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Systematic review of drivers influencing building deconstructability: Towards a construct-based conceptual framework

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Abstract

Deconstruction is an innovative and sustainable option for building end-of-life. It can turn the negative impacts of demolition, including diverting valuable resources from the congested landfill into beneficial use through reuse and recycling. However, the feasibility of deconstruction has placed a massive limitation on the implementation of deconstruction. This research carried out a systematic literature review of 35 academic and 3 non-academic pieces of literature to develop a construct-based deconstructability framework. This framework – built around technical, economic, legal, operational, schedule and social construct – describes the condition under which deconstruction is likely to work and drivers influencing deconstructability. A total of 44 drivers influencing deconstructability were established and ranked from which design and building technology, cost including expense and revenues from the resale, supply and demand of the recovered component and material, the schedule for the deconstruction were identified as most influential. However, every identified driver should be considered during the deconstructability assessment of a building.

Keywords

Building deconstruction, deconstructability, conceptual framework, circular economy, sustainable end-of-life

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Introduction

The built environment industry is an industry with a vast number of activities. These activities include design, planning, construction, alteration, renovation, demolition and maintenance of a building/ structure throughout its lifecycle. The industry is amongst the principal sector of the United Kingdom (UK) and world economy – contributes to over 6% of the economic output in the UK, which is equivalent to £117 billion in the year 2018 (Rhodes, 2019) and over 10% of the world gross domestic product (Crosthwaite, 2000). Construction in the UK and many other countries is not an economic driver alone, but it impacts social lives – the built environment has increasingly enhanced the development and wellbeing of people and support healthier communities (Altomonte et al., 2020; McKinnon et al., 2020; Younger et al., 2008).

Despite the recognized benefits of the industry in the UK and the world, contemporary arguments indicate the built environment to be an environmentally disadvantageous industry. It remains one of the significant resources consumption industries, responsible for around half (50%) of global natural resources consumption, including materials, and energy, to name but a few (Assefa and Ambler, 2017). Furthermore, around one-third of total landfill waste and over two-fifth (40%) of all the carbon dioxide (CO_2) releases (DEFRA 2020; TERI, 2017) are associated with the different stages of the building lifecycle, including the extraction of the raw materials, design, use, management and end-of-life (EOL).

The current construction practices need to be reconsidered to reduce the detrimental impacts and to create a more sustainable industry. In this context, an essential and sustainable option for most buildings at their EOL should be deconstruction instead of demolition, which a typical building was designed. Deconstruction is the careful and selective disassembly of the building or its component for reuse, repurposing or recycling. It is arguably a better sustainable alternative to demolition, which is destructive, rendering more than 90% of the entire building or its components as waste (Del Río Merino et al., 2010). Furthermore,

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deconstruction could address 'Circular Economy Principles' in the construction industry, leading to reduction of CO_2 gas emissions through the gains of reuse and recycling of material/component from building/structure at the EOL (Akinade et al., 2017a; Nakajima, 2014). Regarding diversion of waste from landfills, research indicated that a significant amount of waste can be rerouted to next use through a well-thought-out deconstruction, for instance, approximately 40% (around 16 million tonnes) of the Construction, Demolition and Excavation (CD&E) waste in the UK (DEFRA, 2020) and over 75% (around 460 million tonnes) in the United States of America (United States Environmental Protection Agency (US EPA), 2018) can be transformed from a liability into an asset. In addition, benefits of deconstruction can also include saving costs for landfill tax; for example, the over £500 million landfill tax paid by UK companies yearly can be averted (HM Revenue & Customs, 2019). Aside from diversion of waste and potential savings (e.g. landfill tax), other benefits of deconstruction include the creation of a market for salvaged materials, workforce development, historic preservation of structures or their components, job training, to name but few (Denhart, 2010; Teshnizi, 2019).

Even though there is an increasing interest in deconstruction due to its accruable opportunities, the trend is still far from widespread. This limitation in implementation is because a typical building is not designed for disassembly; it is mostly cast-in-situ, built-in, or chemically bonded together in a way that prevents easy deconstruction (Akanbi et al., 2019; Akinade et al., 2015; Chini and Bruening, 2003; Kibert et al., 2000; Morgan and Stevenson, 2005; Rios et al., 2015). However, deconstruction's economic and environmental advantage have given rise to research trying to evaluate/assess existing buildings for deconstruction and encourage new stocks to be designed for disassembly/deconstruction.

Generally, knowledge on the deconstruction feasibility of a building or its component has placed a massive limitation on the implementation of deconstruction. As a result, it is often hard to decide the candidacy of a building for deconstruction at their EOL. The building deconstruction feasibility, referred to as deconstructability throughout this research, will enable informed decision-making before capital investment. Thus, saving demolisher/deconstruction industry and other stakeholders from demolishing buildings that are deconstructible and encouraging wider deconstruction implementation.

However, the deconstructability assessment is possible only after understanding the concept of deconstruction and the drivers influencing the deconstruction. Thus, this research is the first of its kind to establish and unify all deconstructability influential drivers towards a construct-based conceptual framework. To achieve this aim, the following are the study's objectives:

1. To establish drivers influencing the deconstructability of buildings from literature.
2. To develop a deconstructability construct-based conceptual framework
3. To rank the identified drivers, thus establishing the importance among the constructs

This study will contribute to knowledge by identifying and unifying valuable drivers helpful in deciding the deconstructability of a building irrespective of the type of material of the building. It will change the narratives behind deconstruction, significantly improving the efficiency around assessing existing buildings and creating more awareness around drivers responsible for ease of deconstruction during the design stage. The scope of this work is limited to identifying relevant drivers and developing a construct-based conceptual framework for the deconstructability of buildings.

The rest of this research article is organized as follows: Section 'Demolition and deconstruction' presents a brief introduction on demolition, deconstruction, their difference and benefits. Section 'Methodology' presents the review methodology used in establishing the drivers influencing the deconstructability. Finally, Section 'Result and discussion' focuses on the result and discussion of the systematic literature review (SLR), while the conclusion, limitation and future direction round up the study.

Demolition and deconstruction

Thomsen et al. (2011) defined demolition as 'the complete elimination of all parts of a building at a specific location and time, typically it is the end of life for the building'. Zahir et al. (2016) describe demolition as an engineered process that uses heavy equipment or manual tools to knock down building/structure and render the building/structure into rubble and debris. Equipment/tools used to tear down structure/building include excavator, bulldozer, tearing balls and explosives such as dynamite and Royal Demolition eXplosive (RDX) (Pranav et al., 2015; Rathi and Khandve, 2014).

To carry out a demolition project, there are several drivers to be considered. To name a few, these drivers are a type of construction, safety, cost, scheduling, work sequence. In addition, the preparation and implementation of demolition assignments need to comply with some set of guidelines and criteria, such as safety and environmental assessment of the site and other community-specific regulations (Diven and Shaurette, 2010). Demolition is quicker, uncomplicated and relatively inexpensive. However, many criticized demolitions due to lack of separation, making material reuse and recycling difficult and owing to a large amount of CD&E waste (Chini and Bruening, 2003).

On the other hand, deconstruction also referred to as disassembly is used interchangeably in this research. Deconstruction is the process of carefully knocking down a building/structure into its components to rescue its materials for recycling, reuse and reconstruction reasons (Rios et al., 2015). Thus, deconstruction is the 'means to an end, and it exists for the appropriate recovery of building elements, components, sub-components, and materials for either reuse or recycling in the most cost-effective manner' (Guy, 2004). Other definitions of deconstruction

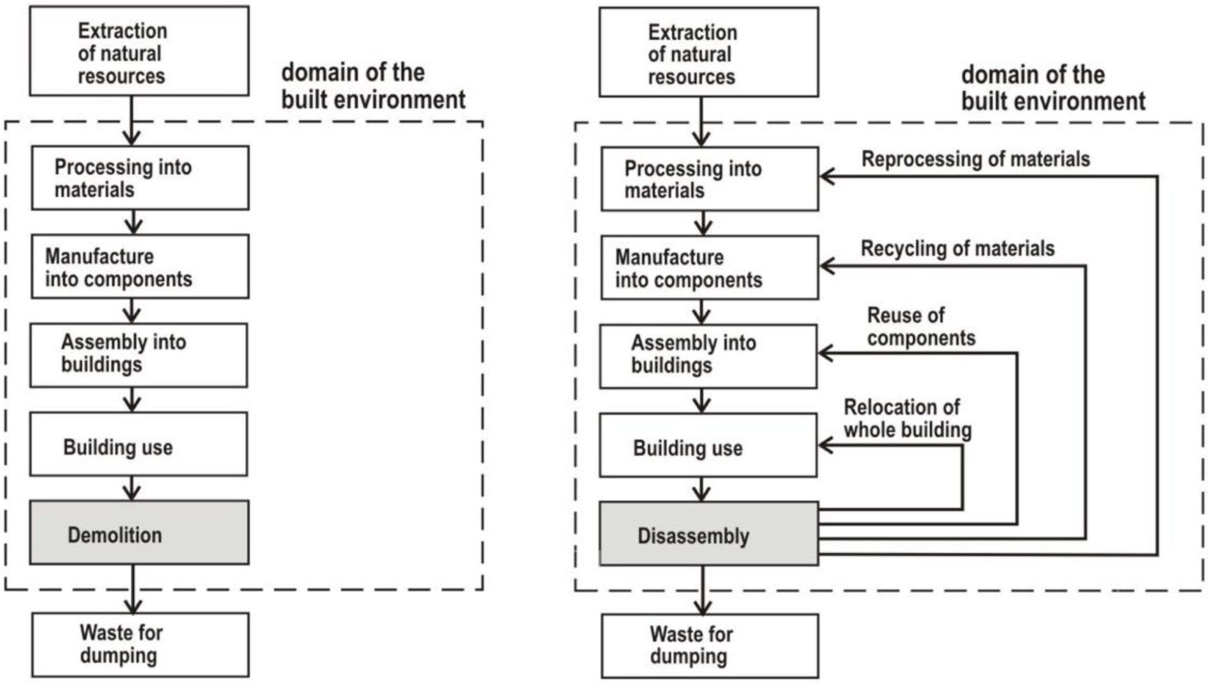

Figure 1. Demolition as building end-of-life option, and deconstruction as an alternative end-of-life option for building (Crowther, 2005).

include 'construction process in reverse' (Greer 2004), 'systematic disassembly of building in order to maximize recovered materials reuse and recycling' (Chini and Bruening 2003), among others.

Deconstruction is cost-effective than demolition, considering a reduction in disposal costs and the returns from the recovered material. For instance, Zahir et al. (2016) research shows that demolition and deconstruction of a building/structure costs between 10,000 to 12,000 and 13,000 to 15,000 in dollars, respectively. However, due to use over time, sabotage or decay, deconstruction of such building/structure can yield a salvage price of approximately 4000–5000 dollars, depending on the material/component quality and the type, accessibility, resale/reuse markets. Based on these findings, it was discovered that the net-deconstruction cost comes out to be somewhat less than its comparative demolition cost. On this note, the gross deconstruction costs (i.e. total cost incurred in the deconstruction assignment) are usually greater than gross demolition costs (all costs associated with the demolition of a building); meanwhile, the deconstruction net cost (cost after considering the resale and recycling of recovered materials) is mostly lower than that of demolition.

Deconstruction is often called 'green demolition' due to viable environmental advantages over demolition (Zahir et al., 2016). Aside from the fact that deconstruction aids the diversion of landfill waste, it helps create a sustainable economy through reuse, recycling, downcycling, upcycling and closes the circle of linear resource use (Akanbi et al., 2019). This sustainability can include reusing the recovered materials/components in new or existing structures and downcycling, upcycling or recycling materials that are not fit for immediate reuse. Examples of materials/components that are fit for immediate reuse include lumber. Recycling can be seen in the case of recovered scrap of steel turned into beams. On the other hand, downcycling can be seen in the case of concrete slabs used as road base, and upcycling is salvaging and creating a value-added product from lumbers, for example, a cupboard from recovered lumbers.

In general, deconstruction can avert many negative impacts of demolitions, as it changes 'waste' into 'feed'. See Figure 1 for the demolition and deconstruction of buildings and how a circularity economy is achieved through deconstruction. Also, see Table 1, which presents the comparison between demolition and deconstruction (Diven and Shaurette, 2010; Guy, 2001, 2004; Guy and McLendon, 2003; Zahir et al., 2016).

Owing to the advantages associated with the deconstruction practices, there has been an increasing interest in its implementation across the globe, both in practical terms and research, encouraging design for deconstruction. However, older built structures are not deconstructible as they were never designed for such purposes. The design mentioned above limit the older structure's deconstructability and increase the uncertainty associated with ease of deconstruction at EOL. However, the deconstructability assessment of a building can avail the contractors and other stakeholders the decision to reconsider the entire building or its component for deconstruction at EOL.

Methodology

This section used a SLR to establish drivers influencing the deconstructability of building from literature and identify the importance from the established. The SLR steps and the

Table 1. Demolition versus deconstruction.

Characteristic	Demolition	Deconstruction
Definition	Tearing down building into waste.	Systematic disassembling of building for maximum material recovery
Environmental impact	Wastage of resources and disposal of waste	Encourages natural resource conservation and reduces waste disposal
Community employment	Not socially beneficial to communities, as it is mainly machinery dependent	The intensiveness of labour help in job creation
Cost and time	Swiftly implemented, with low labour cost as it often involves machines and less human labour	The economic benefit associated with the resale of recovered components makes it cost-efficient, though it takes longer
Tools and equipment	Heavy and big machines are mostly used	Small tools are used
Labour	Less labour intensive, depending on heavy machine operations	Highly labour-intensive operation
Material	Materials are inseparable and mostly sent to landfill	Material is separated into different categories, detached, prepared for reuse/recycling.
Material disposal	A tipping fee is higher due to waste generated	Reduce the tipping fee as most of the waste is being repurposed
Structures suitability	A typical building is built for demolition	Not all building is deconstructible
Pollution	Generates much noise, dust and additional waste during site clearance	Generate less dust and noise

construct-based conceptual framework developed from the SLR are discussed herein. A SLR is a structured approach for research synthesis, providing a comprehensive, up-to-date and unbiased process for locating studies relevant to a research question (Higgins et al., 2019). This approach is well articulated, widely accepted with well-defined features, including clear research objectives and questions, inclusion and exclusion criteria, quality assessment of the included studies, analysis, presentation, synthesis and the transparent reporting of the findings extracted (Aromataris and Pearson, 2014). Furthermore, a SLR has been long established in the medical field because of its unique properties. However, SLR is gaining significance among other research fields, including engineering and management (Alaka et al., 2016, 2018; Charef et al., 2018; Egwim et al., 2021; Rakhshan et al., 2020).

As described, a clear research objective remains a necessity for SLR as it answers a specific question from already existing knowledge. However, selecting the relevant studies includes subjecting these studies discovered from the comprehensive search on the topic to some critical assessment. This assessment includes standardized instruments, checklists, scales that aid transparency and reproducibility of the review process. In addition, data synthesis (extraction) of answers from the perceived relevant studies is an essential feature of the SLR. Depending on the data type, there are various data extraction methods in a SLR (Tricco et al., 2011).

SLR needs to be reported in a way the complete process is reproducible (Tawfik et al., 2019). PRISMA (Preferred Reporting Items for Systematic Review and meta-analysis) checklist (Moher et al., 2010), widely used in research fields such as construction and waste management (Rakhshan et al., 2020; Shahruddin and Zairul, 2020), was employed to report the complete SLR process.

SLR is known for its comprehensive literature search from databases. Following the approach of Rakhshan et al., 2020, a more recent article on the deconstruction of building, Scopus database was considered. This is because Scopus database constitutes research from all over the globe, thus eradicating biases geographically. In addition to Scopus, Google Scholar, which is also a widely accepted database, was considered using the keyword 'deconstructability', generating a total of 31 relevant articles. However, the search here was restricted to title search only to have a manageable record due to its inability to automate filtering.

Comprehensive search helps reduce the risk of missing important studies (Collaboration for Environmental Evidence (CEE), 2013; Kugley et al., 2017). To find relevant articles, a pilot search on Google search engine and search framework on Scopus was conducted. The pilot search was to identify the proper keywords, reduce bias in search and create a framework to retrieve all relevant articles. The pilot search revealed that deconstruction, disassembly is interchangeably used. In contrast, assessment, feasibility, potential, estimation, appraisal and evaluation are used intertwined. In addition to capturing a broad spectrum of research, repeatability and consistency of the whole process is another great point to note. The search framework (('deconstruct*' OR 'disassemb*') AND ('assessment' OR 'feasibility' OR 'potential' OR 'estimation' OR 'appraisal' OR 'Evaluation') AND ('building')) captures all raised concerns as it loops through 'title/abstract/keywords' of each journal.

The exclusion criteria considered in this research included, among others, articles not written in the English language due to lack of funds for interpretation services. However, this is mostly not encouraged in SLR. Examples of articles excluded based on the language are Schwede and Störl (2017) and Caparrós and Astarloa (2017), written in German and Spanish. Due to the high quality of the peer-reviewed articles, other forms of the article

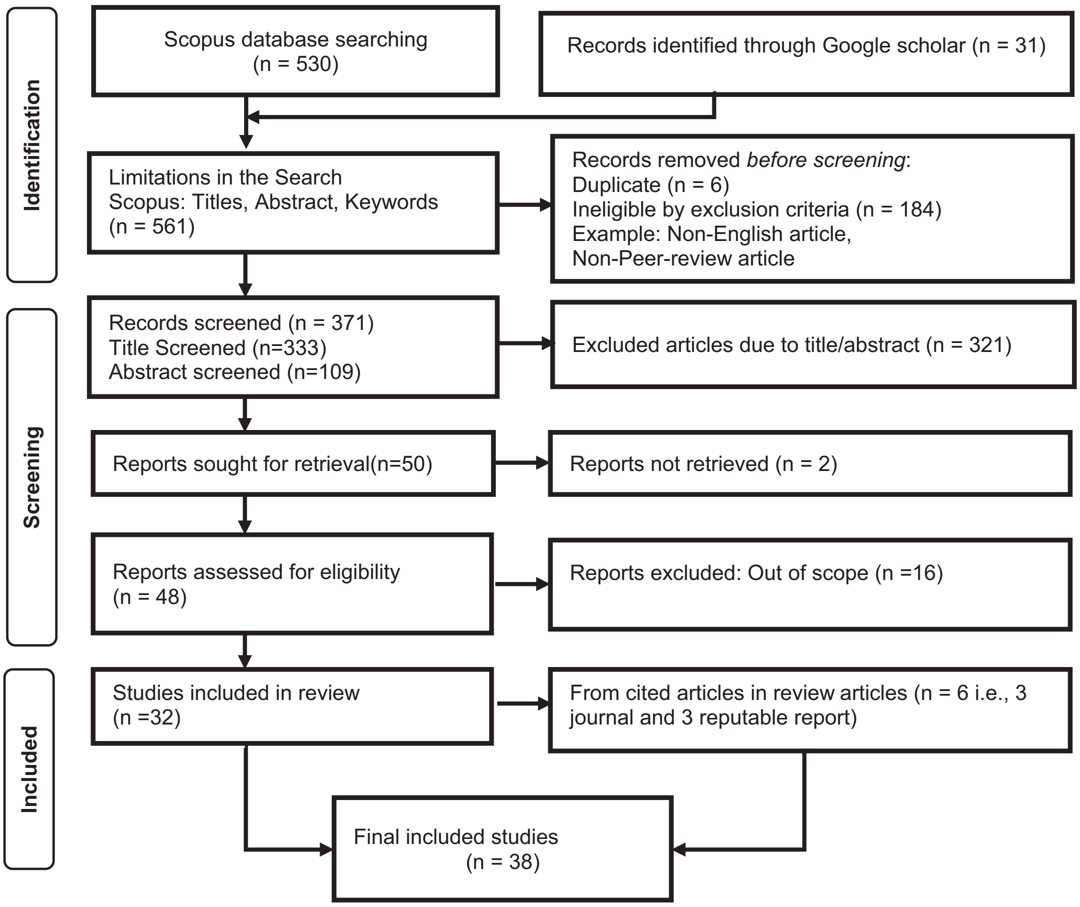

Figure 2. SLR flow diagram (Page et al., 2021).

(i.e. conference papers, trade journals, book chapters) were not considered (Alaka et al., 2017, 2018; Comfort and Park, 2018; Rakhshan et al., 2020)

The decision to include an article may be sorted directly from the title of the research paper. However, some papers were exceptional. In most of these cases, the article abstract was read, and if possible, the introduction and conclusion were read to have the most relevant papers. Unsuitable articles, for example, articles with a focus on life cycle assessment (Vieira and Horvath, 2008; Malabi Eberhardt et al., 2020), sustainable assessment (Akbarnezhad et al., 2014; San-José et al., 2007), circularity indicator (Cottafava and Ritzen, 2021), environmental impact of steel structure (Broniewicz and Broniewicz, 2020), optimization of deconstruction (Sanchez et al., 2020), deconstruction planning (Sanchez et al., 2019), reusability index (Hradil et al., 2019), databank (Bertin et al., 2020) among others were removed. This is because most of these articles are out of scope for this research. A process flow of the methodology is presented in Figure 2.

Result and discussion

In the SLR flowchart, the number of articles is indicated by *n*, and there were 530 and 31 articles retrieved from Scopus and Google Scholar, respectively, using the search framework earlier defined. Of the total retrieved articles, six were identified to be duplicates and were removed. Furthermore, 184 articles were eliminated at this stage, including publications authored in languages other than English and articles that were not peer reviewed. Other articles deleted include articles from other research fields retrieved due to the exhaustive search of the research database and the interdisciplinary nature of ‘deconstruction’. Though this comes after glancing through the article titles, and abstracts. Example, Eisenbach and Grohmann, (2017) was discovered under the arts and humanity domain yet was found relevant after looking through its abstract. A quick judgement to remove all arts and humanity would have led to losing this article. The remaining 371 papers were thoroughly examined by skimming the titles and abstracts. As previously indicated, certain titles are sufficient to decide an article’s candidacy; but, in some situations, the title, abstract and potentially the discussion and conclusion were evaluated prior to the decision to include an article, and 321 papers were screened out in total. Upon scrutiny, a total of 50 papers were found to have promise and to be significant in determining the factors that influence building deconstructability. The next step was to read the complete copies of the 50 prospective articles; however, two of them were not publicly available, and 16 were found to be out of scope, resulting in a total of 18 articles being deleted at this point. After all the screenings, a total of 32 articles were found to be beneficial in determining all the building deconstructability drivers. Following the approach of Alaka et al. (2017), six relevant publications were identified from references/citations of the previously identified articles, this includes three peer-reviewed journal and three reputable reports. This has made the author realize 38 relevant articles for achieving the research aim and objective. The summary of the findings from the SLR is presented in Table 2.

As part of the exploration and discovery from the SLR, Figure 3 presents the count of the driver's rankings by the article authors, then the type of building mostly considered for deconstruction and lastly, the research methods primarily used in the identified articles.

Other deduced knowledge from the SLR includes the building type, material type of the building and the research methods considered in the article. It was discovered that out of the 38 articles retrieved, most articles referred mainly to the deconstruction of residential buildings; this is probably due to its relevance in the social community as everyone seeks shelter as a significant need for life. In addition to the residential type of buildings discovered, an army barrack building constructed during World War II using timber was also discovered; this is obviously because of the reusability of timber materials as they are believed most sustainable material type (Guy, 2006). As for the research methodology of the identified articles, most of the articles are quantitative, though qualitative and mixed research method was discovered for a smaller percentage of the articles.

Deconstructability framework

To develop a construct-based conceptual framework measured using the established drivers influencing the deconstructability of building, there is a need for domain expertise in deconstruction and feasibility analysis. However, with the industrial expertise of the co-author, convergence on the five generic areas of feasibility analysis known as TELOS (technical, economic, legal, operational and schedule) was employed. Other assessment areas identified from the SLR includes social construct (Densley Tingley and Davison, 2012; Densley Tingley et al., 2017). The position of this article is that social construct should form the sixth construct to form TELOSS. The construct-based conceptual framework is thus presented in Figure 4.

Technical construct

This mainly includes every driver established from the SLR, which covers the technical aspect of deconstructability. As deduced, it was revealed that a typical building is permanently built from design and as such, their construction techniques do not focus on the deconstruction when the EOL is reached. The current state of designs connected using bonds, in situ and chemicals make it inseparable, in which case the building components upon dismantling would be damaged and rendered not useable. Other drivers discovered and classified under this construct include the material and its type, components, types and exact quantity and quality of the component/materials recoverable.

Economic construct

This is yet another area with much emphasis on price-related and all kinds of expenditure-related drivers. All the drivers drawn from the SLR, which forms the economic construct, will help decision-makers decide the deconstruction's price benefits. The drivers under this construct include market, labour cost, equipment and tool cost, storage and logistic cost, among many others. In addition, the supply and demand for the recovered components play a crucial role in deconstruction. Example, when there is a problem creating demand or market for these 'recovered' components. Also, many retailers are around with no precise value for the recovered components (Gorgolewski et al., 2006). With no knowledge of the market and value for the recovered components, the appropriate deconstruction cost-benefit may never be achieved, hence influencing the deconstructability of the building.

Another driver under this construct includes knowing the quality and quantity of the reusable/recyclable component. This uncertainty makes it hard to assess the financial benefit associated with deconstruction. For example, there is an unknown revenue stream for recovered structural steel components. The quantity may be unknown as steels are mostly not in 'as is' form (Gorgolewski et al., 2006), that is, steel mainly needs steel modification/recycling before being used in other new construction. This modification often results in inaccurate economic assessment. In addition, the recovered components are mostly not sold onsite, resulting in extra cost for storage and transportation, leaving the component with storage options except for a few cases where there is already an existing market for the recovered components.

The transportation of the components from the regional recycling facility or from the storage to the market cost extra. This is because most regional recycling facilities may be situated far from residential areas where the deconstruction project occurs. Other drivers established under this construct include the cost to hire more manual labour, as most deconstruction project uses less heavy equipment, the cost to seek a permit from the council/government, percentage of damages due to fire for a wooden structure, or corrosion for steel structure or other forms of damages, this tends to reduce the price of the recovered components.

Legal construct

This construct encompasses drivers making sure the deconstruction does not conflict with the legal requirement of the community/government. The drivers under this construct include regulations on waste disposal and generation, especially the landfill tipping fees (Guy and Ohlsen, 2003; NAHB Research Center, 2000, 2001; Rios et al., 2015). An increase in the landfill tipping fees encourages deconstruction. Even though this regulation exists in many communities, waste generators now find cheaper means by dumping waste in private sites, roads, empty plots, streams and islands. Nonetheless, these taxes would probably be

Table 2. Summary from the identified articles through SLR.

S/N	Author	Drivers identified	Author ranking	Building type	Material	Research method	Article type	Country
1	Bertino et al. (2021)	Design and plans Underdevelopment of tools and techniques Type and age of building Connections Materials and its type used in the building Government policy Construction techniques Building complexity – number of components Database for identification of materials and components (documentation)	Design Documentation	Residential	All	Qualitative	Journal	–
2	Cottafava and Ritzen (2021)	Documentation Material and type Supply chain for the recovered Design	Design, material and supply chain	Residential	All	Mixed method	Journal	–
3	Basta et al. (2020a)	Use of Building Information Modelling (BIM) for drawings, identification of components, and provision of deconstruction plan Different types of materials Toxic materials Composite and floor systems Secondary finishes Design Access to components Connections Use of in situ As-built plan Standard structural grid	Design	Residential	All	Mixed method	Journal	–
4	Akanbi et al. (2019)	Design Material specification Material information	Design Material specification	Residential	All	Quantitative	Journal	UK
5	Hradil et al. (2019)	Building material Complexity of the component Market	Material	Industrial	Steel	Quantitative	Journal	Finland
6	Marzouk et al. (2019)	Time Cost Undocumented building condition Salvaged material logistics – buying and selling	Time and cost	–	All	Quantitative	Journal	–
7	Kanters (2018)	Design Materials and connections Construction and deconstruction phase Communication, competence and knowledge Reuse potential and regulation	Legislation, time and cost	–	All	SLR	Journal	–
8	Tatiya et al. (2018)	Component separation/connect Low quality of recoveries Supply chain for recoveries Design	Connections design	Residential	All	Quantitative	Journal	USA

(Continued)

Table 2. (Continued)

S/N	Author	Drivers identified	Author ranking	Building type	Material	Research method	Article type	Country
9	Akinade et al. (2017)	Government policy Design – connection, assemblies, etc. Material related drivers – material type, quality, quantity Site worker – cost, skill, availability	Legislation, policy	Residential	All	Mixed method	Journal	UK
10	Machado et al. (2018)	Material/component/connection durability toxic material reusability/recyclability of the material damage material separation space for equipment and manoeuvring storage risk assessments as built drawings standardization of the component/materials/connections tools/machinery accessibility of connections identification of material/information system quality of the component/materials before deconstruction (conservation time) and damage during deconstruction repair for reuse cost	Cost	–	All	Review (literature)	Journal	–
11	Akinade et al. (2015)	Prefabricated assemblies/demountable connections Design Set and type of materials/connections/component Reusability and recyclability of material/component Connection type Toxic material and secondary finishes Weight of the component/material	Design	Residential	All	Quantitative	Journal	UK
12	Huuhka et al. (2015)	Connections Material and types Cost High labour Material condition and damage after deconstruction	Connection and design	Residential	concrete	Quantitative	Journal	Finland
13	Akbarnezhad et al. (2014)	Price of the material Energy embodiment of the component The travelling distances Energy use associated with the recycling processes Inflation rate and cost of designing the components for reusability Cost associated with the recycling process connection Lack of information	Cost, energy and carbon emission	Residential	concrete	Quantitative	Journal	Singapore
14	Couto and Couto (2010)	Fixed price for salvage material Landfill tax Material specification Development of Suitable tool Cost Time and safety Location and safety Market value of the recovery People/client perception Codes and standards	–	–	All	Qualitative	Journal	–
15	Paduart et al. (2008)	Design Connection	Connection	–	All	Qualitative	Journal	–
16	Leigh and Patterson (2006)	Technical know how Cost and market Logistics of the recovery Separation and storage Time Undefined law/policy	–	–	All	Review (literature	Journal	USA

(Continued)

Table 2. (Continued)

S/N	Author	Drivers identified	Author ranking	Building type	Material	Research method	Article type	Country
17	Guy (2006)	Design, e.g. design for deconstruction (DfD) Toxic material, e.g. asbestos Types of building material Number of building components Type of connectors Reusability of the material Toxic and hazardous materials, e.g. asbestos, mercury switches, leads, etc. Materials recyclable	Design	Barack building	Timber	Quantitative	Journal	USA
18	Crowther (2005)	Design, e.g. DfD Toxic material, e.g. asbestos Deconstruction purpose, e.g. relocation of building Material and component reusable and recyclable Connection type, i.e. bolt/nut, glue Composite material during design Number of building components Available building components Toxic and hazardous materials Secondary finishes Deconstruction purpose	Design connection	Residential	All	Review (literature	Journal	–
19	Blengini and Di Carlo (2010)	Building information/documentation	–	Residential	All	Quantitative	Journal	Italy
20	Kibert (2003)	Deconstruction purpose and design	–	Residential	All	Review (literature)	Journal	USA
21	Warszawski (1999)	Design – connection, key indicators for DfD, methodologies (building construct based conceptual framework)	–	Residential	All	Mixed method	Journal	UK
24	Densley Tingley and Davison (2012)	Material durability Building technique, e.g. volumetric construction, precast flat panel modules, tunnel formwork system, flat slabbing technology, precast foundation, hybrid concrete, etc. Site condition, – access, transportation, waste disposal, handling and storage of materials, availability and quality of electric power, water, etc. Design	Design	Residential		Quantitative	Journal	
25	Guy and Ciarimboli (2008)	Secondary finishes Prefabricated assemblies Composite material Number of building components	–	Residential	All	Mixed method	Journal	
26	Chini and Balachandran (2002)	Connection type, i.e. bolt/nut, glue Type of building components Time, cost and policy	Time Cost	Residential	Timber	Review (literature)	Journal	USA
27	Webster and Costello (2006)	Connection type, i.e. bolt/nut, glue Material reusable Composite material during design Number of building components	–	Residential	All	Review (literature)	Journal	USA
28	Andi and Minato 2003	Design documentation	–	Residential	All	Review (literature)	Journal	USA
29	Chini and Bruening (2003)	Materials recyclable Design	–	Residential	Timber	Review (literature)	Journal	USA

(Continued)

Table 2. (Continued)

S/N	Author	Drivers identified	Author ranking	Building type	Material	Research method	Article type	Country
30	Guy and Ohlsen (2003)	Labour cost Material/component damage, e.g. water damage, fire damage, etc. Salvage material market Information regarding the building Lack of skilled labour Design, i.e. DfD or not Age of the building Disposal fee (local tipping) Building Material type, e.g. wood, concrete, masonry, etc., Complexity/size of the building, e.g. no of floors Number of stores/onsite storage available, e.g., one, two or more Scheduling/time to deconstruct e.g., month, 1–6 months, etc. Kind of building, i.e. historic or in a historic district Kind of regulatory agency to seek deconstruction permit Time and cost to seek/get deconstruction permit Public policy, e.g. policy that encourages deconstruction	Cost	Residential	All	–	Journal	Germany
31	Gorgolewski (2006)	Market for recycling component Damage and Cost Negative attitude of the public towards recovered components	Cost, market	–	Steel	Review (literature)	Journal	Canada
32	Islam et al. (2012)	Market for recycled components The regional recycling capacity The total energy used to recycle and The transportation energy Technical knowledge Distance from the recycling facility and the project sites Regional purchasing habits	Market Energy Regional recycling facility	Residential	All	Quantitative	Journal	USA
33	Rios et al. (2015)	Inaccurate quantity assessment of the recovered components Lack of quality grading system Lack of rules and policy encouraging the practice Lack of technical know/skilled personnel may Negative perception of the use of recovered components	Market	Residential	All	Mixed method	Journal	USA
34	Nakajima and Russel (2014)	Low demand for the recovered components Damages to the recovered components The design of the building Lack of suitable equipment for deconstruction Sorting time Uncertain cost factors for deconstruction Time to deconstruct composite materials Lack of political initiative supporting deconstruction	Design cost	Residential	Timber	Mixed method	Journal	Japan
35	Shami (2008)	Market Incentives Materials Toxic materials Quality of the salvaged material Grading of the salvaged material	–	Residential	All	Quantitative	Journal	USA

(Continued)

Table 2. (Continued)

S/N	Author	Drivers identified	Author ranking	Building type	Material	Research method	Article type	Country
36	Kibert and Languell (2000)	Deconstruction cost Industry/public attitude Deconstruction project time Identifying material quality and quantity Market/resale location, e.g. onsite, or offsite Material damage, i.e. estimated amount of damage the material has Labour cost/availability of labour and skill level of the labour crew Size and type of the structure, i.e. number of floors, rooms, etc. Ease of removing/separating materials Storage facility Transportation cost Resale value Structures containing old/rare wood species Brick building built before 1933 Presence of interesting/old/rare architectural features/hardwood floors Secondary finishes, e.g. presence of unpainted woods Age of structure Design Availability of recycling option Type and condition of the materials in the structure Presence of the as built/original plan of the structure Presence of hazardous materials, Cost for hazardous material handler – asbestos abatement contractor Time of the year – depending on geographic location Jobsite preparation – preparing site for access for transportation, dumpster locations, time scheduling	Cost regional attitude	Residential	All	Mixed method	Report	USA
37	NAHB Research Center (2001)	Project time Code issues Market for the salvaged materials Housing preservation Toxic materials Market perception of the salvaged building materials Alternative use for the salvaged materials					Report	
38	NAHB Research Center (2000)	Documentation Material type, e.g. wood framed with heavy timbers and beams Rare features, e.g. unique woods such as Douglas, unique doors or plumbing/electrical fixtures Constructed with high quality materials, e.g. brick laid with low-quality mortar (to allow relatively easy break-up and cleaning) Structurally sound, i.e. generally weather-tight Equipment	Inventory/ documentation of how and what the building is made of				Report	

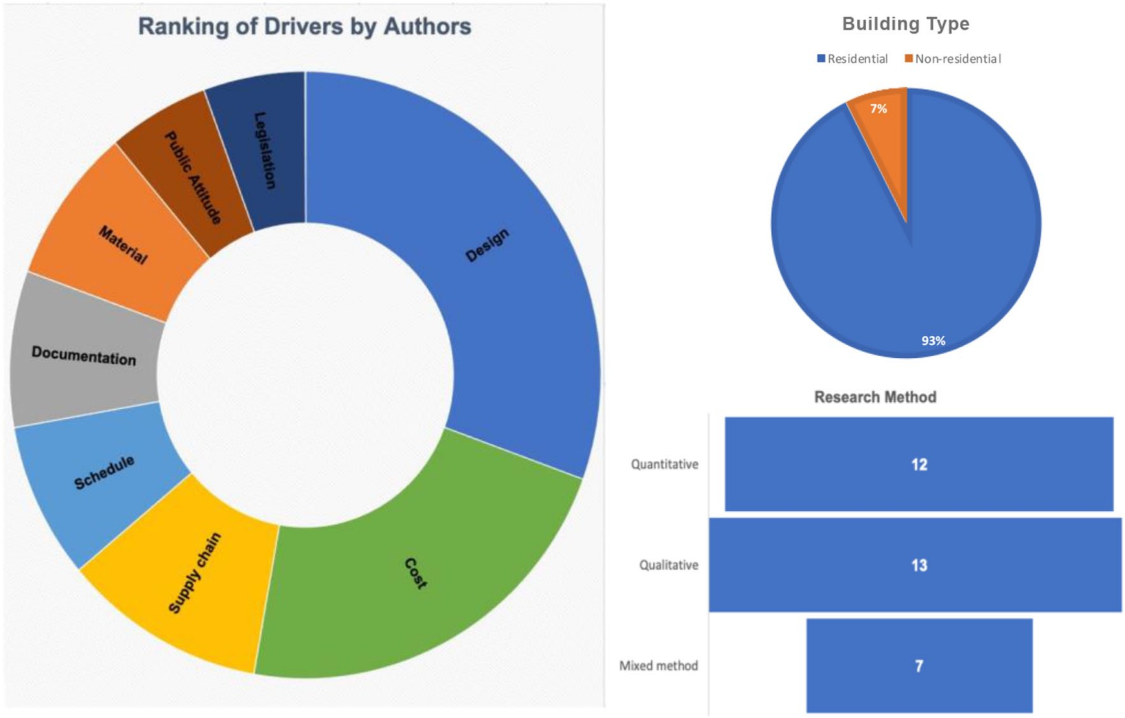

Figure 3. Exploratory analysis from the SLR result.

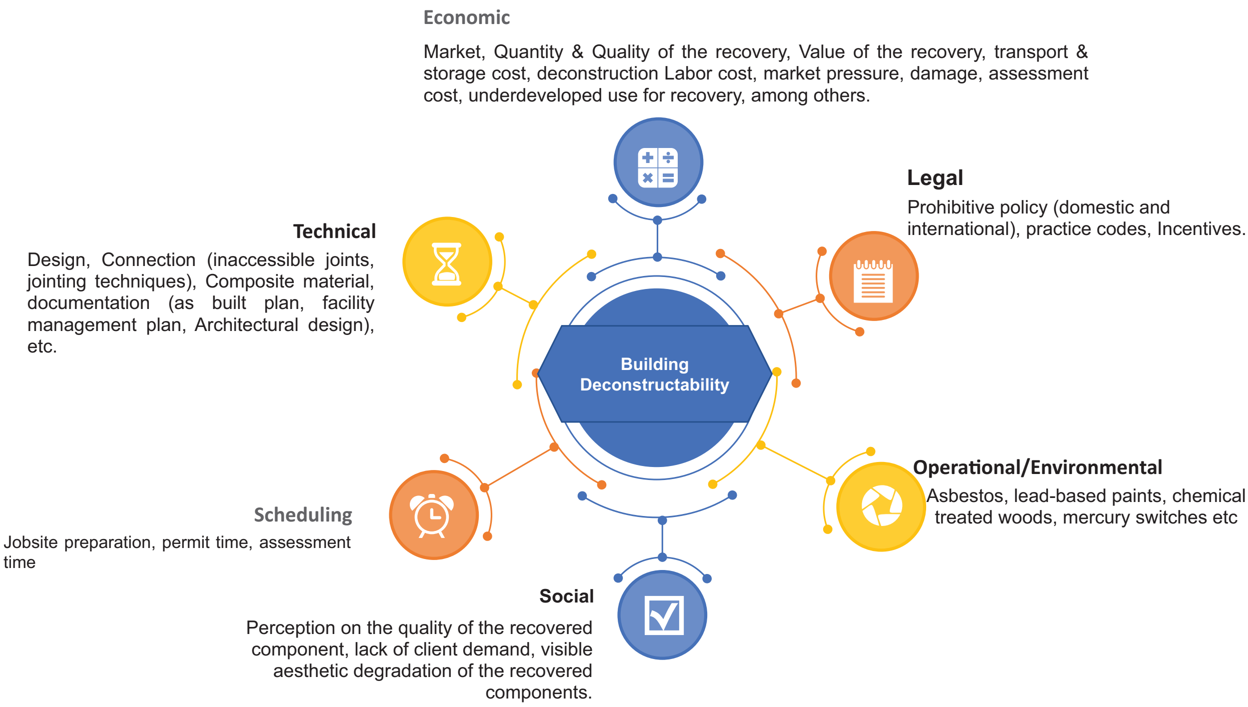

Figure 4. Construct-based conceptual framework for deconstructability of building.

of little efficiency, as unlawful disposal offers a reduced cost compared to the proper disposal. In addition, illicit disposal with no penalties and control further weakens the regulations encouraging deconstruction (Kartam et al., 2004).

In addition, subsidies, allowances and incentives given to virgin resource industries are regulations that directly or indirectly influence deconstruction. These enable the shift of extremely expensive stresses to the environment. An example is the USA percentage-depletion allowance, which in fact, aid timber exploration (Kibert 2000).

Operational construct

The operational construct covers the responsibility to examine and decide whether the building will meet all requirements when subjected to all kinds of assessment (Pollock, Ho and Farid, 2013). This construct mainly covers the cultural drivers established through the SLR. Drivers include health and safety assessments. This assessment is vital as it aids forecasting all risk and mitigating the recognized issues (Mukherjee and Roy, 2017). The assessment of hazardous materials is a culture in construction health and safety, as the presence of toxic material like asbestos, lead-based paints, chemical-treated woods, mercury switches, composite materials, etc. in a building needs to be carefully assessed and handled to ease sorting of the recovered components and to prevent fall, fire or other health and security issues that may arise on site. This often requires trained handlers and thus may cost extra.

Schedule construct

This construct deals with established drivers related to time. A good number of articles argue that besides technical drivers, the time to deconstruct remains a critical driver influencing the deconstructability of building. This corroborates with the findings of Da Rocha and Sattler (2009), as contractors may find it challenging to wait longer to deconstruct building/component due to rigorous deadlines and as the deconstruction process is typically manual, uses hand tools instead of the faster big machinery used in the conventional demolition. Moreover, contractors often sacrifice the benefits of deconstruction as there may be plans to redevelop after building removal. Other examples include the jobsite preparation time, permit time, assessment time and time of the year. It is usually unlikely that the site where the deconstruction project will be carried out is perfect for the process.

In some cases, there will be a need to create storage spaces, cut down some trees, create accessible road networks, especially for houses that have long been abandoned. This preparation depending on the region/location of the building, increases the time it takes to deconstruct a building carefully. Also, the time it takes to get a permit from the government/council and assess the site for environmental and health safety influence the overall deconstruction time. This is because there are procedures in place and must be duly followed. Examples include permits involving disconnection of electrical power, gas and other services and site assessment to prevent future accidents. Lastly, dependent on the region, most contractors may not like to deconstruct during the winter.

Social construct

The assumption on the value of recovered component by the community (i.e. constructors), which is often wrong and harmful, remains a social driver influencing deconstructability (Kartam et al., 2004). Similarly, this negative attitude will make the community view the recovered component as environmentally friendly though low value (Kibert 2000). The community interviews validated these findings, showing that many recovered products available have a poor quality, limiting their use (Da Rocha and Sattler, 2009). Much is expected on the reorientation of the public/community to clarify this misconception as some recovered component like brick, tiles and wooden element performs well or even better than new ones.

In all, the research revealed six primary constructs, measured by the established drivers from the SLR (see Figure 2). The measures were carefully assigned to each construct using the domain knowledge of the author, co-author and pieces of literature. The study by Densley Tingley et al. (2017) is especially worthy of note here. It considered the drivers affecting the reuse of steel from a deconstruction perspective. The research also grouped the drivers into groups, including the social group, which corroborates this research's position.

As discovered from the SLR, authors have strongly noted out some key drivers as most important; some pointed out to just a driver as key (Akinade et al., 2015; Basta et al., 2020), while some pointed out to more than one driver as important (Marzouk et al., 2019; Nakajima and Russel, 2014) and some pointed out to none (Blengini and Di Carlo, 2010). Though most articles with ranks for these drivers do not show scientific proof as to how they come about their rankings, for example, Akinade et al. (2017b) ranked design as the most critical driver affecting deconstructability of a building basing its argument on a general and acceptable notion that a typical building is never design for deconstruction. Despite this argument is valid and correct, some drivers other than design maybe more influential in deciding whether to deconstruct a building. However, the lack of proof as to how the rankings come about thus made this research make a count of drivers according to articles, with the most frequently ranked as most common and essential; see Table 3 for details.

For all the distinct drivers established, the drivers were ranked based on the frequency of occurrence in the studies. Figure 5 shows the count of the distinct established drivers.

The research sorted and presented the drivers by several citations. The jointing technique came as the most cited driver, an aspect of the design corroborating with the literature's knowledge, which identified design as the most crucial driver influencing the deconstructability of building. The following driver identified is the material salvage, which comprises the total recovered material/materials that could be recovered; these materials could provide an economic benefit that could arise from building deconstruction. Other vital drivers based on citation include the building technology, supply chain and market for the salvage materials, followed by the documentation of what the building contains and how the building was put together. Also, the ranking of the construct was done following the computation presented in Table 2. The constructs were ranked according to the citation per construct, though every construct, irrespective of the ranking, cannot be neglected in deciding the deconstructability of a building. Therefore, this ranking only presents the importance in order.

Conclusion

There are many established drivers that hinders the deconstruction of many building at their EOL. Example, a typical building is mostly not built for deconstruction yet could be deconstructed through careful deconstructability analysis. The

Table 3. The constructs identified and their measures/drivers.

S/N	Construct	Definition	Construct measures	References	Citations	Citation per construct
1	Technical	These covers the technological aspect of the deconstruction. In this, all technical drivers influencing deconstructability are measured.	Building technology e.g., prefabricated etc.	Akinade et al. (2015, 2017a, 2017b), Akanbi et al. (2019), Basta et al. (2020), Bertino et al. (2021), Chini and Bruening, (2003), Cottafava and Ritzen (2021), Crowther (2005), Guy (2006), Guy and Ohlsen (2003), Huuhka et al. (2015), Kanters (2018), Kibert et al. (2000), Nakajima and Russel (2014), Paduart et al. (2008), Tatiya et al. (2018), Tingley and Davison (2011), Warszawski (1999)	18	110
			Coatings with (now) banned chemicals, e.g. lead paint	Akinade et al. (2015), Basta et al. (2020), Crowther (2005), Guy (2006), Guy and Ciarimboli (2008), Kibert et al. (2001)	6	
			Damage to the component/materials, e.g. corrosion, fire, etc.	Gorgolewski (2006), Guy and Ohlsen (2003), Huuhka et al. (2015), Kibert et al. (2001), Machado et al. (2018), Nakajima and Russel (2014)	6	
			Documentation of how and what the building contains, e.g. the as-built-plan and the inventory containing all the components and materials contained in the building	Akanbi et al. (2019), Akbarnezhad et al. (2014), Basta et al. (2020), Bertino et al. (2021), Blengini and Di Carlo (2010), Cottafava and Ritzen (2021), Guy and Ohlsen (2003), Kanters (2018), Kibert (2000), Machado et al. (2018), Marzouk et al. (2019)	11	
			Composite Construction	Basta et al. (2020), Crowther (2005), Guy and Ciarimboli (2008), Nakajima and Russel (2014), Webster and Costello (2006)	5	
			Jointing technique, e.g. separatable connections	Akbarnezhad et al. (2014), Akinade et al. (2015, 2017), Basta et al., (2020), Bertino et al. (2021), Chini and Balachandran, (2002), Chini and Bruening (2003), Crowther (2005), Guy (2001, 2006), Guy and Ciarimboli (2008), Guy and Ohlsen (2003), Huuhka et al. (2015), Kanters (2018), Kibert et al. (2001), Leigh and Patterson (2006), Machado et al. (2018), Nakajima and Russel (2014), Paduart et al. (2008), Tatiya et al. (2018), Tingley and Davison (2011), Warszawski (1999), Webster and Costello, (2006)	24	
			Inaccessible joints	Basta et al. (2020), Machado et al. (2018), Tingley and Davison (2011)	3	
			Health and safety of deconstruction, e.g. identification of hazardous materials, etc.	Akinade et al. (2015), Basta et al. (2020), Crowther (2005), Guy (2006), Guy and Ciarimboli (2008), Kibert et al. (2001)	6	
			Materials salvageable, i.e. materials that can be recovered	Akanbi et al. (2019), Akbarnezhad et al. (2014), Akinade et al. (2015, 2017), Basta et al. (2020), Bertino et al. (2021), Chini and Balachandran (2002), Cottafava and Ritzen (2021), Couto and Couto (2010), Crowther (2005), Guy, (2006), Guy and Ohlsen (2003), Hradil et al. (2019), Huuhka et al. (2015), Kanters (2018), Kibert et al. (2001), Machado et al. (2018), Tatiya et al. (2018), Tingley and Davison (2011), Webster and Costello (2006)	20	

(Continued)

Table 3. (Continued)

S/N	Construct	Definition	Construct measures	References	Citations	Citation per construct
			Building characteristics, e.g. the age of the building, complexity of the building, etc.	Akinade et al. (2015), Basta et al. (2020), Bertin et al. (2020), Chini and Balachandran, (2002), Crowther (2005), Guy and Ciarimboli (2008), Guy and Ohlsen (2003), Hradil et al. (2019), Kibert (2000), Machado et al. (2018), Webster and Costello (2006)	11	
2	Economic	This construct covers all kinds of expenditure and gains from the deconstruction of building.	Value of recovered material	Akbarnezhad et al. (2014), Couto and Couto (2010), Kibert (2000), Densley Tingley et al. (2017)	4	61
			Deconstruction labour cost	Akinade et al. (2017), Guy and Ohlsen (2003), Huuhka et al. (2015), Kibert (2000), Rios et al. (2015)	5	
			Cost to dispose waste in landfill, i.e. tipping fee	Couto and Couto (2010), Densley Tingley et al. (2017), Guy and Ohlsen (2003)	3	
			Cost of hauling and transporting of the recovered material/components	Densley Tingley and Davison (2012), Issam et al. (2012), Kibert (2000), Marzouk et al. (2019), Shami (2008)	5	
			The cost to hire the hazardous material handler, e.g. the asbestos expert	Akinade et al. (2015), Basta et al. (2020), Crowther (2005), Guy (2006), Guy and Ciarimboli (2008), Kibert et al. (2001)	6	
			The cost associated to recycling of the materials/components	Akbarnezhad et al. (2014), Chini and Bruening (2003), Crowther, (2005), Densley Tingley et al. (2017), Gorgolewski (2006), Guy (2006), Issam et al. (2012), Kibert (2000), Machado et al. (2018)	9	
			Competition among the recovered material users	Densley Tingley et al. (2017)	1	
			Supply chain, i.e. the demand and supply of the recovered material/components	Cottafava and Ritzen (2021), Couto and Couto (2010), Densley Tingley et al. (2017), Gorgolewski (2006), Guy and Ohlsen, (2003), Hradil et al. (2019), Issam et al. (2012), Kibert (2000), Leigh and Patterson (2006), Nakajima and Russel (2014), Rios et al. (2015), Shami (2008), Tatiya et al. (2018)	13	
			Sources of demand for the recovered materials	Densley Tingley et al. (2017), Nakajima and Russel (2014)	2	
			Access to finance to buy the recovered materials	Densley Tingley et al. (2017)	1	
			Ill-defined benefits	Densley Tingley et al. (2017)	1	
			Cost to store recovered materials most especially for salvaged materials with no available market	Densley Tingley et al. (2017), Guy and Ohlsen (2003), Kibert (2000), Leigh and Patterson, (2006), Machado et al. (2018)	5	
			Quality of the recovered material	Akinade et al. (2017), Densley Tingley et al. (2017), Kibert (2000), Machado et al. (2018), Rios et al. (2015), Tatiya et al. (2018),	6	

(Continued)

Table 3. (Continued)

S/N	Construct	Definition	Construct measures	References	Citations	Citation per construct
3	Legal	This construct makes sure the deconstruction is in no conflict with the legal requirement of the community/government	Policy, i.e. domestic and international	Akinade et al. (2017), Bertino et al. (2021), Chini and Balachandran (2002), Guy and Ohlsen (2003), Leigh and Patterson (2006), Rios et al. (2015), Shami (2008)	7	10
			Policy incentives to encourage deconstruction	Densley Tingley et al. (2017), Nakajima and Russel (2014), Shami (2008)	3	
4	Operational	This covers examination of the building when subjected to all kind of assessment	Environmental assessment in preparation of the site	Densley Tingley et al. (2017), Machado et al. (2018), Rios et al. (2015)	3	11
			Health and safety assessment to avoid accident and other safety concern	Couto and Couto (2010), Densley Tingley et al. (2017), Guy and Ohlsen (2003), Kibert (2000), Machado et al. (2018), Rios et al. (2015), Shami (2008)	7	
			Permit from the council/government	Guy and Ohlsen (2003)	1	
5	Schedule	This construct covers all time related drivers influencing the deconstructability of a building	Number of activities	Shami (2008)	1	22
			Complexity of each activity	Bertino et al. (2021), Shami (2008)	2	
			Sequencing of activity	Shami (2008)	1	
			Resource requirement in terms of labour and tools	Shami (2008)	1	
			Presence of toxic materials	Akinade et al. (2015), Basta et al. (2020), Crowther (2005), Guy (2006), Guy and Ciarimboli (2008), Kibert et al. (2001), Shami (2008)	7	
			Number of components in building	Akinade et al. (2015), Shami (2008)	2	
			Codes and regulation	Basta et al. (2020), Machado et al.,(2018), Shami (2008)	3	
			Time of the year	Kibert (2000)	1	
			The logistics of hauling	Densley Tingley and Davison (2012), Issam et al. (2012), Kibert (2000), Marzouk et al. (2019), Shami (2008)	5	
			Level of technology of building systems	Densley Tingley et al. (2017), Shami (2008)	2	
			Material separation and processing	Kibert (2000), Leigh and Patterson (2006), Machado et al. (2018), Shami (2008), Tatiya et al. (2018)	5	
6	Social	This covers the social responsibility of the community towards deconstruction	Inertia	Densley Tingley et al. (2017)	1	9
			Lack of client demand	Densley Tingley et al. (2017), Nakajima and Russel (2014)	2	
			Perception of second hand materials – sub-standard	Densley Tingley et al. (2017), Gorgolewski (2006), Kibert (2000), Tatiya et al. (2018)	4	
			Visible aesthetic degradation of material	Densley Tingley et al. (2017)	1	
			Risk (fear, moral responsibility, etc. . .)	Densley Tingley et al. (2017)	1	

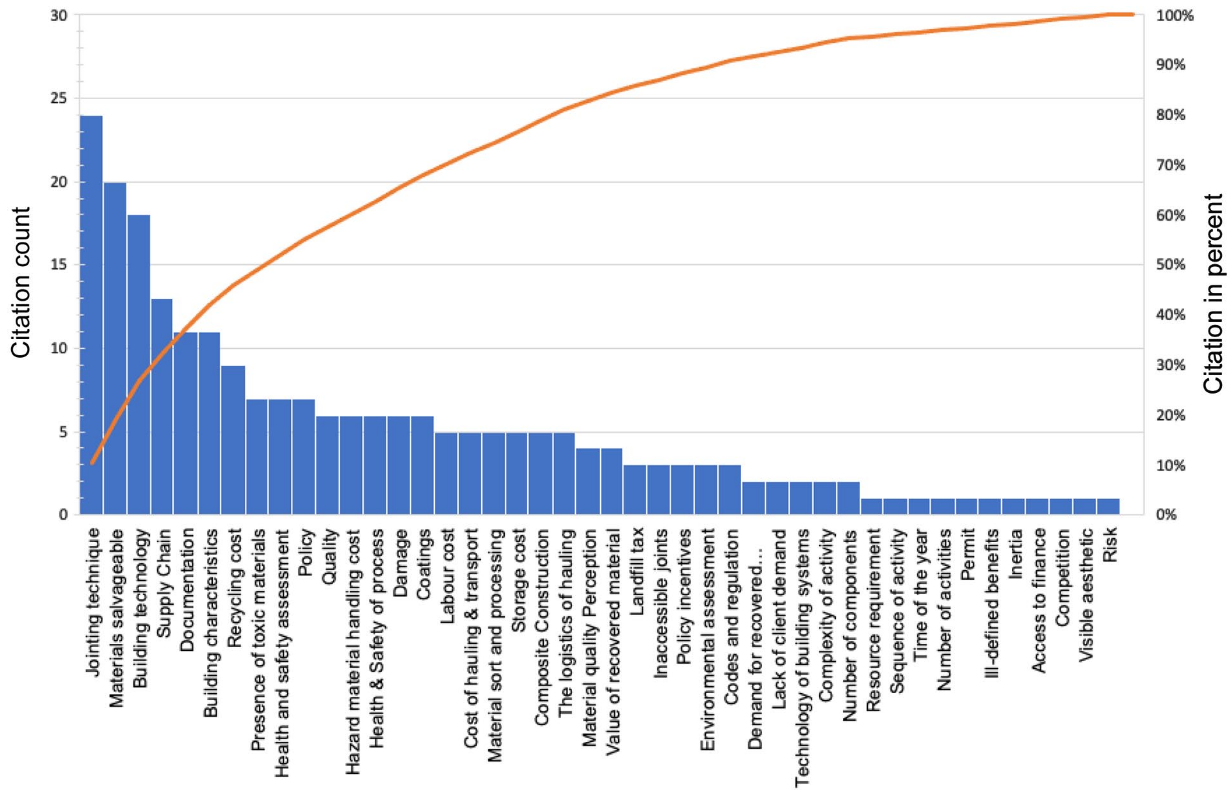

Figure 5. Drivers count by citation.

deconstructability will save investors from losing the massive benefit that deconstruction could generate. To obtain the deconstructability of a building, understanding the concept and drivers influencing deconstructability are required and was achieved in this research.

Through a SLR, the research identified 38 relevant articles, of which 35 were peer-reviewed journals, and the remaining 3 were reputable reports in the deconstruction field. From the findings, 44 drivers were discovered, which were later grouped into six constructs following TELOSS (technical, economic, legal, operational, schedule and social), a common feasibility framework. This research employed the author's domain expertise, the co-author and some notable pieces of literature to classify the drivers.

This research aligns with the study by NAHB Research Center (2001) as it provides analysis of feasibility of deconstruction, describing the condition under which a building could be deconstructible and the barriers that could hinder deconstruction, which must be overcome for wider implementation of deconstruction. Also, the deconstructability construct based conceptual framework proposed in this research identified all drivers from a different perspective, taking note of how the building was made, what the building contains, how the building deconstruction will take place and challenges or benefits after the deconstruction, which include the wrong assumption on the quality of the salvaged materials/components from deconstruction among many other drivers. All this put together will help decide if a building will be worthy of deconstruction or not.

Limitation and Future Directions

This SLR was designed to establish drivers influencing deconstructability of building, identify constructs and develop a construct based conceptual deconstructability framework. Aside from the domain expertise used in placing the drivers (measures) under the respective construct, the proposed framework requires more validation using statistical techniques like factor analysis from a quantitative perspective. The validation thus serves as the direction for future research. Also, future studies could incorporate the established drivers in collecting data that are possibly useful in other quantitative analyses regarding the deconstructability analysis.

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