clarify the stages of disuse prior to standing wholly empty or abandonment.

Vacancy rate (%) is one criterion to identify underuse (Remøy and van der Voordt, 2014; Abdullah et al., 2020). However, there is a lack of sufficient detail in the literature of what constitutes a high vacancy rate for any given building, neither is there any explanation of "underuse" available. The suggestion of 3–8% is a healthy aggregated vacancy rate across a commercial building market to allow for business growth and accommodation flexibility (Remøy and van der Voordt, 2014). However, on a single building scale, there is no such guidance as to what vacancy percentage

constitutes a high, or "unhealthy", vacancy rate and a potential threshold for considering adaptive reuse on a single building scale. Length of vacancy is also considered to be a factor, suggesting that 3 or more years of vacancy can be considered as terminal or "structural vacancy" (Remøy and van der Voordt, 2014).

The literature reviewed tended to use the following terms in association with vacancy: vacant, long-term vacant, abandoned, derelict, obsolete, and redundant, suggesting that the buildings focused on terminal conditions. More nuanced terms were also found, such as underused and underutilized. These nuanced terms acknowledge that there may be a gradual process of obsolescence and highlight that the presence of vacancy could be a useful indicator of the increasing risk of obsolescence. A different perspective is to consider vacancy as an opportunity for development, as a derelict building is not "considered as an empty space but as a potential flexible area" (Vizzarri et al., 2020, p. 57).

Vacancy across property markets is often used as a measure by property market groups to understand supply and demand and investment trends in adaptive reuse decisions (Bullen and Love, 2011; Abdullah et al., 2020). Another observation is that adaptive reuse can be initiated through the community (Yung et al., 2014a) and local government services (Lesneski, 2011), as well as the private sector. Plevoets and Sowińska-Heim (2018) refer to "vernacular adaptation" as the more spontaneous and informal ways associated with adaptive reuse, which has also recently seen a raise in awareness, alongside the more formal approaches employed within architectural and conservation practices. Plevoets and Sowińska-Heim (2018) investigated the division between the vernacular and the formal approaches to adaptive reuse and emphasized the possibilities and risks of joined initiatives between local communities and private or public developers. The vernacular approach is proposed as a valuable bottom-up urban planning strategy, as a means for building and site regeneration, especially since it can provide a better understanding of the intangible values of architectural heritage that are important to the local community, while also providing a better understanding of the needs of the community for the new function of a specific place (Plevoets and Sowińska-Heim, 2018). "Vernacular reuse as part of the adaptation process has strong social significance" and it fosters an intense relationship with the place, as the community is directly involved in the "creation of the functional new place and its contemporary history" (Plevoets and Sowińska-Heim, 2018).

Despite the interest in vacancy data by property markets, data are not routinely collected, and Williams (2019) suggests one reason for this is the low cultural value placed on the vacancy and underutilized land and buildings beyond extracting value from the real-estate or asset management perspective. An examination of vacancy data across markets could be highly useful for evaluating the risk of obsolescence in existing building uses and assessing proposals for new uses as is suggested, "an evaluation of the potential property market and location characteristics must be done by answering the following questions: (i) is there an oversupply of [existing] underutilized historical buildings? (ii) is there adequate demand for the proposed new use?" An examination of supply and demand for both the existing use and potential new uses is suggested (Aigwi et al., 2020, p. 3).

3.3. The iterations and different interpretations of adaptive reuse

Overall, adaptive reuse literature tended to focus on buildings perceived to be wholly empty and with a focus on "whole building adaptive reuse" (WBAR) as the final solution for empty buildings (see Table 2). This finding suggests a consensus that adaptive reuse is currently mainly considered to be a last-resort option for buildings that are prematurely obsolete and still have residual value.

Adaptive reuse can occur at other scales other than whole building as captured in Table 1 (Lesneski, 2011; Wilkinson and Reed, 2011; Yung et al., 2014b; Costa et al., 2019; De Silva et al., 2019; Foster, 2020; Misirlisoy, 2020; Vehbi et al., 2021). Four categories of adaptive reuse are reported in the literature.

Partial adaptive reuse is discussed as a form of adaptive reuse, but reported as both positive and negative (Vehbi et al., 2021). An example is given of a partial adaption of a nearly vacant building, but the remaining vacancy in the unadopted portion of the building is viewed as a threat to the building's ongoing viability.

Several articles discuss the benefits of "temporary adaptive reuse" (TAR), explaining that TAR of abandoned buildings can draw positive attention back to the "forgotten" structures and can be a starting point for a more permanent transformation (Olivadese et al., 2017; Costa et al., 2019). The article recognizes that TAR can be used as a catalyst for obsolescence mitigation, as well as a mitigation solution in itself, as TAR can make forgotten vacant buildings visible again and stimulate interest in their reactivation. TAR, therefore, is considered a cost-effective low-intervention form of adaptive reuse as a strategy to mitigate obsolescence and highlights the need for a more nuanced understanding of the range of adaptive reuse options and the roles adaptive reuse can play in mitigating vacancy before a building reaches its final state of abandonment or dilapidation and considered obsolete.

The addition of new ancillary uses through extending the building is interesting as the adaption points toward the creation of a mixed-use building of new and existing uses (Wilkinson and Reed, 2011).

Adaptions involving no changes of use should be mentioned here, as they are discussed in the literature reviewed. These are conceived as adaptions within the use, with energy efficiency upgrades and maintenance improvements being key drivers (Wilkinson and Reed, 2011). Adaptions without new uses are arguably not adaptive reuse, only adaption. New extensions and selective demolition are two other adaptions within use that change a building's external appearance unless the new extensions include new uses not previously incorporated into the existing building (Wilkinson and Reed, 2011).

The review highlights that different combinations of adaptive reuse extents and the overall vacancy "problem" the adaptive reuse intervention will solve points to further possibilities for adaptive reuse: adaption across a use for several stacked floors, creating mixed-use on "multiple levels of adaptive reuse" (MUML) through consolidating existing tenants but not converting the whole building. A further alternative could be adaptive reuse conversion of only "pockets of adaptive reuse" (PAR) located on single floors or parts of floor plates.

3.4. Vacancy in adaptive reuse decisions

A range of studies captured in this review have tested and adapted MCDA tools for assessing adaptive reuse in the disciplines of architecture, planning, and asset management. Table 2 identifies the articles which have developed or tested MCDA tools or have identified factors to consider on MCDA tools. Research that focuses on MCDA tools is important in this review as adaptive reuse involves consideration of a complex set of competing criteria to convert an existing building for a new use to resolve low demand for a building's current use(s), for example, Hong and Chen (2017), Giuliani et al. (2018), Bottero et al. (2019), Costa et al. (2019), Abastante et al. (2020), and Vehbi et al. (2021). While it is out of the scope of this article to review these tools beyond Table 1, it does find an important gap in research. Without exception, the studies all cited vacancy as a key driver for adaptive reuse in their introduction and discussion sections, but vacancy was not included in the decision-making tools presented, or factors identified as important criteria in the decision-making process (see Table 1). The lack of inclusion of vacancy in adaptive reuse MCDA tools highlights the need for amending how a vacancy is conceived in adaptive reuse decision-making research. Rather than limiting vacancy discussion to end-of-life solutions, this gap highlights the opportunity to understand how vacancy can be useful as an integral factor in asset management decisions, including adaptive reuse feasibility assessments, to mitigate the risk of obsolescence earlier in a building's life cycle.

De Silva et al. (2019) rank and identify remedial actions that can overcome adaptive reuse barriers (see Table 2). They suggest two states of vacancy—whole building or partial vacancy. The research also suggests that vacancy can be a "state" in which buildings are left if there is no adaptive reuse intervention. They concur with the literature (Kincaid, 2002; Wilkinson, 2018) that there are two "parent" categories of adaption, referred to as adapt within-use and adapt across-use. They present two "child" categories of adaptive approaches, referred to as adaption into a mixed-use building and adaption to include ancillary uses. This suggests that the new ancillary use is in harmony with the current uses. It implies that adaptive reuse can be on a partial building basis to address partial vacancy and to slow or reduce the risk of vacancy becoming permanent or spreading.

Vehbi et al. (2021) suggest adaptive reuse of only part of a wholly vacant building is another approach used in practice. However, they describe this as disadvantageous, suggesting that partially converted buildings may not "fully integrate with city life and there is a danger of losing urban memory due to its [ongoing] vacancy" (p. 17). Alongside the attention in research is overwhelmingly on whole building adaptive reuse, this suggests that research into partial adaptive reuse is insufficiently explored, and only whole building conversion is desirable. This article, however, would like to challenge this and present a framework for adaptive reuse which considers vacancy and adaptive reuse at different scales within buildings.

As shown in Table 3, many articles suggest that adaptive reuse can be considered throughout a building's life cycle (Yap, 2013; Yung et al., 2014b; Camocini and Nosova, 2017; Hamida et al., 2020; Misirlisoy, 2020). Several other articles went further to qualify adaptive reuse as useful to address underoccupancy or increasing vacancy (Remøy and van der Voordt, 2014; De Silva et al., 2019; Aigwi et al., 2020; Foster, 2020; Vehbi et al., 2021). However, the lack of discussion of vacancy prevents further understanding of what level or distribution of vacancy may be considered problematic or risky for the long-term viability of a building's current function(s).

Through synthesizing Tables 1, 3, this review suggests that research that discussed a more nuanced understanding of adaptive reuse, other than whole building adaptive reuse, tended to consider adaptive reuse as a remedy to vacancy beyond a building's final "end of life" stage. This review found literature focused on buildings that had or were perceived to be wholly vacant (see Table 1). In addition, there is little discussion of any previous asset management decisions in the case studies presented to mitigate the onset of vacancy much earlier in a building's lifecycle. Research predominantly focuses on adaptive reuse decisions at a building's end-of-life scenario (see Table 1). This is an important gap as adaptive reuse is only one way to extend a building's lifespan sustainably (Wilkinson, 2018) and not all adaptive reuse transformations result in net environmental benefits compared with new construction (Sanchez et al., 2019; Chan et al., 2020).

3.5. The expectation of adaptive reuse uptake

The rationale for greater adaptive reuse is often based on the premise of supply and demand, coupling a shortage of one building use with an oversupply or abandoned stock of an obsolete use. Where this rationale underpins the research, findings often suggest that there is a low take-up of adaptive reuse and look for reasons to explain the perceived low take-up (Ren et al., 2014; Olivadese et al., 2017; add more).

One suggestion is that planning regulations and building codes may be a hindrance (Olivadese et al., 2017). In this comparative review of two different regulatory approaches (Dutch and Italian), regulation adaptive reuse uptake is suggested to be low. The Dutch system offering low compliance standards for adaptive reuse development when compared with new development suggests that regulation may not be an inhibitor of adaptive reuse uptake. If the uptake of adaptive reuse in the Netherlands is considered to be low, the recommendation to relax building regulations in Italy to support adaptive reuse seems an ineffective suggestion. One further explanation offered is that of a failure of policy (Ren et al., 2014). Connecting the perceived low uptake with policy deficiency is a large claim, especially given the difficulty in establishing causality, and the complex range of factors in adaptive reuse decision-making, such as poor location and inadequacy of surrounding infrastructure. There is a possibility that expectations are too high for adaptive reuse uptake and that it is unrealistic to simplistically connect a high demand and low supply in one property market with a building stock suffering low demand and an abundance of underuse or abandonment.

3.6. How vacancy is framed in relation to adaptive reuse

Literature tended to discuss vacancy as an introductory starting point only to justify their article's focus on adaptive reuse. This limits discussion and evidence to explore vacancies more in depth and insightful ways. The sinking stack theory proposed by Atkinson (1988) seems to be a common notion assumed in adaptive reuse research, whereby vacancy in older buildings increases as new buildings are completed and enter the market (Abdullah et al., 2020). In times of economic downturns, a further assumption suggests when there are high vacancy rates, tenants move to newer buildings if rents in newer buildings are comparable (Remøy and van der Voordt, 2014). However, there are no vacancy studies to test the theory of sinking stack in different property markets over time, and whether the theory holds true in different geographic locations or markets, at different points in a property market economic cycle.

Several articles discuss adaptive reuse within the context of avoiding obsolescence at an earlier stage of underuse (Misirlisoy, 2020) and are suggestive that adaptive reuse needs to be incentivized, with economic subsidies and regulation variations to keep building occupied and useful if they have not yet reached the end of their design life (Riggs and Chamberlain, 2018). In buildings that can accommodate a curated mix of uses, adaptive reuse of traditional spaces is seen as beneficial to the continuity of such buildings, such as marketplaces (Misirlisoy, 2020).

Qualitative interviews suggest that there are wider economic benefits of reactivating vacant buildings as the occupation of the previously vacant building can increase visitation to surrounding commercial businesses (Yung et al., 2014a). However, adaptive reuse may not always be sufficient and have the desired positive impacts on areas suffering high vacancy. Adaptive reuse is more viable when surrounding spaces are occupied and utilized, suggesting new uses may not be sustainable in the long term when vacancy is still present (Vehbi et al., 2021). Depending on the scale and social function of the proposed new use, adaptive reuse can physically shift a community's center and its visitation or footfall. A US adaptive reuse study concluded that relocating civic uses, for example, libraries, from urban centers to urban edges, can be another "nail in the coffin" for some urban centers already suffering vacancy (Lesneski, 2011, p. 405). A study of the location of vacancy could help predict potential unintended consequences of adaptive reuse in urban centers with high levels of underuse. The reverse of course could also be argued if the proposed civic function is newly created or a geographic relocation.

One article examines the benefits of adaptive reuse through an economic lens using a hedonic price model to find if the adaptive reuse of cultural heritage buildings can increase the value of surrounding residential properties within Hong Kong (Kee, 2019). It is argued that the increase in value is due to the positive externalities generated by restoring a vacant heritage building. However, as this study does not enter into discussions about vacancy in any depth, it is difficult to ascertain if the previous vacancy and continued disuse of the heritage property had any negative effects on the surrounding residential property values. As the evaluation examined impacts on residential property prices, it could also be argued that adaptive reuse can trigger gentrification (Yung et al., 2014a). This review found no studies which applied the hedonic price model to vacancy, and this review welcomes future studies which apply the hedonic price model to surrounding non-residential properties to examine the economic benefits of adaptive reuse to urban commercial centers.

Vacancy is identified as an economic problem during adaptive reuse decision-making (Abdullah et al., 2020). The presence of vacancy is identified as a problem in how buildings are valued for resale and how adaptive reuse developers calculate the feasibility of adaptive reuse for existing buildings. A market value appraisal for resale is often based on rental potential (Remøy and van der Voordt, 2014). Although vacancy generates no rental income, vacancy is often not reflected in the appraisal value for resale. The resultant asking price does not come close to the residual valuations relied on by adaptive reuse developers. Where vacancy is not factored into valuations, differences between methods of valuations can leave buildings with high vacancy empty for long periods of time (Remøy and van der Voordt, 2014).

No articles captured in the review cited the presence of partial occupancy as a challenge to whole building adaptive reuse, despite space being subject to legal lease agreements, and dissolvement or expiry of leases may take considerable time and resources to occur. Where vacancy was discussed, research mainly presents the simplistic scenario of buildings being 100% vacant, or the scope of the research did not include vacancy. Two studies did calculate aggregated vacancy rates and quantified the area of vacant space across a population of industrial buildings (Ren et al., 2014; Tan et al., 2018). By aggregating the data, however, they did not identify how the vacancy was distributed across the population and whether some buildings were wholly vacant or were being partially occupied. Both studies assumed buildings were standing empty, even though this could not be conclusively deduced from the aggregated data presented as vacant space could be spread across the whole building stock, with low variance in levels of occupied space and underuse. Aggregated data is highlighted as problematic along with incomplete vacancy data (Williams, 2019). The assumption that high vacancy equates to empty buildings is a common assumption where vacancy data is absent or aggregated. This assumption is a problematic gap in adaptive reuse literature.

The narrow application of adaptive reuse to only buildings which are 100% vacant is also problematic when advocating for greater uptake of adaptive reuse at earlier stages of an obsolescence risk, not just of abandoned buildings, but of buildings that are starting to become underutilized. Buildings that are not vacant have occupants who are left with no choice and are often forced to move out of the adaptive reuse projects (Yung et al., 2014a). An article reviewing adaptive reuse literature highlighted a gap in considering the social or equitable aspects of adaptive reuse (Mohamed et al., 2017). Processes to relocate existing tenants to new accommodation are absent in discussions, as is a reference to consolidation action of pockets of space use and vacancy to enable adaptive reuse of only part of a building.

3.7. Vacancy post adaptive reuse event

Vacancy is connected to demand, and the risk of low demand for new space through adaptive reuse is no different from that of new space in a new building. The literature is conflicted about the

impact of former uses on end users. Stakeholders believe that the former use can influence the end-user demand (De Silva et al., 2019) with other research presenting evidence that alternative views of end users are ambivalent about a building's former use if the new design meets their needs (Glumac and Islam, 2020). This alternative evidence highlights the role of design to transform buildings affected by negative perspectives associated with the former use and highlights the quality of design to meet end-user expectations for a converted building, fit for purpose. Design quality in the adaptive reuse process reduces the chance of the new use becoming vacant Glumac and Islam (2020).

4. Discussion

The articles considered in this research, mostly discussed vacancy as a whole building phenomenon only, thus assuming the building had already reached the point of obsolescence in a building's lifecycle. The review highlights that vacancy is mainly assumed, rather than critically discussed, or examined in an analysis of the data presented. Despite the various articles alluding to vacancy, the data presented in the articles do not critically discuss or unpack vacancy. Despite vacancy and obsolescence being mentioned as fundamental drivers of adaptive reuse, critical discussions of vacancy, or disuse, were not a key feature in any of the case studies; and were not included in any framework, tool tested, or developed, to aid adaptive reuse decision-making.

Although vacancy and obsolescence are featured in all articles included in the review, adaptive reuse articles reviewed presented little commentary to explain the process of increasing or pre-obsolescence stages when discussing new tools or frameworks developed to aid adaptive reuse decision-making. It is acknowledged that early intervention to reuse buildings is beneficial as costs and complexity increase when buildings are left vacant for long periods (Yung et al., 2014b). Discussion of vacancy is limited to making generalized points advocating for greater adaptive reuse uptake. This lack of critical discussion about vacancy was prevalent and not dependent on the scope or focus of the research presented, neither at a single building scale, across a sample in any given building stocks, in wider urban regeneration masterplans of geographic areas suffering decline, for periods of shortages of specific markets, nor services such as affordable housing shortages, healthcare facilities, and educational spaces.

This review concurs with Chan et al. (2020), in that current knowledge of adaptive reuse is reliant on qualitative analysis of subjective evaluations of a project's environmental, social, and economic impacts compared with demolition and site redevelopment. Vacancy was not sufficiently unpacked in the multiple criteria decision analysis research and did not appear in the resultant tools or frameworks presented. Its absence is at odds with the framing of vacancy as a primary driver of adaptive reuse. We propose that the inclusion of vacancies in MCDA research outputs can inform the adaptive reuse decision process. For example, the length of time a property has been left vacant and the resultant implications for its rate of decay and condition, and phasing of adaptive reuse development—will the whole building be adapted or will some vacancy be acceptable to ensure the construction economics and returns.

While urban researchers often use social inquiry methods to map and survey what does exist in our urban centers, the mapping of what is not present or what is vacant is more difficult. There is a lack of attention to vacancy in literature, including ways to understand, describe different types of vacancy in space, and quantify vacancy. This lack of understanding could explain why there is little attention to other solutions to vacant space other than adaptive reuse. Greenhalgh and Muldoon-Smith (2017) propose that adaptive reuse is the only option available to mitigate obsolescence and vacancy. They go on to describe adaptive reuse as a higher-level intervention due to the decision complexity and investment required to transition a building from one market to another.

During the COVID-19 pandemic, methods however have emerged to map the absence of people, such as analysis of the City of Melbourne's CLUE datasets which provides visitation data (Loader, n.d.). Overlaying visitation data with building underuse and vacancy data provide a holistic picture of what is not happening in urban centers, and over time the data could be used to evaluate the efficacy and impact of any policy mechanisms applied to urban centers to mitigate vacancy, including adaptive reuse.

5. Conclusion

This article is predicated on the changes that have occurred in the use of our cities and their buildings during and immediately after the COVID-19 lockdowns. These changes demand a deeper understanding of vacancy among stakeholders so that sustainable reuse opportunities can be maximized or alternatives sought. Educating current and future stakeholders about what can be, rather than what is, is imperative (Roberts and Carter, 2020). This is the goal of sustainable, adaptive, reuse approaches, transforming vacancy into potential, as explored in this article.

The review highlighted that vacancy is mainly assumed in research, rather than critically discussed. Despite alluding to vacancy in the articles, data presented in the articles do not unpack vacancy any further than a mere mention or underpinning assumption in any meaningful way. Buildings are considered to be either empty or occupied with no discussion of the continuum between the two states (Muldoon-Smith, 2016).

This literature review finds that there is a predominant focus in research on whole building adaptive reuse; either whole building AR or whole building demolition, with only limited retention, e.g., historic façades, which is not sustainable adaptive reuse. Adaptive reuse needs to be considered on sociocultural grounds, as well as upgrading the physical building. The reason is that the proposed new use may not be viable in the long term, either on economic or cultural grounds. If sociocultural aspects cannot be sustained or if the adaptive reuse "lack(s) a living function", the building is at risk of further premature obsolescence (Günçe and Misirlisoy, 2019, p. 12). Vacancy may persist after adaptive reuse has occurred.

The persistent presence of vacancy and perceived low adaptive reuse uptake can often be framed as evidence of barriers preventing adaptive reuse (Armstrong, 2020). However, the lack of critical attention to the vacancy is problematic when stating this assumption. A recent quantitative study of vacancy by Armstrong (2020) shows that high aggregated vacancy rates do not necessarily

mean buildings are standing empty. High levels of vacancy across a city may be evenly dispersed across a building population—rendering whole building adaptive reuse, therefore, an unlikely "fit" for the vacancy distribution. It is evident that further research is needed to understand adaptive reuse at different scales of application, other than the whole building.

Sustainable adaptive reuse approaches transform the "what is" to the "what can be" and provide space and opportunity for transforming our urban environments. The gap to understand how adaptive reuse approaches can resolve different vacancies in existing buildings is addressed by proposing a framework for adaptive reuse to recognize the different forms of adaptive reuse and aid the selection of adaptive reuse solutions to reduce the risk of premature obsolescence and demolition.

As highlighted by Sassen and Kourtit (2021), the framework recognizes that cities and urban agglomerations have never been static, and aligns with their view that the evolution of cities is a permanent part of the urban landscape.

This article establishes the gap in the literature around vacancy and the importance to address this gap due to the wide range of benefits as a valuable strategy for addressing vacancy as highlighted by Fisher-Gewirtzman (2016), including revitalizing post-industrial cities, densification, addressing shrinking cities, and mitigating urban sprawl, and by Bullen and Love (2010) to mitigate and adapt to climate change through minimizing embodied energy losses and landfill waste. Vacancy is often a factor in assessing and evaluating areas or buildings for redevelopment but there is little discussion on what emerging underoccupancy looks like, other than assumptions about a building being wholly empty. Without a deeper discussion on vacancy, negative impacts from inappropriate adaptive reuse and gentrification will continue to occur (O'Callaghan and Lawton, 2016).

In conclusion, we propose a framework for sustainable adaptive reuse, which is in response to the limitations in the literature pertaining to "vacancy" and "adaptive reuse" as argued in this article.

5.1. The proposed framework for sustainable adaptive reuse

Based on the findings in this article, a new framework for adaptive reuse is proposed, adapted from Wilkinson (2018, p. 8) and Armstrong (2020, p. 97), to refocus and better understand adaptive reuse, as captured in Figure 2.

The framework proposed applies a vacancy lens as vacancy is framed as a key driver in the literature. It invites adaptive reuse researchers, policymakers, and asset managers to consider vacancy upfront as both a rationale for the need for change and also to inform the type of adaptive reuse which is best suited for successful outcomes. The types of adaptive reuse derived from the literature and proposed in the framework are sustainable temporary or trial adaptive reuse (STAR) partial (PAR), mixed-use on multiple levels (MUML), and the well-researched whole-building (WBAR). STAR is an alternative to "wait and see" or "do nothing" approaches when there is a lot of uncertainty in property markets, or the shocks and stresses are new and unforeseeable, such as those experienced globally since the start of COVID-19.

This framework could be adapted to support adaptive reuse decisions in resolving vacant at a single building scale or during master planning in urban regeneration masterplans, as well as informing urban policy development to support sustainable reuse to meet carbon emission reduction targets. In essence, it contributes to a point of departure to understand how adaptive planning approaches could be applied to enhance broader sustainability and resilience initiatives and address inefficient land use and underoccupancy in existing buildings.

The findings and framework align with the development of an adaptive reuse SWOT-PESTLE matrix for adaptive reuse development (Vardopoulos and Theodoropoulou, 2020). The matrix identified several factors in their SWOT analysis considered to be weaknesses of the decision-making process when evaluating buildings for adaptive reuse development. These are political support, including changing existing land use zoning; an inability to estimate economic viability, particularly if a building is not wholly vacant; and requirements for compliance with current building standards. This last weakness could be partly due to uncertainty of what vacancy is or what vacancy looks like during a building's process of becoming empty. The overly simplistic assumption about vacancy levels (i.e., only wholly vacant) could be a driver of this weakness and could contribute to the uncertainty of how to regulate existing buildings that are underused but not wholly empty.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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