

Final report

1. Project details

Project title	A) IEA EBC Annex 72 Vurdering af miljøpåvirkninger relateret til bygningers livscyklus B) Vejledning for BIM integration, metode-udvikling og referencelværdier for bygnings LCA (i IEA EBC Annex 72)
File no.	A) 64017-05180 B) 64020-2119
Name of the funding scheme	EUDP
Project managing company / institution	SBI/BUILD, Aalborg University
CVR number (central business register)	29102384
Project partners	Research representatives from 24 other countries
Submission date	22 April 2024

2. Summary

A) and B) English version

The project *IEA EBC Annex 72 Assessing life cycle related environmental impacts caused by buildings* will focus on the assessment of the primary energy demand, greenhouse gas emissions and environmental impacts of buildings during the building's life cycle. The purpose of the project is to reach consensus on the assessment of the methodology, which yet allows to respecting national and regional traditions regarding data and modelling in order to work towards the definition of national and regional benchmarks. The development of benchmarks is done by collecting a comprehensive amount of case studies for analysis. Furthermore, in order to integrate this knowledge into the design process, the purpose is to better link methods for the environmental assessment with methods and tools used during the design and planning process and to support the participating member countries in developing national or regional LCA databases. Finally, to agree on recommendations for national and international standardization work related to life cycle thinking applied on buildings (e.g. energy performance of buildings directive).

In addition to the above, the purpose of the Danish participation in the project is to contribute with knowledge in order to support the formulation of expected future requirements to buildings life cycle environmental impacts in Denmark, to improve the LCA tools, data and methods used in Denmark in order to prepare the Danish building sector for the requirements expected in near future.

A) og B) Dansk version

Projektet *IEA EBC Annex 72 Vurdering af miljøpåvirkninger relateret til bygningers livscyklus* fokuserer på vurderingen af bygningers primære energibehov, udledning af drivhusgasser og miljøpåvirkninger over bygningers livscyklus. Formålet med projektet er at opnå konsensus om vurderingsmetoden for bygningers livscyklusbetragtninger, ved en metode som dog tager hensyn til nationale og regionale traditioner og behov vedrørende data og modellering. Ved brug af den udviklede vurderingsmetode er formålet at kunne udvikle nationale og regionale kravværdier. Dette gøres ved at indsamle en omfattende mængde af casestudier til analyse. Desuden er formålet at arbejde for at livscyklusvurdering nemt kan integreres i designprocessen ved bedre link mellem miljøvurderingen og de anvendte designværktøjer, og at muliggøre udvikling af nationale eller regionale LCA-databaser for de deltagende lande. Endelig er formålet at nå til konsensus om anbefalinger til nationalt og internationalt standardiseringsarbejde relateret til livscyklustankegangen anvendt på bygninger (fx bygningsdirektivet).

Som supplement til det ovenstående, er formålet med den danske deltagelse i projektet er at bidrage til formuleringen af de forventede fremtidige krav til bygninger samlede miljøpåvirkninger over bygningers livscyklus, at forbedre LCA værktøjer, data og metoder, der anvendes i Danmark med henblik på at forberede den danske byggesektor på de krav, der forventes i den nærmeste fremtid.

3. Project objectives

A)

The overall objective of the project was to prepare the LCA method for further uptake in the building sector. Specific areas of interest in the project were to: 1) map, harmonize, and provide recommendations for methodological issues in the way LCA is applied within building practice and research. 2) investigate the building design process and prepare concepts and tools for integrating LCA into the digital workflow of the building design. 3) collect and analyse examples of LCA benchmarks for buildings and derive recommendations for implementation and further development. 4) map and analyse examples of LCA databases for use in building LCA to prepare guidelines for database developers.

A specific objective of the Danish participation in the Annex 72 project was also to lead the subtask 3 about case studies. This entailed planning content, leading meetings with Annex 72 participant, and managing the deliverables within the subtask 3 (deliverables 4-6 described in "4. Project implementation" below, as well as the background report for deliverable 2).

B)

The objective of the project was to strengthen the Danish participation in the Annex 72 project in specific sub-themes of the areas described above 1) - 4). Specific areas of interest were the cooperation on accounting methods for on-site energy production and absolute sustainability, the cooperation on guidelines for LCA benchmarks, and the cooperation on integration of LCA data into digital design tools

A) and B)

The Annex 72 project deals with the use of LCA methods in building practice and research. Specific technologies associated with the project are primarily software tools intended for decision support in the building design process, i.e. energy demand simulations, building information modelling and design sketching tools. Furthermore, the distribution and flow of data in different formats were addressed as part of the project.

4. Project implementation

A) and B)

The overall Annex 72 project evolved close to the original plan set out by the operating agent and the contributors to the project description (BUILD delegates being part of this). A notable deviation from the plan was altering of the ambition to create a harmonised methodology across all participating countries. In the course of the project, it became increasingly clear that the different LCA methodologies in use largely reflected the national/local focus areas and policy priorities. Hence a viable path for harmonisation seemed unattainable and the objectives concerning harmonisation were revised. See further description below in "5. Project results".

Furthermore, COVID19 lockdowns and the restrictions on physical meetings affected the progression of the project. Even though the semi-annual expert meetings were easily transformed into online meetings, the online platform did not provide the same ground for common motivation and dedication to the work, i.e. some of the participants became somewhat 'invisible'. The project was granted a one-year extension by the ex-co, which allowed for the whole Annex expert group to reassemble and carry the planned work through, although with minor delays on some of the inputs.

In the work period of Annex 72, the general concern about climate change and mitigation needs has increased drastically. Not only have we seen our Annex-based work being cited in the latest IPCC report, several of the Annex experts (including BUILD) have been extremely busy in disseminating findings nationally as well as advising authorities in the implementation of LCA methodology and benchmarks for the building sector.

At the latest ex-co meeting in June 2022, the operating agent of the Annex 72 was informed that the ex-co committee was pleased with the process as well as the results of the Annex 72 work.

A)

The project developed as foreseen, with the adjustments mentioned above. The milestones are addressed individually below:

- M1: Annex 72 webpage and updates
The webpage was launched as planned, hosted by the IEA EBC at <https://annex72.iea-ebc.org/>. The page has been regularly updated with listing of meetings, publications, participants and other news. The project deliverables will be accessible from the webpage as soon as they have been published, fall 2022
- M2: Building assessment methods (ST1)
The report is delivered later than originally planned, at the end of the Annex period, fall 2022.
- M3: Planners guidelines (ST2, ST3)
The guideline is delivered as planned at the end of the Annex period, fall 2022.
- M4: Databases report (ST4)
The report was delayed from the original plan, but was finished during the fall 2021
- M5: Building case studies (ST3)
The report was delayed from the original plan, but was finished during spring 2022
- M6: Reports about benchmarks, method (M6a) and case study application (M6b)
The milestone was readjusted to the revised aim of the benchmark investigation (see above about how project evolved). Hence the two deliverables about method and cases were aligned to supplement each other. Both reports were finished during spring 2022.
- M7: Databases guideline (ST4)
This database guideline became an integrated part of the database report (M4), finished during the fall 2021.
- M8: National database (ST4)

The learnings from database investigation and recommendations were applied to the case of an Indian database. The work on this preliminary Indian LCA database for buildings was finished during the spring 2022.

- M9: Dissemination and implementation of learnings in the Danish building sector at workshops and seminars

The Danish participants from BUILD have, throughout the project period and at various occasions, presented the Annex 72 project as a prime example of international work within the research area of building-LCA. Specific workshops, seminars and presentations where the work have been disseminated in Denmark are elaborated in “5. Project results” in the following.

- M10: Publication in Danish, about Danish case studies and benchmarking potentials

This milestone was not accomplished directly during the Annex 72 project. The reason being that the development of benchmarks for the Danish building regulation was planned in early 2021, BUILD AAU being the key consulting partner for the authorities in this development. We figured that a Danish publication about the various types of benchmarking mapped in the Annex 72 would only confuse the Danish building sector if published alongside the actual benchmark requirements from the Danish building authorities. However, several reports about benchmarking in Denmark has been published as part of the cooperation with the Danish building authorities, for instance the [report about 60 building cases](#) that served as background for defining benchmark values for the 2023 LCA-based regulation of new buildings. Further, the messages about different benchmark approaches were conveyed to the industry by BUILD's participation in a European project funded by the Laudes Foundation¹. Hence, the knowledge was disseminated in an accessible format and to a wider industry audience, albeit on a European level, and not directly as part of the Annex 72 project.

B)

The project developed as foreseen, with the adjustments mentioned above. The milestones are addressed individually below:

- *M1: Industry workshop about LCA and BIM*

Three open webinars were held during 2021 about the BIM-LCA coupling made by BUILD. The coupling is made by a file exchange via the json file format. The first webinar introduced the json file format and the use of it in relation to the LCA-tool LCAByg. The webinar was held in collaboration with the architectural company C.F. Møller. The second webinar concerned the json-based exchange of environmental data. The third webinar was about the json-based possibility of establishing libraries of building components in BIM and translating these to environmental impacts in LCAByg

- *M2: Industry presentation about absolute sustainability and carbon-neutral construction*

The topic of absolute sustainability and carbon-neutral construction, as discussed in the Annex 72, has been elaborated in various industry presentations by the BUILD participants.

- *M3: Guideline publication about LCA methods*

Contribution by BUILD to the guideline about absolute sustainability and carbon-neutrality was successfully carried through, and the guideline/report was finished summer 2022.

- *M4: Guideline publication about benchmarks*

Contribution by BUILD to the guideline about benchmarks was provided in the form of a background report which was finished fall 2022

- *M5: Industry presentation about Nordic cooperation on LCA method and data*

The topic has not had its own presentation per se for the industry. However, the Annex 72 results have played an important part in the background for the Nordic cooperation. Hence, the

¹ [Towards embodied carbon benchmarks for buildings in Europe](#)

Annex 72 results have been highlighted and presented by BUILD at the collaborative workshops initiated by request of the Nordic Council of Ministers. Furthermore, at several occasions the interplay of Annex 72 and Nordic cooperation has been highlighted in other presentations for the industry.

A) and B)

Besides COVID19, the project did not experience any problems

5. Project results

A)

The objectives about strengthened Danish participation in the research areas described in “3. Project objectives” were reached almost in full. However, as described in “4. Project implementation” the project had to deviate from the original aim of establishing a harmonised methodology. Simply because it became clear that the regional/national methodologies already in existence were carefully tailored the local context, and thus a harmonised, international approach would not be accepted and used in practice. Focus for the Annex 72 work on methodology was redirected into mapping and categorisation of different methodological approaches and their background. In this way the project was able to develop methodological recommendations for different contexts of decision making and for different stakeholders. The change of focus for the methodology also affected the planned development of a common LCA benchmarking system. This harmonised benchmarking system was to take its starting point in the harmonised methodology, but focus was readjusted to map existing benchmark systems, and to analyse their background and the experience by implementing benchmarks in policy and practice. This resulted in valuable recommendations for further implementation in countries/contexts where benchmarks are currently not in use.

B)

The objectives about strengthened Danish participation in the research areas described in “3. Project objectives” were reached in full.

A)

The overall Annex 72 project succeeded in developing a broad range of reports and guidelines for further use by research and practice. Due to the general surge of interest in the topic of sustainable building, the project results have been distributed widely and with interest in the participating countries of the Annex 72. The specific outputs of the Annex 72 were planned in the shape of reports and guidelines for research and industry and were executed as described in the following

- Deliverable1: Guideline report on LCA methods for use in buildings and construction. The comprehensive guideline maps methodological approaches and provides recommendations for a range of different decision contexts. The guideline report draws its content from 8 background reports produced by Annex experts. BUILD AAU participants contributed with research to one of these background reports, and to the method discussions facilitated at expert meetings.
- Deliverable2: Guideline report on methods, experiences, and recommendations for LCA benchmarking for buildings. This guideline report draws its content from 2 background reports. BUILD AAU participants contributed with research for the background report about net-zero definitions and absolute sustainability. Furthermore, BUILD AAU participants planned, researched and authored the background report about existing benchmark systems.

- Deliverable3: Guideline report about integration of LCA in building design decisions. The guideline report draws its content from 7 background reports. BUILD AAU participants contributed with research to 2 of these background reports, one about tools for building-LCA and one about the coupling of BIM and LCA.
- Deliverable4: Case study compilation, displaying relevant research used in the Annex 72 project. BUILD AAU participants planned, executed and edited this compilation of case studies. The deliverable was furthermore a part of the subtask led by the Danish BUILD AAU participants
- Deliverable5: Report about optimization strategies for building design. BUILD AAU participants contributed with research to this report. The deliverable was furthermore a part of the subtask led by the Danish BUILD AAU participants.
- Deliverable6: Report about industry practices, in relation to the use of LCA for building and construction. The deliverable was furthermore a part of the subtask led by the Danish BUILD AAU participants.
- Deliverable7: Database survey report, about existing LCA databases and their use in the participating countries of the Annex 72. BUILD AAU participant contributed with the case of environmental data used for Danish building-LCAs
- Deliverable8: Database guideline report, with recommendations on the development of databases for use in building LCA. The case of a newly developed Indian LCA database for construction materials were used to illustrate the recommendations.

Apart from the initially planned reports and guidelines, some important outreach activities were furthermore produced as part of the Annex 72. These were:

- The Graz Declaration for Climate Protection in the Built Environment, which calls for legally binding requirements for buildings before 2025, to reduce greenhouse gas emissions to stay within a 1.5°C increase. The Graz declaration was formulated during the Sustainable Built Environment conference in Graz in September 2019 with the participation of the BUILD AAU participants in the Annex 72. At the expert meeting in Ljubljana 2019, the Annex 72 experts unanimously agreed to sign the Graz Declaration as a group.
- The Monte Verità Declaration on a built environment within planetary boundaries, which contains recommendations for the built environment addressed to a multitude of stakeholder in the buildings and construction sector. BUILD AAU participants of the Annex 72 were part of formulating the declaration. More than 40 scientists from 20 countries signed the declaration, which was handed over to the Swiss representative of the IEA EBC ExCo.

B)

The funding of the project ensured Danish representation in key methodological discussions and research output about on-site energy production and absolute sustainability, for use in deliverable 1 and 2 described above. These research insights - together with the insights obtained from the Danish representation in LCA-benchmarking research - have been of high value for the ongoing partnership between BUILD and the Danish building authorities about developing LCA-based requirements for the building regulation.

Deliverable9: the participation ensured insights and important input for BUILD's further work with BIM. Counting as Deliverable 9: hands-on digital tools and video guides were results of the project that were not planned from the beginning. However, they have established the foundation for BUILD's further research and development in the area of digital sustainability assessment. One other research project is already developing this further, and one more project is at the proposal stage.

For projects A) and B), the same target groups apply.

Added values for stakeholder	Target group				
	Solution / Deliverable	Danish building authorities	Industry associations	Green building certification	Building design professionals
D1 LCA method report	Source for updated recommendations for development of method in building regulation				Inspiration for front-running companies about further areas of expertise, e.g. absolute sustainable buildings
D2 benchmarking report	Source for updated recommendations for development of benchmarks in building regulation		Source for updated recommendations for development of benchmarks in certification		
D3 design decisions report		Concepts for integration of LCA in the design process for further adaptation in the national context			Concepts for integration of LCA in the design process for further adaptation in the context of the individual company
D4 case study report		Inspirational examples for buildings design and LCA method application for further development in the national context			Inspirational examples for buildings design and LCA method application for further development in the specific company context
D5 design optimization report		Practical methods and examples for optimizing design to costs and environmental performance			Practical methods and examples for optimizing design to costs and environmental performance
D6 industry practice report	Insights into the barriers and opportunities for integrating LCA regulation and LCA thinking into practice, on a national/industry level				
D7 database survey	Information about database set-up in different countries				
D8 database guideline	Source for recommendations about creating national-specific LCA databases				
D9 tools and videos for coupling BIM and LCA	Source for knowledge about current status of digitization and LCA-BIM coupling in the industry	Concepts for LCA-BIM coupling that can be elaborated on an industry level			Concepts for LCA-BIM coupling that can be elaborated on a company level

Full list of published scientific conference and journal papers can be found here: <https://annex72.iea-ebc.org/journal-and-conference-papers> . Table below summarises the scientific output and discloses which of the publications have contributions from BUILD AAU:

Published, peer-reviewed articles in journals	A) 13 (of which 4 with contribution from BUILD AAU) B) 3 (of which 1 with contribution from BUILD AAU)
Published, peer-reviewed articles in conference proceedings	A) 36 (of which 9 with contribution from BUILD AAU) B) 7 (of which 1 with contribution from BUILD AAU)

The table below elaborates on some of the main dissemination activities with Danish stakeholders directly involved

Dissemination activities	Relevant for DK stakeholders			
	Danish building authorities	Industry associations	Green building certification	Building design professionals
Regular updates about project results at SoMe profiles of project lead Harpa Birgisdóttir, e.g. Harpa's Twitter and Harpa's LinkedIn	X	X	X	X
Conference contribution and presentation at the IALCCE conference in Ghent, Belgium 2018 about benchmarks for office buildings, in synergy with benchmarking project for Danish Green Building Council	X		X	
Scientific journal contribution in Applied Energy about status of embodied carbon in buildings. Open access paper. Conclusions shared extensively on Twitter/LinkedIn and paper cited in the IPCC 6 th assessment report	X	X	X	X
LCA workshop about benchmarking: 71th LCA forum . Several Danish industry representatives present	X	X		
Conference contribution and presentation at World Sustainable Building Conference in Gothenburg 2020 about "Drivers, barriers and development needs in the Nordic building sector". Conclusions distributed via Twitter/LinkedIn	X	X	X	X
Conference contribution at Sustainable Built Environment conference in Graz 2019 about differing national LCA methods	X	X	X	X
Presentation at Nordic Climate Forum for construction 2020 about LCA in buildings – status and current issues	X			
Presentation about LCA and material choices at Byggeskadedag conference 2020		X		X
Inaugural lecture about buildings' role in the climate crisis, at Aalborg University Copenhagen in 2021. Video available online	X	X	X	X
3 open webinars about the json file format and the use of it to connect BIM and LCA. Videos available online		X		X

6. Utilisation of project results

A) and B)

During the course of the project, the on-going work and intermediate results have been of great value to several Danish stakeholders. The Danish building authorities in particular, have had the opportunity to evaluate the approaches from other countries and to learn from the experiences and recommendations for method and benchmarking put forward in the project. The guidelines on construction of databases for use in buildings LCA will be of high importance, in the current and future considerations about creating a national Danish database for building LCA.

For companies in the Danish building industry, the cutting-edge knowledge about net-zero definitions and absolute sustainability has already now been taken up by front-running companies, determined to set the bar higher than the requirements of the building regulation. This will likely be even more so in the future. Furthermore, the practical solutions to coupling BIM and LCA put forth in this project, presents a viable option for companies or associations to integrate into the design process. This specific

outcome of the project supports the policy goals of digitization in the building industry, and hence will be of high value to the future development in the field.

The process and the results of the Annex 72 project have been of tremendous importance to the research background for BUILD AAU's continuous work within the field. The insights into other national LCA practices/methods, and the network provided in the project, present future opportunities for well-informed consultation with the Danish authorities on the topic. Furthermore, the project has laid a solid research foundation for future international research projects within the field. Currently, the Annex 72 team of operating agent and subtask leaders (BUILD AAU being part of this) are preparing a proposal for a follow-up Annex. The elaboration of this proposal was encouraged by the exco committee of the IEA EBC.

The project has dealt with the life cycle energy use and environmental impacts of buildings. The project serves to educate the industry about design measures to reduce the energy demand and the environmental impacts as well as the methods for documenting these reductions. Hence, there are several policy objectives concerning the building sector where the project contributes, for instance in relation to digitization and reduction of environmental impacts. A specific energy related policy objective is the Danish 70% reduction aim for greenhouse gas emissions by 2030.

No Ph.D's were directly part of the project application.

7. Project conclusion and perspective

A) and B)

The Annex 72 project concludes the following:

- The embodied greenhouse gas emissions of buildings, and of construction product manufacture in particular (about 10% of global GHG emissions), need to get into focus and be reduced drastically.
- There is a need to introduce legally binding requirements to limit life cycle related GHG emissions of new constructions, and of refurbishments by 2025 latest. A roadmap to net zero by 2035 is also much needed to guide activities in the right direction.
- When assessing environmental quality of buildings, the complete building in its entire life cycle must be considered, including all upstream and downstream processes. For the planning and assessment, suitable building and life cycle models with a high degree of transparency are needed to make uncertainties clear and able to reduce.
- Some life cycle modelling is methodologically demanding, and clear rules are necessary here. Examples are the handling of biomass, plants for the generation of renewable energy and permissible approaches to offset for GHG emissions in the balance. A72 provides recommendations for these modelling rules.
- Countries lacking a life cycle assessment (LCA) database for the construction sector are encouraged to get started as soon as possible.
- The LCA database should cover construction materials (both generic and company specific), building technologies (such as ventilation and photovoltaic systems), energy supply, transport and waste management services. It should address life cycle related greenhouse gas emissions as well as other main environmental challenges such as fine particles and biodiversity losses.
- Extensive documentation, independent review and full data transparency are considered main features, which help ensure appropriate data quality.

- Suitable assessment standards in the form of benchmarks and target values are required for the assessment of the environmental performance of buildings, and in particular the greenhouse gas emissions in the life cycle of buildings, These benchmarks and target values form an inseparable unit with the respective method and data basis.
- Currently, benchmarks based on technical and/or economic feasibility are increasingly complemented by target values derived from planetary boundaries, taking into account the greenhouse gas emissions budget still available to meet defined global warming limits.
- The environmental impacts of the building should be followed and reduced throughout the design process. A set of guidelines is developed to provide outlook and recommendations related to the integration of the LCA into design process and design tools to support the stakeholders involved in the building design process and transfer to them scientifically based findings.

A) and B)

In the final stages of the Annex 72 project, following research areas are identified for further investigation:

1. From theory to implementation: Which types of measures (legal, financial, voluntary) are promising and effective in implementing a reduction path to reach a life cycle based net zero GHG emissions building stock by 2050 latest.
2. From efficiency to sufficiency: How can sufficiency aspects be systematically embedded into standard design processes of buildings, sites and districts? What could be the role of tiny houses and of new forms of living together?
3. Technology development and assessments using future scenarios: Some countries like Denmark consider the future development of the electricity mix to cover the operational electricity demand. Initial experiences with life cycle inventories (LCI) of future construction material manufacture are being made. Do such assessments support and accelerate the transition to net zero GHG emissions buildings and building stocks? Which framework conditions and core rules are needed to ensure high quality and reliable future oriented LCIs and how does it affect the definition of benchmarks and target values?
4. Circularity and reuse of building materials, building elements and buildings: What are the lessons learned from LCA case studies of “circular” buildings (or sites/districts, building stocks), i.e. building built with reused building materials and elements? What is the potential and contribution of circularity concepts with respect to the net zero GHG emissions and low environmental impacts targets for buildings, sites and districts and building stocks? Which materials and building elements are suited for reuse, which ones are not? What are the core rules to model reused building materials and elements in environmental LCA?
5. Net zero GHG emissions and low environmental impacts: How do material, resource and energy flows of net zero GHG emissions building stocks look like? Which resources and environmental impacts will require increased attention? How can potential trade-offs between greenhouse gas emissions on one side and environmental impacts on the other be identified and addressed? Do we need a two-dimensional target value framework?

The project has already received high level of attention from policy and decision makers around the world, although primarily in Europe where building regulations are farthest in terms of energy efficiency and CO₂ requirements. The Annex 72 provides comprehensive guidance for practitioners and decision makers in how to measure, monitor and document the life cycle related energy and CO₂, and will thus be the methodological base on which national approaches are generated and adapted. For building designers, the Annex 72 activities and outputs furthermore provide guidance on how to best integrate LCA-based decision-making into the design process, and how to communicate about environmental impact to third parties.

8. Appendices

No annual reports were published in the project

Links to relevant documents, publications, home pages etc. are inserted in the text throughout