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LCA-Framework to Evaluate Circular Economy Strategies in Existing Buildings

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Abstract. **Introduction**: Buildings are responsible for 39 % of CO2 emissions in the world and have the largest consumption of natural resources. The concept of Circular Economy can be used as an approach for mitigating environmental impact in this sector. Circular economy in the built environment can be implemented on a building level through preservation instead of demolition and new construction. In order to assess the environmental impact, the Life Cycle Assessment (LCA) framework can be used. The purpose of this study is to expand the existing building-LCA framework from the CEN TC 350 standards to include existing buildings on the building site in the assessment of buildings and demonstrate the framework on a building case. This is done in order to include the environmental benefits from preserving the building materials that already exists on the building site. **Methods**: The framework is developed based on the existing standard for LCA for buildings and the framework is demonstrated on an existing school building. **Results**: The study develops and demonstrates a framework for performing LCA on buildings when an existing building is the starting point. The framework includes scenarios for 1) preservation, 2) renovation and 3) demolition and new construction. The case building shows the importance of including demolition of the existing building as it accounts for 12 % of impacts. It furthermore illustrates how the scenarios can be compared, especially in terms of when the impacts occur, i.e. that most impacts from scenario 3) happen today, which can be a challenge with a limited climate budget. **Conclusion**: The developed framework allow us to broaden the LCA scope to include existing buildings in the assessment such as demolition of existing buildings on building site. This makes it possible to evaluate the circular strategies on building level using LCA to the benefit of building designers, clients and policy makers.

1. Introduction

1.1. Problem and purpose of the study

Buildings have a large impact on the environment. The construction sector consumes 32% of material resources in EU [1] and is responsible for 38% of the waste generated [2]. Furthermore, buildings globally account for 39 % of energy-related CO_2 emission. Here, 28 % arise from operational energy and 11 % are emissions from energy used to produce building and construction materials [3]. Life cycle assessment (LCA) is an established method to assess the environmental impacts and resource use of buildings. In recent research building materials have shown to be of increasing importance: A study on more than 650 building LCA cases shows, that in energy efficient buildings, the materials account for half of CO_2 emission and in some cases more than 90% [4]. While a study on Danish buildings show that materials account for approximately 75 % of CO_2 emissions [5].

Circular economy (CE) is an approach to reduce the impact from building materials. CE approaches are propagated as a mean for increasing resource efficiency in order to reduce environmental impacts and resource depletion [6,7]. In the building sector, these principles can be applied on a building level, where circular approaches aim at preserving or renovating existing buildings in order to maintain the highest possible value and preventing environmentally exhausting actions. While research show that renovation is typically better than new construction [8], there are still some cases where this does not apply [9]. Individual assessments should therefore be conducted. However, when it comes to existing buildings and renovation, there is no standardized method of conducting the assessment and current praxis is therefore inconsistent [10]. This is due to the standards for LCA on buildings, which are mostly directed towards new construction and not existing buildings. A standardized method for analysing and comparing scenarios is therefore needed to illustrate the effect of CE strategies on a building level. The objectives of the research presented in this paper are therefore to:

- Develop a framework for performing LCA on buildings when an existing building act as the starting point.
- Demonstrate the framework on a building case.

1.2. The method gap of existing buildings

The European standard EN 15978 from CEN TC 350 describes the calculation method to assess the environmental performance of buildings [11]. The life cycle stages included in LCA for buildings is shown in Table 1. The standard describes the method for "new and existing buildings and refurbishment projects", however, the method for existing buildings is not very clearly defined. In building practice, the considerations about the future development of an existing building will concern the following options: 1) preservation, 2) renovation and 3) demolition and new construction.

Renovation is addressed in the standard through the "refurbishment" module B5 (see Table 1). When new buildings are assessed, the impacts from renovation should be allocated to module B5. This module includes impacts from production of new building components (input materials) as well as transportation and construction. It also includes the End of Life (EoL) stages of replaced building components (output materials). Renovation in module B5 is scenario-based because it happens in the future. However, when the renovation is done today on an existing building, the scope changes. The standard addresses this, stating that for buildings that are renovated, and where there have been made no previous assessment; a new LCA should be made. In this case, environmental impacts and aspects of materials and installations processes are allocated to module A1-A5, as the renovation is no longer a scenario in the future, but something that happens today. With the input materials allocated to stage A, it is implicit that the output material of the existing building is not included in the framework. Thus, the approach will not give the complete impact from the building's remaining life cycle, but only the impacts from the new materials in the renovation action itself.

Table 1. The life cycle stages of a building. Adapted from EN 15978 [11]

Product stage			Construction process stage		Use stage							End of life stage				Benefits and loads beyond the system boundary
Raw material supply	Transport	Manufacturing	Transport	Construction, installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction, demolition	Transport	Waste processing	Disposal	Reuse-, Recovery-, Recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D

Preservation is not specifically addressed in the standard, however, it can be assumed that you can either include impacts from the remaining use stage and EoL, or include the impacts that have already happened from stage A. Demolition and new construction is not specifically addressed in the standards either. The scope of the building life cycle in EN 15978 is *one* building, not linking multiple life cycles. Therefore the scenario of demolition and new construction is not addressed, but would belong to two separate building assessments.

1.3. Placing the burden of existing buildings
Existing buildings have already had impacts on the environment and they will continue to have it until after they are demolished. In the building LCA perspective, the question is how the burden from the existing building shall effect the new building project. Hasik et al. [12] argues that, if you include EoL of the existing building, the building project is penalized for the choices made in the existing building. Furthermore, Hasik et al. argues that EoL of the existing building should not be included since it is not part of the whole-building LCA scope. A review article by Vilches et al. [10] shows that there is a very big difference in how much of the existing building is included in a renovation LCA. Only a few of the 13 studies investigated included impacts associated with the existing materials. EoL of the existing building materials are sometimes not included due to their assumed insignificance of impacts [13].

The burden of the existing building can be allocated to the building project to different degrees. Some studies have investigated how to allocate embodied impacts – the impacts that have already happened, such as production and construction stages – from the existing structure to the current building project [14,15]. Impacts that have already happened are not included in the framework developed in this study, because they are not important for the decisions made today. This study argues for the importance of including all current and future impacts for an exhaustive environmental perspective. Today existing buildings are torn down to make room for new and sustainable buildings. But if the existing building is not included in an assessment, a large part of the emission are excluded as well. You also exclude the potential value in the materials in terms of expanding their service life or recycling. Furthermore, the existing building is part of the building site and all processes related to the building site should be allocated to the building project. Another argument is an economical allocation principle; the owner of the building site will be economically responsible for the existing building, thus the environmental impacts should be allocated to him as well.

2. Proposed framework
The three overall scenarios of an existing building is 1) preservation, 2) renovation and 3) demolition and new construction, which are included in the framework. The framework incorporate phases of the existing building that happen at the time of the intervention (today) and future processes. It does not include impacts related to the production and use of the existing building that have already happened. The framework from EN 15978 [11] shown in Table 1 consisted of the stages ABCD. The proposed framework includes both new materials and the existing building materials and consequently the framework is expanded to C_1D_1ABCD. The stages C_1 and D_1 is added in the beginning in order to include EoL of the existing building products. The expanded framework can be seen in Figure 1, where it is presented for the three scenarios for existing buildings.

For the *preservation* scenario there is no contribution from the initial stages C_1D_1 and A, since nothing is done to the building today. The preservation scenarios continues directly into the use stage of the building (stage B), and ends with the EoL stages of the building. For the *renovation* scenario, action is taken today, meaning that some of the existing products are demolished and processed, while other new products are included in the building. In the renovation scenario some of the products are preserved and continues directly into stage B. The renovation scenario therefore includes the initial C_1D_1 and A stages as well as the remaining stages. In the *demolition and new construction* scenario, the C_1D_1 stages includes demolition of the existing building, while the remaining stages only contains burdens from the new building.

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Reuse, recycling and recovery is accounted for at EoL in stage D_1 and D. In the cases where a new building product is made out of reused, recycled or recovered material, this will be accounted for in the product data at stage A or during the use stage (B). It is possible to use materials from the existing building as input in the new building or renovated building. This is illustrated in Figure 1, where recycling goes from use stage in the existing building, to Product stage in the new/renovated building.

Given that the framework is an expansion of the existing LCA methodology, it is not difficult to fit into existing practice. The framework is generic and can be used on all building cases that have an existing building. The goal is to expand the Danish national tool, LCAbyg [16], to better handle existing buildings. The framework can be used for building designers and clients when they assess their building project as well as policy makers, who wish to standardize the assessment of buildings.

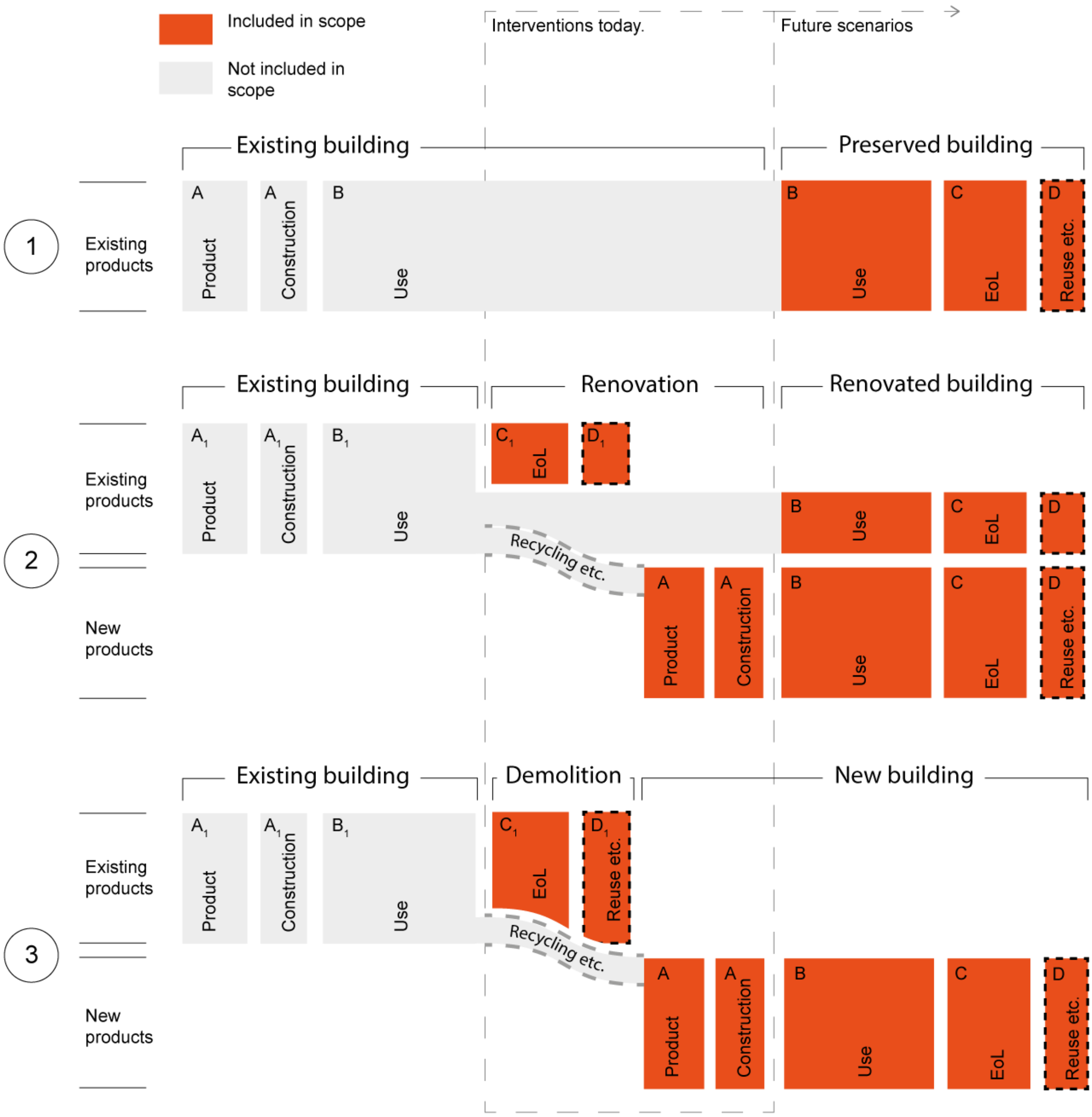


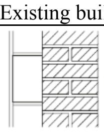
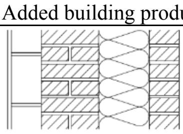
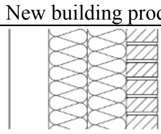
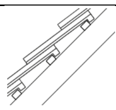
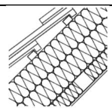
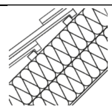
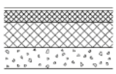
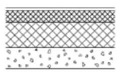
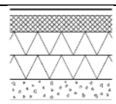
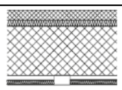
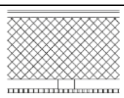
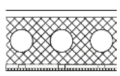
Figure 1. Framework for camparison of scenarios, where existing buildings act as the starting point. The scenarios are 1) preservation, 2) renovation and 3) demolition and new construction. The dottet line around stage D indicates that the stage is beyond the system boundaries and should be communicated seperately.

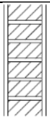
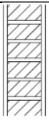
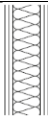
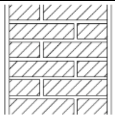
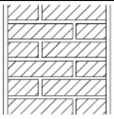
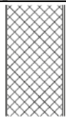
3. Cases study – a demonstration of the framework

3.1. Case building

In this section the framework is illustrated by a case - a 1950’s school building. The building has brick walls and concrete slabs. The roof is wood structure with roof tiles. The original structure can be seen in Table 2 in the preservation column. The table also shows the change in the structure in the three scenarios of the building. In the first scenario (preservation) no actions are taken to update the building. In the second scenario (renovation), the building is insulated in the outer walls and roof. Furthermore the windows are replaced with new windows. In the third scenario, the existing building is completely torn down, and replaced by a new building.

Table 2. Case building scenarios.

	Preservation Existing building products	**Renovation** Added building products	**New construction** New building products
Outer wall Area: 1860 m^2	 paint 15 mm lime plaster 120 mm lightweight concrete block 240 mm brick wall w/ lime mortar	 paint 200 mm mineral wool 120 mm brick wall w/ lime mortar	 paint 150 mm lightweight concrete element 300 mm mineral wool 120 mm brick wall w/ lime mortar
Basement wall Area: 800 m^2	paint 15 mm lime plaster 120 mm lightweight concrete block 360 mm concrete	300 mm EPS insulation	paint 200 mm concrete, insitu 300 mm EPS insulation
Roof Area: 2150 m^2	 roof tiles 39/59 mm wood battens 92/157 mm wood trusses 79/131 mm wood pillar under eaves 100 mm mineral wool 12 mm plasterboards	 roof tiles 25 mm wood battens 45/300 mm wood trusses Roofing underlay 400 mm mineral wool Vapour barrier	 roof tiles 25 mm wood battens 47/350 mm wood trusses Roofing underlay 300 mm mineral wool Vapour barrier 95 mm mineral wool
Ground floor slabs Area: 1518 m^2	 2 mm vinyl 4 mm fibreboard 30 mm screed layer 50 mm aerated concrete 100 mm reinforced concrete 50 mm gravel	 2,5 mm linoleum 3 mm sound insulation	 2,5 mm linoleum 3 mm sound insulation 40 mm screed layer Foil, PE 120 mm reinforced concrete Vapour barrier, PE-foil 350 mm EPS-insulation 150 mm gravel
Floor decks Area: 4168 m^2	 2 mm vinyl 4 mm fibreboard 20 mm screed layer 250 mm reinforced concrete 39/66 mm wood battens 20 mm mineral wool 26/52 mm wood battens 4 mm acoustic panel, wood fibre	 2,5 mm linoleum 3 mm sound insulation 28/45 mm wood battens 15 mm perforated plywood Acoustic foil	 2,5 mm linoleum 3 mm sound insulation 40 mm screed layer Foil, PE 320 mm hollow core slabs 28/45 mm wood battens 15 mm perforated plywood Acoustic foil

Internal walls, *not* load carrying Area: 840 m^2	 paint 15 mm Lime plaster 120 mm brick wall w/ lime mortar 15 mm Lime plaster paint	 paint 100 mm aerated concrete paint	 paint 2 x 13 mm plaster boards 100 mm steel frame wall w/ 95 mm mineral wool 2 x 13 mm plaster boards paint
Internal walls, load carrying Area: 1489 m^2	 paint 15 mm lime plaster 360 mm brick wall w/ lime mortar 15 mm lime plaster paint	 paint 15 mm lime plaster 15 mm lime plaster paint	 paint 100 mm reinforced concrete element, lightweight paint
Window Area: 446 m^2	wood frame 2-layered insulating glass	wood/alu frame 3-layered insulating glass	wood/alu frame 3-layered insulating glass
Doors Area: 247 m^2	Wooden door	Wooden door	Wooden door

3.2. Life cycle assessment
The LCA is done in compliance with the ISO standards 14040 and 14044 [17,18] and EN 15978 [11] for LCA on buildings. The framework from EN 15978 is expanded to include the existing building, as presented in the previous section.

In the modeling is included the same stages as in the typical building modeling in Denmark, i.e. in DGNB certification. The included life cycle stages are: Product stage (A1-3), replacements (B4), operational energy use (B6), waste processing and disposal (C1 and C2), and benefits and loads beyond the system boundary (D). Data for module D is not included for all materials. The functional equivalent is set to m^2 gross floor area of a school building (equivalent to the existing building) over a period of 50 years. For simplification, the results are only shown for the environmental indicator, Global Warming Potential (GWP). The modelling is done with a beta-version of LCAbyg, since the current version does not yet support the expanded framework. LCAbyg is a Danish national tool for LCA on buildings [16]. The background environmental data is a combination of the Ökobau and Ecoinvent databases.

The LCA is a comparative study of the building between three scenarios: 1) preservation, 2) renovation and 3) demolition and new construction. In scenario 1 and 2, some of the building products remain in the building. In order to determine impacts from module B4, the building products that remain in the building are given a remaining service life of 1/3 of the service life of a new similar product. Service lives of new building products are from Danish guidelines [19].

3.3. Results and discussion
The results of the case building can be seen in Figure 2. The figure shows the C_1D_1ABCD combination of stages. The results of the scenarios in Figure 2 show that the *preservation* scenario have the highest impacts from the energy use module (B6). It also has the highest impact of the three scenarios from the replacement stage (B4). The *renovation* scenario also has the majority of impacts from energy use. Remaining impacts are primarily from production (A1-3) and EoL (C3-4). The *demolition and new construction* scenario shows a high impact from product stage but has the smallest impact from energy use of the three scenarios. Remaining impacts are from EoL stages. In conclusion; the renovation scenario and the demolition and new construction scenario, reduce GWP from use stage (energy use and replacements) at the cost of an increase in GWP from production stage and demolition of existing materials. When the results are summed up, the renovation scenario has the overall lowest impact. This is due to low impact from production stage compared to new construction, and low impacts from energy

use compared to preservation. This quantification and comparison from the framework can help clients make environmentally sound solutions.

The framework also illustrates the differences in the scenarios between impacts that happen today from demolition and product stage, and impacts that happen in the future and are based on scenarios. Impacts that happen in the future are naturally less certain than the impact that happen today, and emission from material production may be reduced in the future. It is also important to lower emissions that happen today, in order to stay within the carbon budgets. The preservation scenario has zero impact today, while the impacts today are high for the demolition and new construction scenario. Here, the impacts from demolition of the existing building, that takes place today, accounts for 12 % of the total impacts. Had the impacts not been included, the scenario would have appeared significantly better than preservation. This illustrates the significance of including the existing building in the assessment.

The case only includes business-as-usual EoL scenarios. If the building case had incorporated more circular material scenarios, it should be possible to see more benefit in stage D_1 or a reduction in A due to reuse of materials in the existing building. The inclusion of circular materials in the framework should be investigated in further research, especially how to allocate materials that are reused in the existing building.

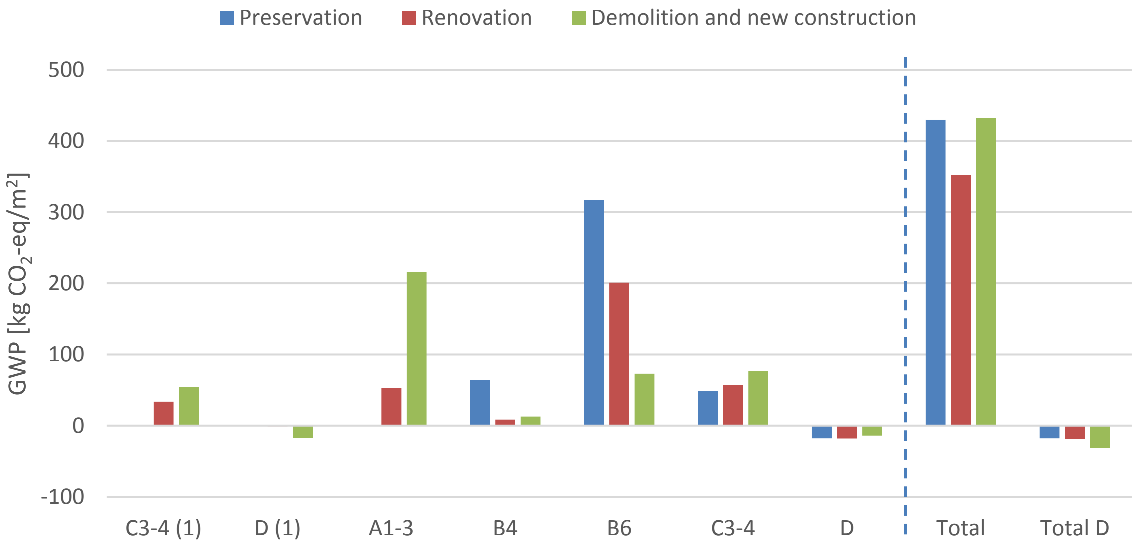


Figure 2. Results for GWP using the LCA framework presented in this paper. The results show the temporal difference in the scenarios for when impacts occur.

4. Conclusion

LCA can be used on existing buildings to test circular economy strategies such as preservation and renovation. This paper develops and tests a framework for existing buildings. By including the existing building in the LCA, we get the complete picture of impacts related to the building project. The framework is generic, and can be used on all building projects with existing buildings. The method easily fits into the existing LCA practice by expanding the standardized methodology to accommodate decision support for the considerations in play for development projects concerning existing buildings. The framework can be used for building designers and clients when they assess their building project as well as policy makers, who wish to standardize the assessment of buildings.

The frameworks shows the environmental impacts that happen today and over the building project's life cycle. It illustrates the differences in environmental impacts from the scenarios 1) preservation, 2) renovation and 3) demolition and new construction, which is relevant information for clients and decisions makers. The timeline for *when*, the impacts happen in the scenarios are very different. Where scenario 3) has a large impact today from demolition of existing building (which accounts for 12% of the building's impacts) and building products for the new construction, the two other scenarios have impacts that mainly occur in the future. This temporal aspect may be considered in an assessment as well, especially due limited carbon budgets, and highlights the importance of including the existing building.

Further work should investigate how the framework incorporates circular materials (reuse, recycling recovery) in the assessment.

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References

[1] European Comissions Eurostat
[2] European Commission 2018 *Improving energy and resource efficiency*
[3] Global Alliance for Buildings and Construction 2018 *2018 Global Status Report*
[4] Röck M, Ruschi Mendes Saade M, Balouktsi M, Nygaard F, Birgisdottir H, Frischknecht R, Habert G and Lützkendorf T 2019 Embodied GHG emissions of buildings – The hidden challenge for e ff ective climate change mitigation *Appl. Energy* **258** 114107
[5] Rasmussen F N, Ganassali S, Zimmermann R K, Lavagna M, Campioli A and Birgisdóttir H 2019 LCA benchmarks for residential buildings in Northern Italy and Denmark–learnings from comparing two different contexts *Build. Res. Inf.* **47** 833–49
[6] Pomponi F and Moncaster A 2017 Circular economy for the built environment: A research framework *J. Clean. Prod.* **143** 710–8
[7] Eberhardt L C M, Birgisdottir H and Birkved M 2019 Potential of Circular Economy in Sustainable Buildings *IOP Conf. Ser. Mater. Sci. Eng.* **471**
[8] Saade M R M, Guest G and Amor B 2020 Comparative whole building LCAs: How far are our expectations from the documented evidence? *Build. Environ.* **167** 106449
[9] Schwartz Y, Raslan R and Mumovic D 2018 The life cycle carbon footprint of refurbished and new buildings – A systematic review of case studies *Renew. Sustain. Energy Rev.* **81** 231–41
[10] Vilches A, Garcia-Martinez A and Sanchez-Montañes B 2017 Life cycle assessment (LCA) of building refurbishment: A literature review *Energy Build.* **135** 286–301
[11] CEN – European Committee for Standardization 2012 *EN 15978: Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method*
[12] Hasik V, Escott E, Bates R, Carlisle S, Faircloth B and Bilec M M 2019 Comparative whole-building life cycle assessment of renovation and new construction *Build. Environ.* **161** 106218
[13] Pittau F, Amato C, Cuffari S, Iannaccone G and Malighetti L E 2019 Environmental consequences of refurbishment vs. demolition and reconstruction: A comparative life cycle assessment of an Italian case study *IOP Conf. Ser. Earth Environ. Sci.* **296**
[14] Rasmussen F N and Birgisdóttir H 2016 Life cycle environmental impacts from refurbishment projects - A case study *CESB 2016 - Cent. Eur. Towar. Sustain. Build. 2016 Innov. Sustain. Futur.* 277–84
[15] Wijnants L, Allacker K, Trigaux D, Vankerckhoven G and Troyer F De 2015 Methodological Issues in Evaluating Integral Susatinable Renovations *Proc. Int. Conf. CISBAT 2015 Future Build. Dist. - Sustain. from Nano to Urban Scale* 197–202
[16] Birgisdottir H and Rasmussen F N 2019 Development of LCAbyg: A national Life Cycle Assessment tool for buildings in Denmark *IOP Conf. Ser. Earth Environ. Sci.* **290**
[17] ISO 2018 *ISO 14040: Environmental management – Life cycle assessment – Principles and framework.*
[18] ISO 2006 *ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines.*
[19] Aagaard N-J, Brandt E, Aggerholm S and Haugbølle K 2013 *Levetider af bygningsdele ved vurdering af bæredygtighed og totaløkonomi*