University Library

MINERVA ACCESS

A gateway to Melbourne's research publications

Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:
Skillington, K;Crawford, RH

Title:
Design for Dematerialisation: Examining an approach for reducing the life cycle energy requirements of residential buildings

Date:
2020-11-20

Citation:
Skillington, K. & Crawford, R. H. (2020). Design for Dematerialisation: Examining an approach for reducing the life cycle energy requirements of residential buildings. Iop Conference Series Earth and Environmental Science, 588, (3), pp.032049-032049. IOP Publishing. https://doi.org/10.1088/1755-1315/588/3/032049.

Persistent Link:
https://hdl.handle.net/11343/251899

License:
CC BY

PAPER • **OPEN ACCESS**

Design for Dematerialisation: examining an approach for reducing the life cycle energy requirements of residential buildings

To cite this article: Katie Skillington and Robert H Crawford 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **588** 032049

View the article online for updates and enhancements.

This content was downloaded from IP address 182.239.187.80 on 25/11/2020 at 20:48

IOP Conf. Series: Earth and Environmental Science **588** (2020) 032049 doi:10.1088/1755-1315/588/3/032049

Design for Dematerialisation: examining an approach for reducing the life cycle energy requirements of residential buildings

Katie Skillington[1], Robert H Crawford[2]

[1] Faculty of Architecture, Building and Planning, University of Melbourne, Melbourne, Victoria, Australia
[2] Faculty of Architecture, Building and Planning, University of Melbourne, Melbourne, Victoria, Australia
Email: k.skillington@student.unimelb.edu.au

Abstract. Responsible for significant energy demand and emissions, the building sector has an opportunity to contribute to global sustainability efforts. In creating resilient and sustainable human settlements, alternative design approaches that address life cycle energy requirements are needed. Design for Dematerialisation is one such approach that aims to lower life cycle energy requirements by reducing material and resource inputs. Yet, despite its conceptual simplicity, the application of the approach within the building sector and its effect on life cycle energy demand is poorly understood. This study seeks to briefly outline the approach from the perspective of the building sector and examine the effect of dematerialisation actions on the life cycle energy requirements of a multi-residential building in Melbourne, Australia. This study demonstrates that while an effect is observed – most notably in recurrent embodied energy – a partial rebound effect exists. Savings from the reduction of key materials and components are partially negated by the energy intensity of alternative materials introduced, and/or additional elements required to maintain the building's fitness-for-purpose. The assessment highlights the need for designers to address energy performance holistically, by taking into account the effect of actions on multiple life cycle stages concurrently. By employing this considered approach, dematerialisation has the potential to be an accessible strategy for designers tasked with creating sustainable, resilient urban settlements.

1. Introduction

Sustainable Development Goal (SDG) 11 calls for the development of resilient and sustainable urban settlements. In pursuit of this goal, the core fabric of urban settlements – buildings – cannot be overlooked. Building construction and operation is responsible for approximately 32% of global final energy use and 17% of direct CO_2 emissions [1]. Furthermore, 50-year forecasts demonstrate that the sector is expected to add 230 billion m^2 of new floor area and global energy demand will increase by 50% if no efficiency measures are implemented [1,2]. Driving much of this increase is the residential building sector, which is growing to accommodate rising populations and accelerating global affluence.

To address the negative environmental effects of buildings, a range of different solutions have been proposed, including eco-technologies, regulations, assessment tools, and design approaches. Design for Dematerialisation (DfD) is one such design approach. DfD seeks to lower material and resource inputs while not negatively impacting the buildings' original functional intent. Although the approach has been historically applied in the manufacturing and industrial design fields, little evidence of its application to

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

buildings exists. Furthermore, it is unknown if DfD positively or negatively affects life cycle energy requirements. As such, this study adds to the growing body of academic literature that explores DfD by clarifying its definition from the perspective of the building sector and aims to investigate – at a high level using select DfD actions – the potential for the approach to reduce life cycle energy requirements.

2. Defining design for dematerialisation

From the perspective of the building sector, DfD is designing for reduced material and resource inputs, while not impeding the buildings functional purpose [3–5]. DfD application – which primarily occurs during the design phase – is guided by a series of principles that direct DfD actions (Figure 1). Some practical examples of DfD actions include: the removal of secondary internal finishes, elimination of excess functions (e.g. car-parking, second bathrooms, etc), and lowering dependence on non-renewable resources through high-efficiency appliances and/or on-site energy production. Actions by building users – such as transport choices, non-fixed elements – are not considered part of the approach, as personal values and behaviours around consumption are inconsistent and difficult to predict [6].

Importantly, DfD requires more than just incremental improvements in material efficiency. Due to projected significant increases in global demand for building materials and associated raw resources, the implementation of material efficiencies *alone* may not yield significant benefits for society as a whole [5]. Effective use of DfD requires a re-evaluation of the entire building design at the conceptual phase. It is hypothesised that DfD may reduce life cycle energy demand. However, due to a lack of research examining the approach, this hypothesis has not been tested. Verification of the effect of DfD on building performance is thus required to understand its potential benefits.

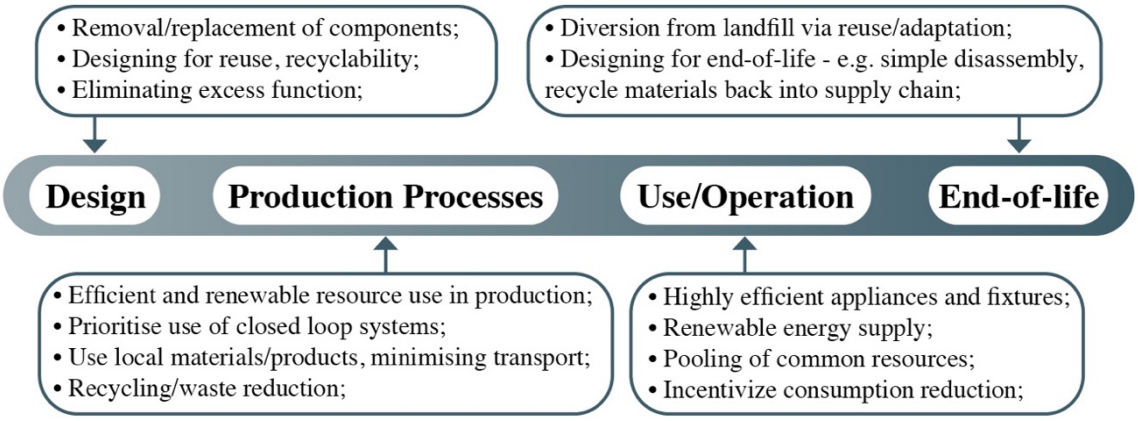

Figure 1. Guiding principles for DfD actions and their relevant life cycle stage

3. Method for quantifying life cycle energy demand

Quantification of the life cycle energy requirements of a building employing DfD actions was conducted to understand the effect of the approach on building energy demand. A life cycle energy analysis (LCEA) was used to quantify the life cycle energy requirements of two generic, hypothetical multi-residential buildings demonstrating typical practice and *limited* DfD actions, over a 75-year period. DfD actions considered include no second bathrooms, minimal internal linings/finishes, and removal of mechanical cooling in favour of passive design strategies (i.e. improved insulation/glazing). For the typical building, characteristics were informed by an inspection of recent, local, multi-residential projects, and the dematerialised building was informed by local existing buildings demonstrating DfD actions. More detailed characteristics of the hypothetical buildings are published online [7].

Although dematerialisation actions may affect all life cycle stages, the system boundary for the LCEA in this study encompasses modules A1-A5, B1, B4 and B6 of EN15978:2011 [8]. As the floor area between the hypothetical buildings varies, the functional unit used for comparison between each building was gigajoules per m^2 of habitable space. Equations used for the quantification of initial and

recurrent embodied energy can be found in [9]. As a brief summary, hybrid coefficients developed using a Path Exchange method and published in the recently released EPiC Database [10] were used for the quantification of embodied energy. In the calculation of recurrent embodied energy, material service lives for different elements ranged from 10 years for water-based paint [11] to 75 years for structural steel [12]. Material replacement and building cost were calculated using a local cost guide [13] and the operational energy for each building was quantified using the Passive House Planning Package v9.6.

4. Results and discussion

Total embodied and operational energy demand for each of the hypothetical buildings is summarised in Figure 2. The total life cycle energy requirement for the stages examined is 67 GJ/m^2 for the typical building, and 59 GJ/m^2 for the dematerialised building, representing a reduction of 12.1%. Reduction in initial embodied energy in the dematerialised building was minimal and savings in other stages were moderate. From the result, it is apparent that a partial rebound effect occurred – embodied energy savings from the reduction of key materials or components were partially offset by additional embodied energy of alternative materials introduced, and/or additional elements required to maintain the building's fitness-for-purpose. For example, in the dematerialised building, the removal of mechanical cooling necessitated a more energy intensive window assembly and more insulation to ensure that operationally, the building maintained a comfortable indoor temperature (between 19-26°C). This finding is in line with similar findings by Crawford and Stephan [14]. The finding demonstrates that achieving a balance between embodied and operational energy is a key challenge for designers employing DfD. When using DfD, the initial embodied energy of a material and/or component must be considered along with the possible direct and indirect consequences of that material across the entire life cycle of the building.

The dematerialised building also used materials that had a longer service life (e.g. timber flooring instead of carpet) and limited internal finishes (e.g. paint), resulting in savings in recurrent embodied energy (43.1%). This result highlights the importance of considering durability and material/building service life when designing low-energy housing. Operationally, savings were modest (10.9% saving in the dematerialised building). However, this modest result is likely due to the operational aspects of the dematerialised building having very minor changes (omission of mechanical cooling only). It is anticipated that further reductions in operational energy could be achieved if all mechanical systems were eliminated, and appliances/fixtures were high-efficiency and accounted for in the analysis.

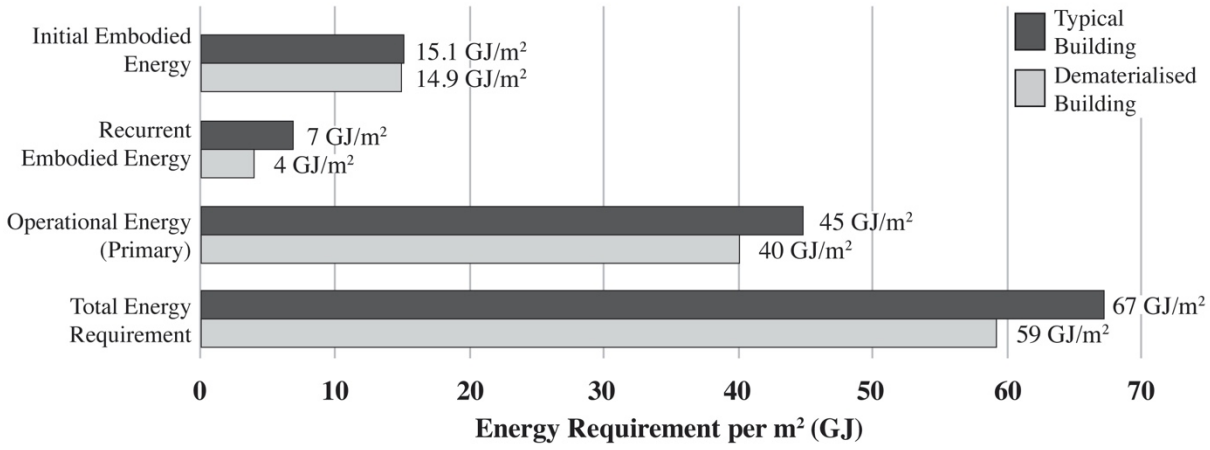

Figure 2. Summary of life cycle energy demand, by stage and building

5. Conclusion

This study demonstrated that the life cycle energy demand of a building can be affected by dematerialisation actions, with the greatest savings found to be in a building's recurrent embodied energy. The results demonstrate that designers must use caution when using DfD and consider the

building's entire life cycle, as a single DfD action may have unintended rebound effects that partially negate energy savings attained. Furthermore, as select DfD actions may require additional or more energy intensive materials to maintain a building's fitness-for-purpose, a systems-based perspective to applying DfD in building design that considers trade-offs between materials and performance is critical.

The core limitations of this analysis are its focus on one environmental flow and use of generic, hypothetical buildings, including one with very limited dematerialisation actions. While efforts were made to ensure that the generic buildings represented reality, an infinite number of variations were possible. DfD actions were intentionally limited in modelling, due to the restricted length of this paper.

This study is a demonstration case prior to a larger, post-occupancy study – incorporating multiple environmental flows and existing buildings – being undertaken. Further research will examine flows in a post-occupancy context, improving our understanding of interactions between material requirements and energy demand in a real-world situation. Furthermore, as SDG11 also considers human wellbeing, an analysis of the effect of DfD on occupant comfort is also crucial to understanding its whole potential.

Acknowledgments
This work forms part of PhD research supported by the Australian Government Research Training Program (RTP) and the Thrive Research Hub scholarship at the University of Melbourne, Australia.

References
[1] International Energy Agency. Transition to Sustainable Buildings [Internet]. 2013. Available from: http://www.iea.org/etp/buildings/
[2] United Nations Environment and International Energy Agency. Towards a zero-emission, efficient, and resilient buildings and construction sector - Global Status Report 2017. 2017.
[3] Brown M, Lutz-Carrillo S. Dematerialization - a changing paradigm in architecture. Austin, Texas; 2009.
[4] Fernandez J. Material Architecture: Emergent Materials for Innovative Buildings and Ecological Construction. Oxford: Architectural Press; 2006.
[5] Allwood JM, Ashby MF, Gutowski TG, Worrell E. Material efficiency: A white paper. *Resour Conserv Recycl*. 2011;**55**(3):362–81.
[6] Whitmarsh L, Capstick S, Nash N. Who is reducing their material consumption and why? A cross-cultural analysis of dematerialization behaviours. *Philos Trans R Soc A Math Phys Eng Sci*. 2017;**375**(2095).
[7] Skillington K. Appendix 1: Design for dematerialisation: examining an approach for lowering the life cycle energy requirements of residential developments [Internet]. 2020. Available from: https://bit.ly/2FrW1HH
[8] European Committee for Standarisation. EN15978 - Sustainability of construction works - Assessment of environmental performance of buildings - Calculation Method. 2011.
[9] Rauf A, Crawford RH. The relationship between material service life and the life cycle energy of contemporary residential buildings in Australia. *Archit Sci Rev*. 2013;**56**(3):252–61.
[10] Crawford R, Stephan A, Prideaux F. EPiC Database [Internet]. Melbourne, Australia: University of Melbourne; 2019. Available from: https://melbourne.figshare.com/articles/EPiC_Database/10257728
[11] Crawford RH. Post-occupancy life cycle energy assessment of a residential building in Australia. *Archit Sci Rev*. 2014;**57**(2):114–24.
[12] Scheuer C, Keoleian GA, Reppe P. Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. *Energy Build*. 2003;**35**(10):1049–64.
[13] Rawlinsons. Rawlinson's Australian Construction Handbook 2015. Perth: Rawlhouse Publishing; 2015.
[14] Crawford RH, Stephan A. The Significance of Embodied Energy in Certified Passive Houses. *Int J Archit Environ Eng*. 2013;**7**(6):427–33.