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Analysis of life-cycle boundaries for environmental and economic assessment of building energy refurbishment projects

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ABSTRACT

Despite the standardization of the life-cycle assessment methodology for the construction sector, analysts tend to apply some simplifications in relation to the system boundaries, omitting some of the life-cycle stages. In particular, for building energy refurbishment projects, there is a general focus on the operational stage, linked to the main objective of reducing operational energy use. This paper evaluates the relevance of each life-cycle stage in relation to the overall environmental and economic impact on residential building energy refurbishment projects. The results from the analysis of the refurbishment strategies at a case study in Spain show the relatively minor importance of the transport and end of life stages. The construction process stage is also of relatively minor importance regarding the environmental performance. The product, maintenance and replacement stages are generally of higher importance, particularly for economic evaluation. An extensive sensitivity analysis demonstrates the difficulties of simplifying the life-cycle boundaries, suggesting that potential simplifications should take into account various parameters, including the climate region, building typologies, and expected service life. As an example, the results have shown that for cold climate zones and buildings, where large energy savings from energy refurbishment strategies can be achieved, the other life-cycle phases are less important and, in most cases, represent less than 10% of life-cycle environmental impacts.

1. Introduction

Buildings are one of the world's largest energy-consuming sectors, accounting for nearly 30% of the final global energy consumption and reaching 40% in the European Union (EU) [1]. With new construction adding at most 1% a year to the EU existing stock [2], there is large potential for improving the energy performance of the other 99% of the building stock, making "energy refurbishment" a top priority in current EU and national policies. The focus on reducing building operational energy use through the last decades has meant that buildings are becoming more energy efficient, therefore increasing the relevance of the environmental and economic impact of the other life-cycle stages. In this context, according to the European Commission [3,4] or studies related to the "Life Cycle Zero Energy Building" [5], life-cycle assessment (LCA) is well recognized as a valid framework to assess the potential impacts of construction projects. General LCA methodology is covered by ISO 14040:1997 [6] and 14044:1998 [7] standards, and based on these standards, technical committees such as CEN TC 350 [8] or ISO TC 59/SC17 [9] have worked on the development of specific standards for the construction sector.

As Fig. 1 shows, the evaluation scope and life-cycle stages for building assessment with a life-cycle approach have been defined in standards such as EN 15978:2011 [10].

However, despite these standardization efforts, there are very few studies (see Table 1) that have assessed all the described life-cycle stages.

Table 1 shows that only the product stage (A1–A3) and the operational energy use stage (B6) have been assessed by the authors in all identified studies. The transport of products to the site (A4) is also evaluated in most of the identified studies (83%). Other life-cycle phases are less frequently assessed, with only 66% of studies considering the construction process (A5), 62% considering end of life (C1–C4), 61% considering replacement (B4), and just 46% of the studies considering the maintenance phase (B2).

These omissions of life-cycle stages on the evaluation are mainly due to the lack of information, the difficulty of predicting future scenarios, and the relatively low impact of those phases in comparison to the whole life-cycle. For example, Sartori and Hestnes [51] have shown that the construction process normally accounts

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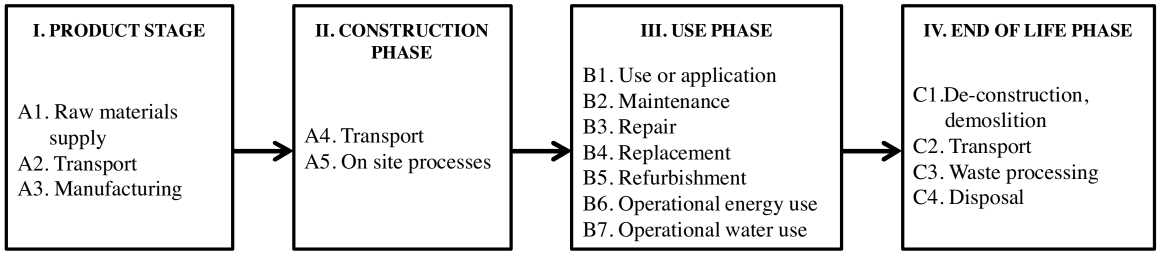

Fig. 1. Different stages of the building according to EN 15978 standard [10].

Table 1
Building life-cycle stages in relation to existing studies analysed.

	A1-3	A4	A5	B2	B4	B6	C1-4
Junnila, 2004 [11]	X	X	X	X		X	X
Citherlet & Defaux, 2007 [12]	X	X	X	X	X	X	X
Nemry et al., 2008 [13]	X	X				X	X
Zabalza et al., 2009 [14]	X					X	
Utama & Gheewala, 2009 [15]	X	X	X		X	X	
Kofoworola & Gheewala, 2009 [16]	X	X	X	X		X	X
Blom et al., 2010 [17]	X	X		X	X	X	X
Blengini & Di Carlo, 2010 [18]	X	X	X	X	X	X	X
Gustavsoon & Joelsson, 2010 [19]	X	X				X	
Hernandez & Kenny, 2010 [5]	X				X	X	
Ortiz et al., 2010 [20]	X	X	X	X		X	X
Dodoo et al., 2010 [21]	X	X	X			X	X
Malmqvist et al., 2011 [22]	X					X	
Tae et al., 2011 [23]	X	X	X	X		X	X
Wallhagen et al., 2011 [24]	X					X	
Rossi et al., 2012 [25]	X	X				X	
Sharma et al., 2012 [26]	X	X		X		X	
Gazulla & Oregi, 2012 [27]	X					X	X
Iyer & Wong, 2012 [28]	X	X	X		X	X	X
Stephan et al., 2012 [29]	X	X	X	X	X	X	
Cuellar & Azapagic, 2012 [30]	X	X	X	X	X	X	X
Ramesh et al., 2012 [31]	X	X			X	X	
Stephan et al., 2013 [32]	X	X	X	X	X	X	
Asdrubali et al., 2013 [33]	X	X	X		X	X	X
Allacker & De Troyer, 2013 [34]	X	X	X	X	X	X	X
Paulsen & Sposto, 2013 [35]	X	X	X	X	X	X	X
Vrijders & Wastiels, 2013 [36]	X	X	X	X	X	X	
De Angelis et al., 2013 [37]	X	X	X			X	X
Ostermeyer et al., 2013 [38]	X	X	X	X	X	X	
Mosteiro et al., 2014 [39]	X	X	X		X	X	X
Bull et al., 2014 [40]	X				X	X	X
Dodoo et al., 2014 [41]	X		X			X	X
Stephan & Stephan, 2014 [42]	X	X	X	X	X	X	
Russell-Smith et al., 2014 [43]	X	X	X		X	X	
Rodriguez & Freire, 2014 [44]	X	X	X	X	X	X	X
Bastos et al., 2014 [45]	X	X		X	X	X	
Devi & Palaniappan, 2014 [46]	X	X	X			X	X
Cellura et al., 2014 [47]	X	X	X		X	X	X
Assiego de Larriva et al., 2014 [48]	X	X			X	X	X
Cetiner & Edis, 2014 [49]	X	X	X	X	X	X	X
Oregi et al., 2015 [50]	X	X	X		X	X	X

for less than 1% of the life-cycle energy use, while other studies [52,53] have stated the same 1% for the end of life stage.

From this brief analysis, it can be noted that, despite the achievements on the standardization of the life-cycle assessment methodology for the construction sector, analysts tend to apply some simplifications in relation to the building life-cycle boundaries, omitting some of the life-cycle stages. This simplification is generally due to the complexity of the building as a product and to data availability and quality.

In particular, for building energy refurbishment projects, where the main objective is generally to reduce operational energy use, there is no scientific consensus on the need and added value of the application of a life-cycle methodology. When LCA is applied, the decisions regarding the selection of the appropriate boundaries are frequently not well documented, and can substantially differ between different studies.

This paper evaluates the relevance of each life-cycle stage in relation to the overall impact derived from residential building energy refurbishment project and discusses the influence of life-cycle boundaries simplification on environmental and economic analyses. A residential building case study is used to perform a detailed environmental and economic analysis of building energy refurbishment options, and the results are discussed for the whole life-cycle, as well as for the relevance of the different life-cycle phases. An exhaustive sensitivity analysis for a variety of parameters affecting the life-cycle assessment is also carried to discuss the potential simplifications of the life-cycle boundaries.