TOWARDS ZERO CARBON BUILDING REFURBISHMENT: A NEW CONCEPTUAL FRAMEWORK FOR DECISION SUPPORT TOOLS

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To alleviate the climate change impacts, the construction industry needs to enhance the carbon performance of both new and existing buildings. The purpose of this paper is to examine the current decision support tools for building refurbishment and their applications to zero carbon refurbishment in the early design stages. A critical review was conducted with the final selection of 15 state-of-the-art decision-making tools for building refurbishment, which might be suitable for emerging or modification into zero carbon refurbishment decision support tools. Based on existing evidence, a conceptual framework is proposed for future development of zero carbon refurbishment decision support tools. The study provides perspectives on the lessons-learnt for the future development of zero carbon refurbishment decision support tools such as the application of the carbon budget and Value-Focused Thinking in the goal-setting stage, the inclusion of refurbishment strategies, the involvement of project stakeholders and end-users throughout the refurbishment process and the potential integration of incentive schemes to take up zero carbon approaches. The insights gained from this better support the construction industry to develop and deliver zero carbon refurbishment projects.

Keywords: zero carbon; refurbishment; existing buildings; decision support

INTRODUCTION

In the light of climate change, the world wrestles with reducing global warming to no more than 1.5 degree and achieve net-zero greenhouse gas emissions by 2050. Having responsibility for more than 40% of international energy use and one-third of global greenhouse gas emissions (Lucon *et al.,* 2014), the building and construction industry can significantly contribute to reducing climate change impacts. To decrease carbon emissions, one response is zero carbon buildings (Xing *et al.,* 2011; Pan and Pan 2020). However, the description of zero carbon buildings is confused. At present, the term encompasses several categories, such as "low energy", "low emissions", "sustainable" and even "green" buildings, leading to the problematic process of adoption and implementation. Thus far, Pan (2014) proposed a model using two fundamental dimensions of zero carbon buildings' concept: (1) specific to general, and (2) carbon/energy to holistic sustainability. Zero carbon building

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Bui, T T P, Wilkinson, S, Domingo, N and MacGregor, C (2021) Towards Zero Carbon Building Refurbishment: A New Conceptual Framework for Decision Support Tools *In:* Scott, L and Neilson, C J (Eds) *Proceedings of the 37th Annual ARCOM Conference,* 6-7 September 2021, UK, Association of Researchers in Construction Management, 594-603

includes the reduction of operational and embodied carbon throughout the whole life cycle of the building. To achieve net-zero carbon target by 2050, many existing buildings will need to be upgraded, refurbished or renewed as much of the current existing building stock will still be in use in 2050. This study focuses on refurbishing buildings to reduce the highest level of carbon reduction. The term "refurbishment", which represents a "modification and improvement to an existing building to bring it up to an acceptable condition" (ISO 2010; BS_EN 15978 2011). Vilches *et al. (*2017) define the building refurbishment boundaries according to BS-EN 15978: 2011 and EN 15804:2012. These boundaries are the production of new components, transport of new components, construction as part of the refurbishment process, waste management and end-of-life of the substituted and remaining existing building components. Building refurbishment towards the concept of zero carbon buildings defined above is called "zero carbon refurbishment".

Successful zero carbon refurbishment for existing buildings can be attained if effective decisions are made throughout the refurbishment process. Over the years, researchers have paid attention to the design and development of decision support tools to aid the optimal refurbishment solutions (Jensen and Maslesa 2015; Li and Froese 2017; Gade *et al.,* 2018; Serrano-Jiménez *et al.,* 2021). Several systematic reviews of decision support tools have been undertaken in academic studies (Thuvander *et al.,* 2012; Ferreira *et al.,* 2013). The latest review was conducted by Nielsen *et al. (*2016), which provided a state-of-the-art overview of the development of decision support tools in the pre-design and design stages. The authors have identified 43 decision support tools that are applicable in the pre-design and design phase of renovation projects. This view has shown a constant improvement of decision support tools for building refurbishment from the mid-1990s until 2015. However, most of them were designed for sustainable building renovation. The review was also limited to refurbishment strategies, which characterised distinctive levels of building refurbishment, depending on each urban and socio-economic context from different countries (Li *et al.,* 2017; Penna *et al.,* 2019). Apart from a hierarchical process towards zero carbon refurbishment for buildings established by Xing *et al. (*2011), there is a limited number of simple and holistic decision support tools that can address zero carbon problems for existing buildings. Making decisions about the refurbishment of buildings and the incorporation of net-zero carbon target are more difficult as decision-makers must deal with a combination of zero carbon problems and constraints and limitations. This paper examines the present decision support tools for building refurbishment in the early design stages and determines lessons-learnt for developing zero carbon refurbishment decision support tools.

METHODOLOGY

A critical literature review has been undertaken to assess, critique, and synthesise the literature on decision support for building refurbishment in a way that facilitates a new conceptual framework for future zero carbon refurbishment decision support tools. The critical literature review search strategy used the keywords: "building refurbishment" OR "building renovation" OR "building retrofit" AND "decision making" OR "decision support" in the title, keywords, and abstract fields via Scopus database to ascertain the relevant literature within the scope of the review. Scopus was chosen for the document search because it is the most present, influential, all-inclusive, and broadly used by academic researchers for peer-reviewed literature (Falagas *et al.,* 2007). Initially, 160 papers including articles, review, book chapters, conference papers published in English from 2016 to 2021 were found. Then, the mainstream chosen for reviewing included top-ranking journals and conferences in the construction field ranked by Scimago Journal and Country Rank (e.g., Building and Environment), publishing the largest number of papers in the research context. 80 papers were examined and evaluated by reading abstracts to confirm that they were relevant to the research scope, which was limited to the decision making in the early design stages including pre-design and design phases. The final selection included 15 state-of-the-art decision-making tools. The reviewed decision support tools were analysed according to six themes: country, target users, types of buildings, functionality, assessment methods and methodology.

RESULT

The decision support tools are defined as mechanisms or approaches that can assist decision-makers, such as building clients and other building stakeholders, to make informed decisions related to building projects (Nielsen *et al.,* 2016; Jensen *et al.,* 2018). Literature shows that there is a continuous development of decision support tools in the last five years. The reduced version of the up-to-date decision support tools review, categorised according to target users, types of buildings, and functionality is illustrated in Table 1. Aside from those designed in the US, Canada and China, many decision support tools were developed in Europe. European policies have advocated the refurbishment of the existing building stock towards the sustainable development, as demonstrated in the Directive (EU) 2018/844 (European Commission 2018). There were no decision support tools for building refurbishment in Oceania. The majority of tools were designed to support the decision-making for residential buildings rather than other building types. In the past, most of decision support tools were targeted at decisions and evaluation on individual refurbishment projects whilst the current trend moved from individual buildings into multi-buildings (Gade *et al.,* 2018; He *et al.,* 2019; Salvia *et al.,* 2021). The tools were primarily generating and ranking refurbishment solutions and evaluating the economic benefits during the design stage, targeting a group of building professional users who had experience in building energy and cost modelling. Only Kamari *et al. (*2017) developed a new simplified holistic sustainability decision-making support framework, which could be used by non-professional building users in any stages throughout the refurbishment project life cycle.

In view of assessment methods and methodology, many of the designed tools were focused on sustainability, with at least one or two sustainable dimensions such as environment, economy and society. A combination of Life Cycle Costing and Life Cycle Assessment methods was proposed for measuring two sustainability aspects including economy and environment. Details of the methodology used for the development of decision support tools is demonstrated in Table 2. Considering the environmental dimension, both operational and embodied carbon emissions had been assessed in the process of choosing improvement options (Olsson *et al.,* 2016). Whereas Net Present Value and the Global Cost calculated by analysis were predominantly used to appraise the economic sustainability of various design alternatives (Guardigli *et al.,* 2018; He *et al.,* 2019; Penna *et al.,* 2019). Nonetheless, most of the tools have taken environmental and economic aspects as the main concerns, the social aspect has mostly been overlooked. In fact, Serrano-Jiménez *et al. (*2021) considered both impacts and benefits of the refurbishment applications through a procedure of quantifying and weighting multiple social, technical, and economic variables, whilst Kamari *et al. (*2017) engaged the involvement of multi-stakeholders and end-users through the application of Soft Systems Methodologies with Value-Focused Thinking. Although scholars have attempted to deal with the social issue by setting social criteria and additional parameters, social issues have remained on the fringe of mainstream practice (Jensen *et al.,* 2018).

Table 1: Summary of key findings from the review of up-to-date decision-making tools

Tools	Types of buildings	Target users	Functionality
BECEREN (Olsson *et al.*, 2016)	Residential buildings	Multi-decision makers	Provide alternative improvement options and renovation measures, evaluate different improvement options
(Seddiki *et al.*, 2016)	Masonry buildings	Multi-decision makers	Rank different thermal renovation solutions
(Jafari and Valentin 2017)	Residential buildings	Homeowners	Calculate the economic benefits of energy retrofitting, determine the optimum retrofitting budget, select the optimum energy retrofitting strategy
(Kamari *et al.*, 2017)	All types of buildings	Relevant stakeholders	Audit, develop and assess building renovation performance. Support decision-making during the project's life cycle
SWAHO (Li and Froese 2017)	Residential buildings	Homeowners	Enable trade-offs among renovation actions based on the homeowner's perception of sustainability
REDIS (Gade *et al.*, 2018)	School buildings	Danish municipality	Support the building owners in choosing which buildings to renovate within a building portfolio, or which renovation actions to initiate across multiple buildings
(Li *et al.*, 2018)	Multi-story residential buildings	Relevant stakeholders	Select low-carbon refurbishment solutions for multi-story residential buildings in high-density subtropical cities
(Guardigli *et al.*, 2018)	Public housing stocks	Investors	Assess different renovation strategies, evaluate the economic sustainability of various design alternatives
(He *et al.*, 2019)	Multi-buildings	Investors	Optimise energy efficiency retrofit investment in numerous buildings under financing budgetary restraint
NovaDM (Kamari *et al.*, 2019)	Large-scale residential buildings and social housing	Designers	A constraint-based renovation design support
Klimakit model (Penna *et al.*, 2019)	Social housings	Multi-decision makers	A tool for promoting the energy refurbishment of social housing
(Napoli *et al.*, 2020)	Public buildings	Multi-decision makers	Support the decision process of regional or local authorities in the context of a large number of energy retrofitting actions of public buildings
PARADIS (Kamari *et al.*, 2021)	Residential buildings	Designers	Support informed decision making for optimal renovation scenario design
(Serrano-Jiménez *et al.*, 2021)	Residential buildings	Housing managers	Select feasible and sustainable housing renovation strategies
PrioritEE toolbox (Salvia *et al.*, 2021)	Public buildings	Local decision-makers	A web-application Decision Support Tool for comparing and ranking a portfolio of energy interventions

These findings suggest that refurbishment project goals should be based on construction stakeholders and end-users' perspectives and consider wider aspects such as benefits and impacts of refurbishment projects, aside with sustainable aspects.

Table 2: Summary of methodology used in developing up-to-date decision-making tools

Tools	Methodology
BECEREN (Olsson *et al.*, 2016)	Case studies. LCC and LCA approaches
(Seddiki *et al.*, 2016)	Delphi, Swing and PROMETHEE methods, and Graphical Analysis for Interactive Aid (GAIA)
(Jafari and Valentin 2017)	Building energy simulation: eQuest. LCC formulation
(Kamari *et al.*, 2017)	Literature review, individual and focus group interviews, and application of Soft Systems Methodologies (SSM) with Value Focused Thinking (VFT)
SWAHO (Li and Froese 2017)	A design science method
REDIS (Gade *et al.*, 2018)	A design science method
(Li *et al.*, 2018)	Identify sustainable refurbishment solutions, assess emission reductions. develop system process, validate with industry experts
(Guardigli *et al.*, 2018)	Evaluate the economic sustainability of various design alternatives with the net present value (NPV) and the global cost (GC)
(He *et al.*, 2019)	Use a multi-objective optimization model. Validate the model with 27 buildings of non-governmental organisations
NovaDM (Kamari *et al.*, 2019)	The IDEF5 methodology for knowledge engineering and ontology development
Klimakit model (Penna *et al.*, 2019)	Literature review, workshops, economic analysis based on Net Present Value (NPV)
(Napoli *et al.*, 2020)	Collect database of the building stock, develop of the multi-criteria model, apply ELECTRE TRI-nC method, sort the energy retrofitting actions into categories
PARADIS (Kamari *et al.*, 2021)	Building Information Modelling (BIM) based decision support system
(Serrano-Jiménez *et al.*, 2021)	Apply an iterative design process based on data and experiences from two case studies
PrioritEE toolbox (Salvia *et al.*, 2021)	Literature review, using national database, develop a web-based application, test in five local pilots

The review has demonstrated new decision support tools, which had additional parameters such as impacts and benefits of the refurbishment suggestions, and/or apply for a specific situation in different nations. This might be because these tools were designed for definite purposes and practical cases. Some tools were not available for use online or with local languages and databases. Thus, even though there were many tools developed in the past with the same functionalities, researchers have intended to create new tools based on existing theoretical foundations, making them more suitable in different contexts. The literature showed that there is a lack of tools to support decision-making processes in the early stages for building refurbishment specifically towards zero carbon target.

DISCUSSION

The development of zero carbon refurbishment and decision support tools for building refurbishment was critically examined. A new conceptual framework for the future development of zero carbon refurbishment tools is recommended based upon the analysis and is provided in Fig 1. Overall, the development of the conceptual framework for zero carbon refurbishment is based on the theoretical framework of the refurbishment process in the early stages, including five main parts: (a) Goal setting; (b) Building diagnostics; (c) Refurbishment strategies; (d) Refurbishment actions; (e) Performance evaluation. For zero carbon refurbishment projects, there is a need to examine the carbon measurement and performance, employ the refurbishment strategies towards zero carbon, engage with construction stakeholders and end-users, and consider the incentive schemes in a way that enable maximum the carbon reduction.

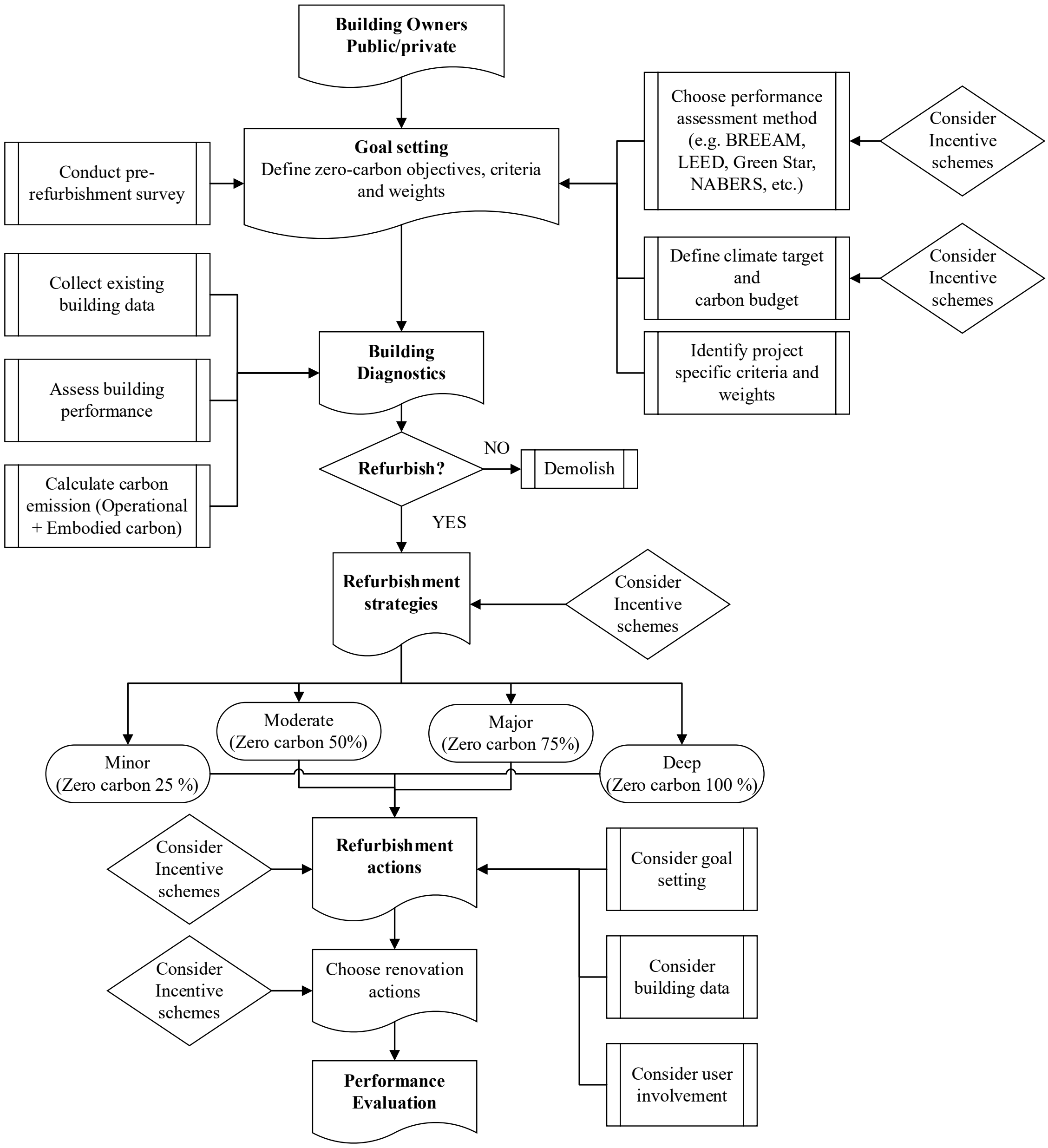

Fig 1: A conceptual framework for future zero carbon decision support tools

Setting the right goal

Setting the right goals is the first step in the refurbishment process (Ferreira *et al.,* 2013; Nielsen *et al.,* 2016). For zero carbon refurbishment project to be successful, a building's life cycle carbon performance must be integrated with other project criteria, particularly clients' requirements and stakeholders' values. The concept of Value-Focused Thinking introduced by Keeney (1992), with the emphasis on the goal-setting aspect of the decision-making process, has been applied in a few recent decision support tools because it promoted the uptake of sustainable building renovation while satisfying the client's preferences and requirements (Olsson *et al.,* 2016; Kamari *et al.,* 2017; Gade *et al.,* 2018). As such, an implication for the future development of new decision support tools for zero carbon refurbishment projects is using Value-Focused Thinking as a fundamental basis to identify project criteria and weights. Moreover, there is potential for the use of carbon budgets for individual buildings suggested by Chandrakumar *et al. (*2020), to help define the carbon performance goal in decision support tools for zero carbon refurbishment. A meaningful zero carbon refurbishment decision support tool should consider the carbon impact of its building in order to achieve net-zero carbon target by 2050.

Renovation strategies

Research on zero-carbon strategies for building refurbishment is limited. In the UK, Xing *et al. (*2011) established a hierarchical process towards zero carbon buildings refurbishment. Nevertheless, this concept may not be applicable in all building types as Dotzler *et al. (*2018) argued that it might be more efficient to refurbish the building services in the first place. Different countries may adopt different renovation strategies, for example, the UK has committed with decarbonising British electricity, and as a result, carbon emissions from electricity have fallen 46% in the three years to June 2016 (Staffell 2017). Recently, partial or over-time refurbishment strategies seem to be a trend in some nations towards sustainable refurbishment (Jensen *et al.,* 2018). For zero carbon refurbishment, long-term strategies also need to be established with regard to partial refurbishment, particularly the carbon budget can be established (e.g., 25%, 50%, 75%, 100% carbon reduction) in the early stages and achieved over time.

User-centred refurbishment process

User-involvement in the decision-making process is critical for bridging the "energy performance gap" and improving occupant well-being (Ma *et al.,* 2012). However, in the early phases of a refurbishment project, the involvement of end-users is often ignored before making final decisions (Jensen and Maslesa 2015). Prior to the work of Li *et al. (*2018), which reflected user-habits and methods of assessing emission reduction in the process of selecting refurbishment solutions, the role of end-users was largely unknown. Users should be involved in both goal setting and choosing refurbishment stages, aiming to generate appropriate refurbishment actions. For example, a biomass boiler can be a good selection in the case of low levels of user dependency (Kesidou and Sorrell 2018). Future decision-making tools must be able to consider user-involvement throughout the refurbishment process.

The potential of integrating incentive schemes in future decision support tools

One criticism of the literature is that there are many decision-support approaches and tools available while the uptake of high-performance building renovation is very low. For example, despite much of the previous research has aimed at developing more sophisticated Life Cycle Costing models and tools, Gluch *et al. (*2018) claimed that managers' interest in these refinements seems limited. Government incentives, rewards, and tax policies could potentially drive consumer's and developer's decisions towards low-carbon building interventions. Penna *et al. (*2019) has encompassed the public incentives in the decision support tool to reduce the payback period and increase the cost-effectiveness of the refurbishment solutions. A robust energy intervention selection framework could be used to integrate set of government policies and practices (Perera *et al.,* 2018). Such interventions should be integrated in decision support tools to drive users to make zero-carbon decisions for refurbishment projects.

CONCLUSIONS

This study set out to examine the current application of decision tools to zero carbon refurbishment for existing buildings. The literature review showed how future zero carbon decision-making tools can be developed to better support building professionals in the process of building refurbishment. The findings provide a new understanding of decision support mechanisms for zero carbon refurbishment projects. The analysis of the climate change target and carbon budget undertaken here, has extended our knowledge of setting the right goal for zero carbon refurbishment projects. The involvement of project stakeholders and end-users in the building refurbishment process is supported by the current findings. When zero carbon targets are considered in the project goal and criteria, there is a need for a balance among stakeholder's values, end-users' interaction and benefits, and other project requirements. Developing acceptable specific refurbishment strategies for the zero-carbon refurbishment project is required, especially partial refurbishment strategies that can be established and achieved over time. The integration of incentives schemes is possible to take up zero-carbon approaches. Tools are created to not only support decision-makers but also encourage them to lead the uptake of zero carbon projects. Overall, this research provides implications for the future development of zero carbon refurbishment decision support tools, better assisting the building sector to develop and deliver zero carbon refurbishment projects. However, being limited to empirical data, the study lacks practical implications for specific building situations. Further experimental investigations are needed to evaluate the proposed framework through the development and implementation of case studies.

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