ANNEX 72

EBC
Energy in Building and Communities Programme

International Energy Agency

Understanding the impact of individual, industry & political decisions on transitions towards environmental sustainability

Energy in Buildings and Communities Programme

February 2023

Technology Collaboration Programme
by iea

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)

Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Equivalent Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65: Long Term Performance of Super-Insulating Materials in Building Components and Systems
Annex 66: Definition and Simulation of Occupant Behavior Simulation
Annex 67: Energy Flexible Buildings
Annex 68: Design and Operational Strategies for High IAQ in Low Energy Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

Summary

There is a wealth of research and now data on greenhouse gas emissions from individual construction materials and components and from whole buildings (embodied impacts), and on their measurement through a life cycle assessment (LCA) approach. There is a general assumption that measuring and reducing these impacts is a rational decision, and one which will therefore inevitably be taken, given the correct tools and understanding.

However at present it is clear that, in the majority of construction projects and the majority of countries, this is not the case. LCA is generally not used, and embodied impacts are not measured or reduced, despite the existence of an accepted methodology for ten years, of an increasing number of databases and calculation tools, and of growing awareness and knowledge. If the apparently rational decision to measure and reduce these impacts is not being taken, it is important to explore what other factors might be relevant. This subtask has focused on researching how environmental impacts of buildings are addressed, and what mechanisms and factors influence decisions, in 'real world' contexts. The ultimate purpose is to develop recommendations about how life-cycle based assessment approaches might be most effectively introduced and applied in different national and industry contexts.

The initial hypothesis proposed that these decisions are affected by four additional factors: firstly, the role of individuals in projects, including their own knowledge or interest of environmental impacts, as well as their social and individual power to make decisions; secondly, the tools and artefacts that are used in policy, construction and design, and their apparent and real impact on building decisions; third, the industry and organizational context within which individuals work and in which projects are realized; and finally, the national policy and regulation landscape.

A number of qualitative case studies of real world situations were developed to consider the impact of these factors across three European countries with contrasting industry cultures: Sweden, Cyprus and the UK. Qualitative case study was chosen as the methodology in order to include the complexities of real world decisions and to explore these complexities in their context. The case studies included: multi-family public housing projects in Sweden, Cyprus and the UK; single housing developers in Sweden; in-house LCA tool developments in the UK; and the longitudinal development of regulation in Sweden and the UK.

Individuals and tools

First of all the role of tools and artefacts was found to have a significant impact on individual decisions. In the public housing projects in Sweden and Cyprus, compliance with requirements and regulations was shown to be a major driver of design choices, meaning that some individuals external to the project such as policymakers, planners and developers could steer building sustainability by setting minimum performance requirements. Meanwhile at project level, certification systems and sustainability assessment tools translated the concept of sustainability into practical criteria and thereby acted to facilitate decisions within the design teams. However, these tools also limited the definition of sustainability, and by doing so potentially silenced important issues and restricted design ambitions.

The UK study of LCA tool development demonstrated their impact on the knowledge of both the developers and of the professionals and clients using the tools. For some tools this was an intentional purpose, while for others improved understanding of users had been unintentional. A number of respondents mentioned their reliance on typical recommendations for reducing embodied carbon, but also discussed counter-intuitive results which had demonstrated to them the need for such tools not just their own understanding.

Industry and organizational contexts

Different industry contexts significantly determined the stakeholders involved in making decisions affecting environmental sustainability. In Sweden the municipalities played a major role, while in Cyprus there was far greater individual power, with more dependence on the knowledge of individual designers. Decisions also varied with the project type. For single family house builders in Sweden most designs were standardised and built offsite in factories. Therefore opportunities for design changes, including the reduction of environmental impacts, were few. Meanwhile large public housing projects, although more individual in terms of design, were characterised by tight time and budgets which limited the opportunities for reducing environmental impacts.

National policy

The first three factors - individuals, tools, and industry contexts – also were each shown to play a role within the development of policy towards whole life impacts of buildings. Examples from Sweden and the UK demonstrated the impact on policy development both of loose 'issue networks' within the construction industry, and of more controlled 'policy communities' which were formed of industry individuals but closely linked to political agendas. In both countries a charismatic individual could also be identified as having had a key role in the introduction of life-cycle based assessment into regulation. The early release of open and reliable data in the UK had been instrumental in allowing the development of in-house tools and in increasing industry expertise and knowledge well ahead of that in Sweden. In Sweden in contrast there was only limited industry focus on whole life impacts, until they became of political interest: this was arguably at least in part due to the lack of open access national data. However, embodied carbon is now included in Swedish regulations, while the UK regulations still omit it at time of writing.

Recommendations

As LCA gathers more and wider interest outside academia, it will be important to ensure that it responds to the national context in the most effective manner. The studies show that this will vary depending on the national political and industry context, on the type of project, and to an extent on the individual power and knowledge of the designers. The report therefore concludes with a number of recommendations for the introduction and use of LCA and related life-cycle based assessments.

Evidence from the UK strongly supports the recommendation that open access databases should be developed by nations for their own context. LCA tools should also be developed which are similarly adapted for the national context; in particular individual companies developing their own tools also helps develop knowledge within industry. However it is important that all assessment tools and standards are open to scrutiny, rather than a 'black box', so initial assumptions are apparent.

The level at which LCA is introduced will also be context and nation specific. In Sweden, for example, LCA could usefully be implemented at the municipal level at which standards are developed, while in Cyprus

LCA calculations could be required as part of planning applications, or could be introduced at organizational level. The type of the project will also have an impact. Where there are tight budgets and high degrees of standardisation, LCA could be used most effectively outside the project boundary to help develop guidelines, for example identifying the most suitable materials, components and assemblies. The process of developing these standardised solutions is likely to also have the effect of widening industry knowledge. LCA should be used to check and minimise environmental impacts for all prefabricated and standardized designs in order to avoid any negative consequences due to the lock-in nature of prefabrication.

In some countries such as the UK where there is a degree of both LCA literacy and design autonomy, LCA could be used at multiple stages of a project. At the feasibility stage it should be used to assess high level decisions and compare major choices such as whether to retrofit or demolish and replace a building. At the detailed design stage LCA should be used to compare the environmental impacts of various materials and systems.

The purpose of this analysis was to consider the most appropriate and effective route to the introduction of LCA, with the ultimate aim of reducing whole life impacts from buildings. From the three countries studied it is clear that the answer will vary country to country. However each of the four factors considered – individuals, tools, industry context, and policy – were found to have an impact on how sustainability decisions are made, and therefore were likely to determine the effectiveness of different approaches to the use of LCA. They were also shown to be inter-related: for example the policy landscape is affected by local practice & pressure from industry. Therefore for a transition to low impact buildings, we need to understand not just the technical details of different materials, but also each of these contextual aspects of the projects and how they interact. We hope that the recommendations made within this detailed collaborative research project, carried out by researchers from each of the three countries studied over the last five years, will support this transition.

Table of content

Some of the content of this report has been, or will be, published in the following papers:

Chapter 3:

Francart, N., Polycarpou, K., Malmqvist, T., & Moncaster, A. (2022). Demands, default options and definitions: How artefacts mediate sustainability in public housing projects in Sweden and Cyprus. *Energy Research & Social Science, 92 (2022).*

Chapter 4:

Polycarpou, K; Francart, N; Malmqvist, T; Burnley, S; Zamenopoulos, T and Moncaster, A. (2022). Facilitators and drivers of low-carbon and energy residential developments. In: *Energy and Climate Transformations: 3rd International Conference on Energy Research & Social Science*, 20-23 Jun 2022, Renold Building, University of Manchester, UK. *http://oro.open.ac.uk/84472/.*

Chapter 5:

Polycarpou et al. (forthcoming)

Chapter 6:

Brismark, J., Malmqvist, T., & Borgström, S. (2022). Climate Mitigation in the Swedish Single-Family Homes Industry and Potentials for LCA as Decision Support. *Buildings*, *12*(5), 588.

Chapter 7:

Anderson, J., & Moncaster, A. (2021). Embodied carbon, embodied energy and renewable energy: a review of Environmental Product Declarations. *Proceedings of the Institution of Civil Engineers-Structures and Buildings*, 1-33.

Chapter 8:

Moncaster, A. M., & Malmqvist, T. (2020, November). Reducing embodied impacts of buildings–insights from a social power analysis of the UK and Sweden. In *IOP Conference Series: Earth and Environmental Science* (Vol. 588, No. 3, p. 032047). IOP Publishing.

Furthermore chapters 3-5 and 7 form part of the following PhD theses:

Francart, N. (2021). Decision support for the implementation of low carbon measures in the building sector. Doctoral thesis awarded by KTH, Sweden (**chapter 3**)

Polycarpou, K. Low embodied carbon buildings: decision decisions and the role of LCA. Doctoral thesis, Open University, UK (**chapters 3, 4, 5**)

Anderson, J. Environmental Product Declarations (EPD) and their role for the construction industry. Doctoral thesis, Open University, UK (**chapter 7**)

1. Introduction

This is the report of subtask 3.4 of Annex 72 of the International Energy Agency Energy in Buildings and Communities programme, IEA EBC Annex 72 - Assessing Life Cycle Related Environmental Impacts Caused by Buildings (http://annex72.iea-ebc.org). The sub-task and this report responds to the part of the brief for Annex 72, to share and learn from the different experiences in the participating countries and to better ‘foster the application of LCA on buildings in countries with little experience’. This introductory section explains further how this brief has been interpreted for ST3.4, and then describes the structure of the following chapters.

There are several current areas of study within the existing literature on the life cycle greenhouse gas emissions due to the use of materials – in industry commonly referred to as ‘embodied carbon’ - and its measurement through life-cycle based assessments. Most fall into one of three groups: the impact of different assessment methodologies; design and construction strategies for reduction; and possible approaches to the multiple uncertainties in the calculations. This is undoubtedly critically important work. However all three are based on the assumption that measuring and reducing these impacts is a rational decision, that will therefore inevitably be taken, given the correct tools and understanding.

This belief in the rationality of decisions is common. It is reflected in the converse situation – if our decisions, taken for a number of different reasons, are then explained through what appears to be rational argument, then this will add weight and validity to them and they are more likely to happen. Many decisions taken during design and construction projects are supported by numbers to demonstrate their ‘rationality’; this includes direct quantities based on modelling (of predicted energy use, or predicted construction costs, for instance), but also proxy numbers which equate to less easily quantifiable aspects, such as in environmental impact assessments or Cost Benefit Analysis. The decisions may in reality be based on a very different reason – this choice of material is cheaper, or the supply chain is in place and the skills already exist, or the decision implies lower risk, or competitive edge, or simply that it is believed to be a better choice or has been done before and so is familiar. The power of numbers to support an argument, and therefore the desire to support even qualitative decisions by numbers, has been discussed within many disciplines. While it is indeed useful to use numbers in this way, it is also important to understand what other factors are likely to feed in to decisions in the ‘real world’.

Looking at this ‘real world’ for the specific context of LCA, at present it is clear that, in the majority of construction projects and indeed in the majority of countries, LCA is generally not used, and nor are embodied impacts therefore reduced. While operational emissions are reduced through design software and increased energy efficiency measures, embodied emissions on the whole are not. The existence of an accepted methodology since 2011 (EN15978), as well as the existence of an increasing number of databases and calculation tools, and of growing industry (and academic) awareness and knowledge, has not (yet) been enough to make the measurement and reduction of embodied greenhouse gas emissions the norm for building projects.

The question ST3.4 has considered is, therefore, why and how are decisions to reduce the environmental impact of buildings taken, in order to thereby understand what might speed up the transition to low impact buildings across all nations. While other studies within Annex 72 focus on LCA-related methodological issues, the present studies attempt to better understand the implementation context of such tools, and current practices related to design for enhanced environmental sustainability, in order to understand how LCA might be introduced most effectively.

The hypothesis that was tested is that decisions in design and construction projects are affected by four mechanisms: firstly, the role of individuals in projects, including their own knowledge or interest, as well as their power to make a decision; secondly, the tools and artefacts that are used in design to specify and encourage aspects of sustainability; third, the industry and organizational context within which individuals work and in which projects are realised; and finally, the national policy and regulation landscape. These four aspects are inter-related and iterative – the policy landscape is affected by local practice & pressure from industry for example. Therefore for a transition to low impact buildings we need to understand the aspects individually, but also their interactions.

This report describes the development of a number of qualitative case studies of real world situations, in order to shed some light on how the individuals, artefacts, industry contexts and political landscapes act and interact. It describes a number of studies that have been conducted by the five authors across three countries in (geographical) Europe, Sweden, Cyprus and the UK, which between them are considered to cover a significant range of contextual specificities.

The following chapter discusses the methodology, including a brief overview of qualitative case study research and a description of the case studies that have been carried out, as well as details of the various methods used. The next two chapters consider public housing projects in Sweden and Cyprus, first looking at the role of 'artefacts' (including tools and organizational documents) in chapter 3 and then at the role of individuals in chapter 4. Chapter 5 then adds the case of the UK to Sweden and Cyprus and compares the three national contexts. Chapter 6 develops a study of single housing developers in Sweden, and chapter 7 a study of LCA tool developers in the UK. The process through which regulation has been and is being developed in Sweden and the UK is considered in chapter 8. The final chapter draws together the work, producing conclusions and recommendations for industry and policy.

The aim of the report is therefore to add the missing link in understanding the process of a transition to sustainable buildings, and reveal insights which will enable a better understanding of how and where LCA might be best introduced as a tool to move us towards a lower impact built environment.

2. Methodology

2.1 Qualitative case study research

The case studies developed within this report are not of the technical object of the building, but of the socio-technical process of building and the context within which that happens. The approach is based on understanding from the social sciences, where case study research is often undertaken in order to shed light on complex and messy real-world situations (Donaldson et al, 2010). The point of focusing on and developing specific cases in these situations is to reduce some of that mess (Fiss, 2009), and to produce 'theoretically structured descriptions of social life' (Ragin, 1992, p.225). This type of case study research is suitable for answering 'why' and 'how' questions (Yin, 2009) and despite its imperfections Campbell suggests that it is all that we have (Campbell, 1975). Results from individual cases may not be directly generalized to all situations, but it allows for an in-depth understanding of real world settings which is impossible for more quantitative research design. Flyvbjerg, who has carried out seminal case studies of major construction and infrastructure projects, believes that it offers 'the most advanced form of understanding (Flyvbjerg, 2006, p. 236). It is the most appropriate for the consideration of contemporary phenomena in a real-life context, where the boundaries between the phenomenon and its context are not clearly evident. In this case the contemporary phenomenon we are considering is that of a successful transition towards environmental sustainability, and specifically the use of LCA, in the building sector, and each of the case studies considers this phenomenon from a different perspective.

2.2 Case studies

2.2.1 Swedish public housing cases

In Sweden, municipally owned real-estate companies (MRECs) have a mandate to provide affordable rental housing. MRECs own and operate about half of the rental apartments in Sweden. The two case studies of public housing projects in Sweden are defined as SE1 and SE2. SE1 is a project comprising eight multi-family buildings, located in Southern Sweden. The project started at the municipal real-estate company MREC1 in late 2016, and the last tenants moved in in early 2021. SE2 comprises six detached multi-family housing towers and is located in central Sweden. Both MRECs operate in medium-sized municipalities in Sweden.

2.2.2 Cypriot public housing cases

Both Cypriot projects CY1 and CY2 were developed at the National Land Development Association (NLDA). The NLDA's objective is to provide affordable housing to low- and medium-income applicants, following governmental strategies.

CY1 represents a common project type implemented by the NLDA, i.e. in-house design in own land and involvement of contractors only for the construction stage through traditional procurement procedures and construction contracts. The project consists of 15 semi-detached houses for sale, and is the second phase of a larger development plan in a rural area. The design of CY1 was carried out entirely in-house.

CY2 represents a different approach, regarding both management and design decisions. It was initiated following strategic and political discussions among the Board of Directors and governmental representatives, and was procured through an architectural competition, with the aim of improving quality in architectural design as well as affordability and social and environmental consciousness.

2.2.3 UK public housing cases

The UK cases were developed by a private housing association (PHA) who also acts as landlord. PHA's objective is to develop and provide affordable homes as well as manage and maintain their existing building stock. The studied cases (UK1 and UK2) represent two phases, both part of a large neighbourhood regeneration project. The whole project includes the development of both private sale and affordable housing units, either through new design or refurbishment.

UK1 represents a fairly standard and straightforward project, dealing with the design of new homes on a former garage and storage area site, with no existing houses and a clear ownership status. UK2 represents a more complicated project, the regeneration of an area with existing homes. The design includes a thorough assessment of various design alternatives in consultation and participation with the existing residents.

2.2.4 Single housing developers in Sweden

This case, instead, explored decision-making processes in relation to embodied carbon mitigation in the single family homes industry in Sweden. This was done through an interview study with five single family homes developers, during 2020. The companies were strategically selected, both in terms that they needed to display some interest in sustainability to be of interest for the aim of the study and to embrace a diversity regarding size, manufacturing type and costumer focus. 2-4 respondents were interviewed in each company to provide a good picture of the decision-making processes of interest, thus encompassing for example technical, sustainability and sales managers. Finally, the sector organisation was interviewed to give additional insight into decision-making rationales in this industry context.

2.2.5 LCA tool developers in the UK

This case considered the role and experiences of Architecture, Engineering and Construction (AEC) professionals based in the UK with experience of developing building LCA or life-cycle based tools like embodied carbon assessment tools. The individuals interviewed are included in the table below.

Interviewee	Background and Experience	Tool
A	Structural engineer. Working on LCA and embodied carbon since 2014 for an architect, and then in the UK, for a consulting engineer and then an LCA tool developer.	Developed an in-house BIM integrated LCA tool for an architectural practice in Europe.
B	Mechanical Engineer by background. Sustainability lead for an architectural practice in the UK. Focused on embodied carbon since 2018.	Developed an in-house early design stage tool for an architectural practice in the UK, later made freely available to the industry

C	Structural Engineer and sustainability consultant for an international engineering practice based in the UK since 2015.	Developed an in-house embodied carbon tool for an international engineering consultancy based in the UK
D	Architect by background. Started work on embodied carbon in 2014. Has since worked at a UK research body and then an engineering practice in the UK.	Worked on the ongoing development of an in-house embodied carbon tool for an Embodied carbon consultancy based in the UK
E	Architect by background. Sustainability Design Advisor for a UK architectural practice. Worked on embodied carbon since 2017.	Worked on the ongoing development of an in-house embodied carbon tool for an architectural practice in the UK, later made freely available to the industry
F	Structural Engineer by background. Has worked in sustainability and embodied carbon for a US façade and structures consultancy since 2011.	Developed an in-house early design embodied carbon tool for use in an international structural and façade engineering consultancy.

2.2.6 Policy and industry instruments in Sweden and UK

The two case studies considering the development of policy instruments in Sweden and the UK both draw on data from a variety of sources in the two countries. As situated research, the two authors for this research (Moncaster and Malmqvist) have both been active participants in the move to integrate life cycle assessment and embodied carbon management in their respective building and construction sectors over many years. Each case study includes three components: a historical narrative, interpreted through the insights of the authors' personal experience; a study of the production of an identified key report in each country; and the study of a building project which demonstrates the consideration of LCA in practice. Each component is further based on a number of sources of qualitative and documentary data.

2.3 Methods

Within case study research it is common to apply a number of different methods to gather multiple sources of evidence. The following methods were used across the case studies:

Semi-structured interviews These were conducted with project participants for studies a, b, c, d and e. They were based on an interview template but allowed the interviewer to depart from the template to ask follow-up questions following the direction of the conversation in a more natural style. Written permission was sought from each participant beforehand and guarantee of anonymity was offered where required. The interviews were digitally recorded and transcribed. For the interviews with tool developers (study e) the interviews were transcribed, and thematically analysed using a process similar to that outlined in Braun and Clarke (2006). Themes were then identified based on similarities of this content, followed by a review that considered differences in themes between interviewees.

Participant observation These were observations at design team meetings for studies a, b and c. Again permission was obtained, and the observations were recorded through written notes.

Ethnographic observation These were conducted during construction site visits, again for studies a, b and c. Permission was gained to record observations through written notes and photos.

Documentary analysis Documents relevant to case studies a, b, c, and f, including reports, drawings, minutes of meetings, and sundry documents relevant to the development of the narrative accounts, were read and coded fully or in part to develop the analyses.

Coding Coding of qualitative data is the process of identifying themes and the relationships between them. The coding of data including interviews and documents was conducted for case study e using the proprietary software package NVIVO, and for all other studies the same process was carried out by hand.

3. The role of artefacts in public housing

3.1 Introduction

This study investigates how existing artefacts mediate building design within four case studies of building projects, two each in Sweden and Cyprus, focusing on how they support or define conscious aspirations towards environmental sustainability. The definition of artefacts used here includes physical and digital items such as drawings, models, and software tools, as well as documents such as design guides and regulatory requirements. Further details of the case studies were described in section 2.2 as studies a and b.

The introduction of new requirements, guidelines, certifications and assessment tools (such as life-cycle based approaches built on LCA) for the environmental performance of buildings is expected to influence actors towards more sustainable design. However, the context of implementation also matters, and the uptake of practices that support low-carbon and other aspects related to sustainable designs by practitioners is also dependent on multiple social and organisational factors (Häkkinen & Belloni, 2011; Kadefors et al., 2021; Moncaster & Malmqvist, 2020; Moncaster et al., 2019; Nykvist & Nilsson, 2009). Consequently, there is a need to examine design processes in their context, including the key actors and decision situations, in order to understand how the introduction of new artefacts such as assessments built on LCA might affect design practices.

3.2 Results

In the cases studied, it appeared that many of the most important decisions determining the environmental sustainability of the building's final design are not taken within the project itself, but outside and upstream of the project. The influence of these decisions on the building's design can be seen through the effects of various artefacts, which set boundaries to the range of possible design choices, simplify and standardize the design, and shape how actors understand and operationalize the ambiguous concept of sustainability.

3.2.1 Artefacts set boundaries to the range of possible design choices

Designers only have a limited freedom when choosing design options. On one hand, **artefacts enforce a minimum level of work with designs for improved environmental sustainability**. In many cases, actors engage in sustainable design practices only to the extent required to fulfill environmental- or energy performance requirements enforced by artefacts. These include legal requirements conveyed in the building code, as well as demands from the client or the public authorities, conveyed in procurement or planning documents, respectively. Both of the Swedish cases also included additional energy- and environmental performance requirements codified in internal handbooks and directives. However, as shown in this quote, once minimum levels are reached this can prevent further effort:

I think that working with environmental performance means meeting the requirements that we have. [...] We think we are at a good level where we meet our owner directives. That's why we are not working with it further. (SE_2 project leader)

Artefacts also **restrict the range of possible design options for improved environmental sustainability**. Both Swedish and Cypriot organizations followed requirements related to keeping costs low:

Materials are more or less predefined, due to financial limitations; we did use the most affordable options. (CY_1 General Manager - Architect)

Public procurement law also restricts the client's ability to experiment with options that are not widely available, especially in traditional contracts, and development plans can restrict the use of certain materials and design options:

It says in the detailed development plan that the facades should be brick and plaster [...] They should match the other facades. (MREC$_2$ Project leader)

Height restrictions in development plans can also present challenges to construction with wooden frames, which requires thicker floor structures and therefore reduce the number of storeys possible. Overall, artefacts set the boundaries of actors' work with various aspects of sustainable design. On one hand they ensure a minimum level of attention to environmental aspects, while on the other they often restrict the range of possible design options.

3.2.2 Artefacts simplify the design process

Actors within housing projects must handle complex design processes with limited time and resources. Therefore, they often use solutions to simplify and streamline building design and avoid starting each project with a blank slate. Some design choices within the project are therefore **simplified**. In early design, this entailed the use of default designs and drawings in the Cypriot cases, as well as checklists of possible sustainable design solutions in one Swedish case. In later design stages, this entailed the use of internal design handbooks and guidelines in both Swedish cases as well as databases of technical specifications in the Cypriot organisation. These documents are developed outside the project, at the level of the organisation, and applied to all new projects. This implies that **some of the key design decision situations that influence the building's final environmental performance are not found within the project itself, but are better addressed at the level of the organization**. These artefacts play an enabling role by simplifying decisions, presenting default alternatives and again limiting the number of options or indicators considered. However, it should be noted that these internal standards and default solutions are sometimes adapted on a case-by-case basis, and can be updated. In the Cypriot organization studied, for example, any employee is able to propose modifications of the technical specifications at any time, and if approved by the management, this modification will then be applied in future projects – they are therefore not static, and can respond to wider knowledge within the organisation.

3.2.3 Artefacts shape actors' practical understanding of what constitutes "sustainable design"

Some artefacts specifically shape how actors operationalize the ambiguous concept of sustainability and translate it into tangible, actionable criteria (Schröder, 2018). Tools and criteria to assess the environmental performance of buildings and construction products can act as **boundary objects: they allow actors to collaborate and reach a common understanding of what sustainable design could constitute at a practical level, by providing a common language, framework and reference points** (Georg, 2015; Nicolini et al., 2012). This was particularly noticeable in the Swedish cases.

The first example is the Miljöbyggnad certification. Some projects that are *not* certified are nevertheless still designed *according to* Miljöbyggnad. The certification is so widespread that it has been internalized as a *de facto* definition of what it means for a building to be "environmentally sustainable", and has become a reference for setting sustainability criteria and targets. The Miljöbyggnad certification thus played a key role in translating the ambiguous concept of sustainability into practical design criteria. It "imports" into the project a technical understanding of building sustainability produced elsewhere, and infuses the local project with a wider national context regarding sustainability (Georg, 2015).

The second example is the fact that both Swedish housing organisations studied required the selection of construction products with a high enough "sustainability grade" from a third party database of products' environmental impacts. This simplified and outsourced assessment determines what aspects of sustainability designers consider or ignore, based on criteria that most users are unaware of. This "black box" provides sustainability criteria and references that are taken for granted and unchallenged, which elicits action (Rydin, 2013). Designers use a product's grade in the database to judge whether it is "sustainable" or not. Some might misunderstand the scope of the criteria in the databases, wrongly assuming e.g. that a product's grade considers its climate change impact or energy use, even if in fact it reflects its health and local environmental impacts:

As an engineer… I do not go through the product sheets of each product or calculate the carbon dioxide consumption, but I download that data and see "yes, this product is approved ". And then someone else has already done that work for me. (SE_1 Contractor)

In the Swedish cases, the concept of building sustainably has therefore recently become strongly codified, through an ecosystem of interconnected and interdependent artefacts referencing each other, including internal design guidelines and handbooks, environmental databases for construction products, certification criteria and the building code.

3.2.4 The variable role of individual agency in design decisions for improved environmental sustainability

The agency of individual actors also shapes "sustainable design", and this was particularly evident in the Cypriot cases, which showed much less evidence of codification of what could constitute "sustainable design". The views of professionals seem to be based on their **experience and awareness of existing design solutions for improved sustainability**, which varies widely between practitioners:

[The tools I use are] my brain, my knowledge, and social sensitivity that comes from a more general perception of the role of the organization. (CY_1 Civil Engineer)

You do it a bit instinctively. You use your instincts and work with materials depending on the area. (CY_2 Architect)

In the Cypriot cases, actors' work is enforced by minimum requirements and limited by practical constraints, but within that space their ambitions and work with sustainability depend on their motivation, skills, knowledge and ability to convince their peers, to a larger extent than appears in the Swedish cases. The comparison of the cases in Sweden and Cyprus therefore reveals important differences between practices in different national contexts. This suggests that the introduction of decision support tools such as LCA needs to be understood as context-dependent; there is no one-size-fits-all solution.

In both the Swedish and Cypriot cases, requirements, constraints and standards are sometimes bent, departed from and adapted by actors on a case-by-case basis. Standard designs are reinterpreted and adapted to the specificities of each project, guidelines are followed to various degrees, and exceptions are sometimes made to requirements regarding the environmental performance of the selected materials. Individual actors in housing organizations also influence artefacts in return, by updating standard typologies and databases and communicating with public authorities. Therefore, requirements, constraints and default solutions are better understood as mediators that influence human decisions, but do not determine them through rigid cause-and-effect relationships. This highlights the relevance of an approach that examines design decisions as a chain of human and non-human mediators, each of them influencing the outcome (Latour, 2005; Latour & Yaneva, 2018).

4. The power of individuals in public housing projects

4.1 Introduction

This chapter draws on evidence from the studies in Sweden and the UK, described above in section 2.2 a and b.

The previous chapter described how legislation, design handbooks, certification systems and other artefacts can help in ensuring a minimum level of sustainability to be included in design decisions. However these predefined restrictions do not have the same effect on all stakeholders or in all projects, and they are not always or not solely the driver. Part of the reason lies in the various interpretation level of internal and external limitations by individuals, depending on their personal profile and interactions with their peers. Social power is a tool that can be used to influence others to do (or believe) something that they otherwise would not (Walls and Berrone, 2017; Dahl, 1957; House, 1988). However, power is not necessarily formal and individuals with power are therefore not only those in managerial roles, but also in lower posts. It is important to understand who are those individuals and what is the source of their power – for example, informal power results from their personal characteristics and "influence over others solely upon their knowledge, expertise, and proven ability to perform" (Peiró and Meliá, 2003; Singh, 2009, p.168).

4.2 Results

4.2.1 Actors and artefacts interact

Legislation and regulation were both considered by the interviewees as their most important design parameters, although in different ways. Some respondents referred to these as a target that they have to reach and often blindly follow, and considered these to be the most sustainable design option. Other actors considered these to be an opportunity for improvement, and the minimum benchmark that they would have to overcome. Among the latter stakeholders most considered sustainability as their own responsibility and had a strong will to improve the current conditions. They did not only consider legislation as the minimum guidance they had to meet, and saw environmental performance as the norm.

4.2.2 There are differing understandings of responsibilities

In the Cypriot case studies, such individual environmental performance decisions could either be initiated upstream, from the management and directors, or from the designers or other officers. It was also clear that different people understood these responsibilities and obligations, and who held them, differently – this was true of other performance requirements, such as cost, quality, etc, as well as environmental performance. In one example, a person from the Technical Department (an architect) believed that the most important decision-maker regarding the environmental performance of the project was the Architect, since it was the Technical Department (including the design team) that would decide and advise the management on the project design, hence having an obligation to improve the environmental performance. However, this actor also believed that the financial cost would be the most important limitation for the Board of Directors (BoD). However when questioned, members of the BoD stated that the cost was not in fact the most important factor for them, and they would expect improved quality and sustainability, within reasonable additional cost.

Yet another project actor, an engineer, also felt that the most important actor in the design was the architect, but that the sustainability of the project depended on the management and BoD, because this is where the guidelines came from. He expected therefore to receive any instructions on the improvement of the sustainability from the directors. However, BoD member considered it to be the expectation (and perhaps indeed an obligation) of the Technical Department, including the engineers, to examine and suggest improvements to sustainability, and to submit various scenarios to the BoD.

4.2.3 The influence of actors varies with their formal power and their informal networks

The literature supports the idea of the architect being the most influential actor in building design; however, the case studies demonstrated that this was not always the case for sustainability decisions for the large-scale residential projects from housing associations. This is more evident when considering the introduction of more sustainable decisions, and most importantly their future adoption. Various individuals highlight different people as the most influential actor, either themselves or another person in various roles.

In these case studies, the actors that were found to have a higher impact on the sustainability outcome were those who considered it their personal responsibility to do so, through their motivation and willingness to provide a better design. This type of behavior was found in various roles within the organization and depended on the individual's profile. Their ability to enact this change successfully appears to be an effect of their informal power, although formal power, through a key position, was clearly an additional help. Whichever level the instigator was at, it was clear that it was important that s/he could convince the rest of the stakeholders about her/his aspirations and gain support(ers) in order for this to progress. It was also apparent that if this level of support was insufficient, even if the change had been successfully instigated in one project, when the individual left the new changed approach would be lost.

Three such attempts to change / improve the design of buildings were reported in the two Cypriot cases. The first two initiated from two individuals at management level, and these were clearly easily introduced after they had convincedtheir seniors. Both changes were adopted and included in design documents. However, after both had retired, one of the changes was then abandoned while the other change was kept. The second change was retained because the individual who had instigated it had been able to inform and convince his peers in various positions and roles of the significance of the improvement. A third attempt was initiated by an individual in a less senior position who did not have a key role. This required additional effort for successful introduction, including convincing other peers and gaining supporters in various posts as well as initiating collaborations, laying the ground for the change. While this attempt involved a longer process, it was successfully adopted and it too was still being built on after that person left.

5. A comparison of three contexts: Sweden, Cyprus and the UK

5.1 Introduction

One area this report is interested in examining is the effect of the industry and cultural context on the design outcome. The case study comparisons between the UK, Sweden and Cyprus, described in section 2.2 a, b and c, demonstrated that these aspects not only predefine how design teams work and their activities, but also the number of stakeholders and decision-makers involved in the projects, and the decision channels. This was particularly evident when considering these large residential developments and public housing projects.

5.2 Results

5.2.1 Pre-project decisions that shape the design taken at different levels in different contexts

The industry context seems to result in associated consequences / variabilities in the decision-making process and the characterization of the important decision makers. As mentioned in the previous chapter, the first decisions which will affect the sustainability of a project are taken before the project starts, at the level of spatial and urban planning. Where and how these decisions are taken is therefore outside the project; however in the different countries considered, these factors varied. This may be a factor of the relative sizes, with Cyprus by far the smallest of the three countries. Sweden has almost 10 times the population, and almost 50 times the area of Cyprus. The UK differs again in size and population, being about half the size but with 6 times the population of Sweden.

In the Swedish case study it appeared that planning decisions are taken mainly by the local municipalities, at a local level. Local authorities produce local development plans, by which they can predefine the basic typology of the buildings, such as the façade materials, the frame type and a minimum performance level or rating of materials. Moreover, the development of a new project still arises from the same local authority, which means that the location and the layout of new projects is again controlled at a local level. Spatial planning and policy and implementation is also dealt with at a local level. The decision-making process is mainly influenced by these artefacts, and structured by rules and regulations.

Local and zoning plans in Cyprus are instead considered mainly at a national level. In Cyprus the plans produced by the national authorities provide restrictions on the height and land cover factors of the proposed developments and suggestions on the characteristics and the environmental performance of proposed developments. However, they mostly rely on the role of individual designers to propose and include environmental solutions, and aim to include (and rely on) the designer's creativity. Decisions to develop a new project therefore start upstream, from political decisions. Those normally include only the location and size of the project, but they might include other requirements such as the improvement of the product or even the procurement method, in the form of policy directions. In this context, regional and contextual requirements as well as national legislation and regulations were some of the main influences of designers.

The important decisions of the designer were considered to be the orientation of each building and the selection of materials. Design templates and databases of specifications are used and updated to ease the design process and to secure that the most recent updates are included.

Within the UK case study, a more project specific level decision making was observed. Residential developments in the UK are mainly conducted by private associations, and they often involve the development or improvement of existing neighbourhoods/communities. Such a design process is a rather long but at the same time transparent and thorough process. The whole procedure is conducted collaboratively and aims to feed public consultation feedback in every stage. In our case studies, the most important actor was the association (client-owner), since its sustainability aspirations (carbon strategy) was the first element that drove the architects' design decisions. At the same time, regular and consecutive consultation with the existing community led to the acceptance of the design and to amendments according to the user's profile. In this context, decisions were driven by various actors; it is important to mention though that every change was assessed and evaluated for the long-term cost-benefit and energy. The knowledge and experience of the designers, as well as feedback from previous projects, is used to inform design-decisions, which for these case studies were then presented to the local community through a meaningful public consultation process which produced further design changes.

6. Swedish single family homes manufacturers

6.1 Introduction

This case study (study d in section 2.2) zooms in on the industry context of single family home producers in Sweden and their decision-making in relation to mitigating embodied carbon. By studying a specific branch of the building and construction sector, a more in-depth record of the particularities of implementation contexts and decision-making situations in which life-cycle based quantitative assessments may or may not have a role for driving climate mitigation, could be studied. The study aimed at revealing critical aspects for climate mitigation in the building and construction sector by better procedural understanding of the actual decision-making in building processes. In addition, the role of life-cycle based information in current processes was explored.

The Swedish single family homes industry is entirely dominated by timber construction. A few companies still use in situ construction methods, but the industry is otherwise nowadays dominated by off-site industrial production methods. Historically, manufacturers mainly produced panel elements; however lately volumetric element production has increased, particularly when some of the companies also have entered multi-family home production. Three of the five companies in the study are part of larger trade groups which can cover various brands for single or multi-family homes as well as other parts of the value chain, like sawmills, hardware store and project development.

The resulting environmental performance of the buildings, including that of embodied carbon, can for this industry context be seen to be an effect of decisions taken in four main decision situations outlined below. The study also sought to explore what role LCA could play, to potentially deliver relevant decision support in decisions taken in this industry context, and this is discussed following the decision situations.

6.2 Results

6.2.1 Very limited development of, or change in, the building system

The building system, that is primarily the structural solution, often also called product platform, is of course key for the resulting environmental impact of the building from a life cycle perspective. This is because it involves the choices of main structural materials and products as well as the resulting heat transfer of the external wall. Since changing the building system has major implications for the brands as well as the automated factory lines of these companies, such changes are investigated very carefully in advance and executed very seldom. From our interviews, nearly only changes in regulation triggered such investigations and changes among the studied companies. A number of examples were given on how the sharpening of energy efficiency requirements triggered changes of the building systems. One company recalls how the previous revision of the EPBD directive triggered the generation of 14 different proposals which were evaluated based on a wide range of aspects. In the end, the company still concluded that the wall system was already performing well and no changes were done. The only other example of how changes in the building systems were triggered, mentioned in the interviews, was a case when a new technical solution of importance for improving the production efficiency in their factories, was investigated. The studies thus point at the reluctance to invest in the process of revising the building system, meaning that the window of opportunity for making radical improvements of the resulting environmental impact is limited.

6.2.2 Development of different house models are driven by perceived demand

The second decision context is the development of the variety of so called house models each firm is marketing, that is, different geometries, sizes, add-on products, etc. applied on the building system. Decisions on house models have implications on embodied emissions primarily through material intensity. The single family home manufacturers normally publish catalogues covering a number of different house models, targeting potential buyers. Naturally, perceived demands from the targeted client groups, as well as trends, very much drive the development of various house models. Up to this date, the companies studied perceive very limited drivers from customers concerning environmental performance. However, they do work with the Nordic Swan environmental label which is quite well-known among the public in Sweden. This certification has however not yet specifically targeted reduction of embodied carbon in buildings. Apart from offering some Swan labelled house models, no specific environmental consideration is taken in the development and offering of house models. However, an issue raised in the interviews is that climate concerns often go hand in hand with customer affluence. Some of the companies studied offer low price models, which are also lower in embodied carbon since they are smaller and have simpler forms. Nevertheless, companies also continue to offer much larger (and hence higher embodied carbon) houses for the customers who desire or need larger houses and can pay for it.

6.2.3 Products and product suppliers for the buildings change for a variety of reasons

The individual choice of products and the suppliers the companies work with, also have a role for the resulting environmental impact. This concerns both choices of products for the building systems as well as the offer of add-on products for the customers. All the studied companies work with some sort of product advisory group consisting of representatives from all parts of the company. In these groups, new products or changes of products and suppliers are discussed from different perspectives, before deciding. Perceived customer preferences play a role also in these decisions, but the interviewees revealed numerous examples of how changes regarding products were initiated for a wide range of reasons. Considerations included for example production technology improvements, reclamations, problems with the use of some products resulting in increased costs after hand-over, experiences regarding deliveries and guarantees, input from contractors work with the products, input from the market and sales departments regarding customer preferences as well as niching towards competitors, availability of information about products from suppliers and of course price.

Two examples from the interviews of how decisions about new products and suppliers with consequences in relation to climate mitigation, took place as follows. One company started to offer photovoltaics based on an initiative of their heat pump supplier who had set up a “package” which made it very easy for the company to bring in this product since it would not affect other parts of the buildings. Another company did consider changing the insulation product in their external wall system based on embodied carbon considerations. However, the change was not pursued since their contractors opposed the change due to work environment considerations.

6.2.4 Impact of customer choices

Finally, each purchase of a house is also an individual project process in which a number of decisions are taken by the customer, which can have an impact on the resulting environmental performance. The companies have a role, or their sales officers, to guide towards more climate-friendly choices. Primarily the decisions concern details regarding geometries and internal designs as well as individual product choices regarding both the interior and exterior appearance based on the offer of procured products by the company. The respondents conclude that still very few questions are asked by the customers regarding environmental performance. However, a few more questions are asked about energy performance and photovoltaics, compared to earlier. Since very few customers have the more technical competence, the discussions with the sales officers mainly deal with design of interior space, colours, choice of interior finishing, etc. The respondents mention that this also means that it is often more difficult to talk about environmental performance with the clients. One company brings up that local preferences sometimes lead to decisions impacting embodied carbon. That is, bricks and render are more popular as façade materials in the south of Sweden, compared to the rest of the country.

6.2.5 Potential of regulation for embodied carbon in this sector

Requirements regarding embodied carbon in regulation could trigger changes in the building system of single family home manufacturers, and therefore improvements. Some interviewees brought up this issue since a new national regulation on a mandatory climate declaration (including components of life cycle calculations) applies in Sweden from the 1st of January 2022. But otherwise, for this industry context, environmental improvements are scarcely done on a voluntary basis since it entails changes in the factory lines. When a change is initiated, however, LCA can and should definitely be one of the decision support tools. So far, none of the interviewed companies had used it for this purpose. But a few have made studies of reference buildings for internal learning purposes, since they see a competitive advantage in competence building on the embodied carbon issue.

6.2.6 Future role of customer choice

The interviews revealed that, so far, there were no examples of customers who asked about the environmental performance with respect to embodied carbon. With the coming regulation, this is assumed to be about to change, as was seen with the aspect of energy performance. There are also examples of some respondents reasoning that they should offer climate declarations of their house models as part of the information in their sales catalogues. One aspect discussed in a few interviews was that as long as LCA results are normalized per m2, life cycle based information as decision support for developing house models might be of limited relevance. One could potentially instead think about whether a cap for emissions for example per person would be an interesting goal internally when developing house models.

6.2.7 LCA of products

A few of the companies in the study had performed LCAs of more generic reference buildings to identify hotspot materials and components and to establish an order of priority of materials for which they start to find more low-carbon alternatives. This seems like a relevant use of LCA in this industry context. Similarly, such a generic and basic LCA model could be used to communicate for the customers how larger changes concerning designs, such as the number of or size of windows, impact on the resulting embodied emissions. But in relation to customers, the respondents instead mentioned plans on presenting embodied carbon for all products in their catalogue of optional products and also highlighting “sustainable choices”. To do that they demand reliable environmental data from suppliers and several respondents say that they already ask for that.

7. The impact of tool development on individual knowledge

7.1 Introduction

Embodied carbon has become more prominent in the UK construction industry in recent years. There are several commercial tools which have started to have traction in the market, but leading practices and consultancies have also developed their own tools to consider embodied carbon. Through interviews with individuals in the UK involved in developing embodied carbon tools, this research highlights the effect of tool development suggested from these interviews. It is based on a qualitative review of attitudes expressed around issues of knowledge, the benefits of developing embodied carbon tools on knowledge, the purpose of embodied carbon tools, and the place of guiding principles, intuition and play in embodied carbon assessment.

There have been several surveys of users of LCA and Embodied Carbon tool users, e.g. (Anand and Amor, 2017; Häkkinen et al., 2015) to identify ways in which assessment can be improved. Schlanbusch et al. (2016) looked at the experiences of those working on LCA for buildings in Nordic countries. However there is a lack of research focusing on the experience and views of adapted LCA and embodied carbon tool developers themselves. Ariyaratne and Moncaster (2014) interviewed the developers of two Building LCA tools alongside other stakeholders to obtain expert views on the tools, BIM and use of modelling software but didn't focus on tool developers' particular viewpoint.

The design and development of any design tool can have a significant impact on the design output and design process (see for example Moncaster, 2013). Understanding the drivers, assumptions and other embedded decisions that go into the design of the tool is a matter of significant interest given the complexity of the activity the tool is required to undertake.

7.2 Results

7.2.1 Embodied carbon knowledge

Only one participant, an architect, was taught about embodied carbon at university. Others were taught about material efficiency or materials processing but not embodied carbon, one saying it was not a topic in the curriculum at the time of her/his studies.. One interviewee mentioned that it was not that hard to calculate embodied carbon, "Actually embodied carbon isn't difficult. If you've got the figures, it's multiplying two numbers together" and another highlighted "these kinds of tools are easy to learn anyway". But others hinted at the difficulty, "it does require a bit of practice in doing the calculations", "there was a very steep learning curve", "[I] had some great colleagues who helped me learn all that they knew about it"; and one highlighted that "It's this weird stage where [embodied carbon]'s understood as a thing, but [there]'s so much nonsense marketing and stuff around the outside of it."

Two of those interviewed mentioned the need to have a good knowledge of construction to consider embodied carbon – warning that both LCA professionals and architectural staff don't always have that understanding of how buildings are put together, and even that architects often don't know "how long bits of buildings last for". A lack of knowledge about construction means that tool users may not be able to identify the need to adjust volumes of materials in the studies, for example where a tool takes quantities from a CAD or BIM model and a profiled sheet or stud wall are considered as a solid material.

7.2.2 Tool development and knowledge

Several of the tool developers highlighted the effect the process of developing a tool had on their knowledge of embodied carbon "was very, very useful", "fundamental", "probably the most useful exercise I did". One commented, "I think it's really interesting that so many people have developed their own tools. I wonder if it's a bit about knowledge generation internally as well as just the process of making it, [it] means that we're also skilled up in it very quickly."

7.2.3 Purpose of tools: engagement

The main focus for tools though seems to be to encourage and engage with design teams on embodied carbon however. One said the purpose of their tool was "to try and get structural engineers to consider embodied carbon more in the design process." Another structural engineer said that architects found it really useful to be provided with embodied carbon assessments, and that "I know they've been really, really receptive to that, so I think it's worked very well".

Although the tools were not aimed at clients as users, several participants suggested that using the tools allowed them to engage clients in embodied carbon. One mentioned, "the purpose of this internal initiative, it's to encourage people to do it, and feel confident enough to do it and to bring it up as an important point, even if the client isn't thinking about it."

7.2.4 Purpose of tools: education

A participant stated part of the reason their tool existed was "an education piece" for the practice. An interviewee whose practice mandated use of the tool commented, "I think it's just about educating; so [clients] are not asking, but they are very excited when they hear [about embodied carbon]". Another said although their tool hadn't been designed specifically to educate people, they saw helping users understand more about their designs as a beneficial side effect of getting people to use the tool. Several commented that they thought people were learning from using the tools: "I think that when people do use it, they become a bit more educated. They see the impacts of different materials on the design", they are "understanding where carbon goes in the building, what's emitted, what are the root causes".

One theme which came out of the interviews was the concept of "playing" with tools, both as a way of users learning about embodied carbon, and in finding solutions for a particular building. One explained they had developed a tool for architects to see the impact of design changes very quickly to "enable them to play and it become part of the design role", another described playing with the environmental credentials of materials (e.g. recycled content of a metal) within a tool, one interviewee talked about playing with several tools to look at different aspects of embodied carbon, and two mentioned playing with the outputs from the tools.

7.2.5 Playing with tools

Play, in these contexts, can be linked directly to design mechanisms that rely on exploration, iteration, prototyping and so on. These playful actions are supported by a more critical cognitive activity that is constantly evaluating and feeding back on the activity, theorised as Reflection in Action (Schön, 1991). It is this awareness of the value and purpose that play can have that is potentially particularly useful to the design process and decision making.

7.2.6 Knowledge, experience and intuition

Overall general knowledge of embodied carbon assessment was seen as very useful, particularly in identifying errors, with one participant commenting, "What I notice when I'm reviewing the younger staff's work, they don't have a feel for the numbers, so I can look at numbers in the quantities of carbon for different materials and you immediately get a sense of "that seems incredibly high" or "why is it like that"", another, "You just get a sense of those numbers after a while" and another, "I think it's just a mixture of experience of knowing, being around those numbers and seeing again in a sense check, if something doesn't feel right".

The use of phrases like "feel for the numbers", "you get a sense of 'that seems incredibly high'", "seeing again in a sense check, if something doesn't feel right" suggest that intuition plays a strong part in reviewing the results of embodied carbon studies, and when asked directly, other interviewees said, "there's certainly an element of intuition", "I think a lot can be done by intuition, if you know the general principles".

7.2.7 Guiding principles

It was clear however that the knowledge gained from experience was key to developing intuition – "I think once you have a bit more of that knowledge, I think you can make those kind of intuitive decisions without having to do the calculations", "if you have assessed 20 buildings...I think you can have intuition about the results", "if you have carried out a few projects over a few RIBA stages, you can have intuition", "You just get a sense of those numbers after a while".

One interviewee observed a link between intuition and another well-known mechanism in design decision-making, "I think a lot can be done by intuition, if you know the general principles".

Using guiding principles in design, for example heuristic strategies such as rules of thumb, is a well-used approach to decision making in design (Lawson, 2005) and all the interviewees mentioned approaches which they expected to reduce embodied carbon. Examples of guiding principles referred to by interviewees were:

> *"Using a hierarchy based on the PAS 2080, 'Build nothing, build less, build clever framework'"*
>
> *"Using less material is good"*
>
> *"Increasing cement substitution"*
>
> *"Facade aluminium that's 100 percent recycled, it's definitely better than zero percent recycled content"*
>
> *"Using timber is a great thing if you want to reduce your embodied carbon".*

These align with those found in reviews of embodied carbon reduction approaches, e.g. (Malmqvist et al., 2018; Akbarnezhad and Xiao, 2017; Lupíšek et al., 2016; Pomponi and Moncaster, 2016).

One rule to address embodied carbon not however found directly in the literature was, “It's the hidden bits, that's the real impactful stuff”, which was clarified as, “the finished surfaces of your facade and your internal wall mean almost nothing, it's what's behind it that we have to get to”, giving the example of various façade options which had the same external appearance, but had very different embodied carbon impact due to the use of different supporting structures.

7.2.8 No simple answers

As a counter to the use of intuition and guiding principles however, many of interviewees observed there are rarely universal solutions, warning that some approaches didn’t work for all buildings:

> *“They roughly go hand in hand, volumes of materials, and embodied carbon. Obviously there are some exceptions, you get different materials that are really high.”*
>
> *“The complexity of projects, I think it does change the story all the time.”*

This was particularly apparent for embodied carbon analysis for structures based on column grids spacing for example:

> *“I do framing analysis or different grid comparisons and so many people think, "Well, that's just the answer". No, you can't, it doesn't count. Not one size fits all”.*
>
> *“If it's just a standard building, then it's always going to be like that, isn't it - but no building is ever like it.”*
>
> *“I would expect that by reducing the [column] grid, you would get lower impacts. But after a point, if you reduce it too much, then you might get more impact again because you increase the columns.”*

Using intuition can be a positive and even necessary act as part of any design process, particularly where complex or uncertain decision-making routes are required. It can, however, have a negative effect, when it means an activity becomes harder to scrutinise or even ‘invisible’ in the design process. How expert designers deal with ensuring the appropriateness of intuition becomes important, as was recognised by some interviewees. One interviewee, for example, was concerned that intuition is what has been used to address embodied carbon in most buildings for the past 40 years, “it's just been done through intuition, which means it's just been part of the marketing”. Drawing on a previous discussion of the embodied carbon of aluminium – “no one knows that aluminium is terrible”, they highlighted, “everyone uses aluminium framing for everything these days… And that, in my opinion, is a massive failure of this approach of just using your intuition”.

There were also concerns around the use of timber. Although one interviewee mentioned that “using timber is a great thing if you want to reduce your embodied carbon”, another highlighted, “I was pretty surprised when I first started learning more about timber emissions and understanding that an A to C assessment for timber you can show that it can be worse than a steel frame and concrete slab building or a fully concrete building”. Similarly, one participant said that new graduates they employ know what embodied carbon is, but “they think that concrete is terrible, which it isn’t, and I think that wood is amazing but [it] isn't always”.

7.2.9 Need for measurement

A number of participants highlighted the need for measurement and numerical assessment rather than rules of thumb or intuition; “It's probably more about natural materials generally feeling better than processed materials. And I think there's probably an assumption that if it's natural, it's better…. whether there's numbers to back it up or not.” The need to rely on calculated embodied carbon results rather than intuition was mentioned by another participant who emphasized, “we've been very strong on [this] within our office because of how much people do use intuition at the moment, and we're saying no, [embodied carbon] has to be a number.” Another also encapsulated this view by saying, “if you don't measure [embodied carbon], then you're not able to say with certainty if what you're doing is good, or how good it is”.

8. Development of national policy and industry practice in Sweden and the UK

8.1 Introduction

Industry measurements of embodied impacts of buildings have increased over the last ten years (Hakkinen et al, 2015; De Wolf et al; 2017; Jusselme et al, 2020), but this varies between countries. This section describes the recent history of embodied impact assessment in two contrasting countries, Sweden and the UK. The chapter also considers how policy and regulation are developing in both, either responding to or pushing the changing industry practices. The section is based on a paper presented at the World Sustainable Built Environment conference (Moncaster and Malmqvist, 2020), and further details and analysis are included in that paper.

8.2 Results

8.2.1 Industry leadership and policy-industry networks developed Swedish policy after 2014

The focus on environmental aspects in the Swedish building sector started in the 1990s. LCA tools for buildings were developed by academia, the Stockholm municipality, and later the building research institute, IVL. However only IVL continued to update their data, and they did not make the tool or data publicly available. During the 2000s, individual actors attempted to introduce embodied carbon assessments, but without access to updated data their arguments held little sway. Meanwhile the political discourse in the 2000s was to avoid regulation and promote dialogue and market-driven voluntary commitments. The large umbrella initiative Bygga-bo-dialogen developed dialogues with over 40 industry partners, leading to the national environmental certification tool for buildings, Miljöbyggnad. An indicator for embodied impacts was discussed, but considered too demanding at the time.

A significant change towards action and regulation for embodied impacts followed a particularly influential 2014 report from the Royal Academy for Engineering (IVA). The IVA represented powerful industry stakeholders, and the report had more of an impact than previous research (even though these had said much the same things) because of the actors involved, and of the effective communication of key messages. A research project was then initiated by an influential individual with a well-developed professional network. The Swedish Construction Federation were appointed the official project leader, , and it was funded by the construction industry's R&D fund (SBUF), which has a close relationship with construction industry stakeholders. Meanwhile the research was undertaken by experts from the university KTH and the research institute IVL; the use of renowned academic experts from two different institutions, and the fact that they were saying the same thing, increased the acceptance of the report. An active steering committee and reference committee also emphasised the urgency and reassured business that the findings were valid and unbiased. The results were announced in July 2014 at a well attended event in which the housing ministry also participated. The key messages - that 50% of greenhouse gas emissions from buildings came from the product and construction stages, of the same order of magnitude as all car journeys in the country, but that there was no regulation to reduce them – were reported extensively in the media, and also reached policy makers through the networks of key actors.

In 2015 Boverket (the national board for building, planning and construction) was commissioned by the Swedish Government to investigate “climate impact of buildings from a life-cycle perspective”. Their resultant report encouraged the use of LCA. By 2017 the need for including embodied carbon in regulation was seen as a priority, and was being actively promoted by the building sector, who included it in their road-map to 2045. Following the complicated election result in 2018 the issue was one of the 73 points in the government negotiations. In 2018 IVL partnered with a number of property developers and municipalities to develop a further tool, BM, and at this point parts of the IVL database became openly available. The government has since supported the development of a database with nationally relevant climate data, for developing mandatory climate declarations and embodied impact calculations for buildings; these came into regulation at the start of 2022.

8.2.2 Developers and material manufacturers looking to increase market share have influential roles

The case of a new-build multi-family building is an example of what was happening in construction during the same period. This was one of the first buildings in Sweden in which embodied carbon assessment was used to influence the design, and was to be a demonstration case, with embodied carbon of the structural solutions considered at the early design stage. Both the sustainability manager of the developer, a charismatic person with a powerful position at the company, and her recruited environmental manager, who had research experience of building LCA, were instrumental in driving this project. Working with representatives of both the timber and concrete industries, an initial study suggested that, under a set of very specific conditions of use, a concrete solution could have lower embodied carbon than the timber concept studied. The developer then collaborated with researchers, and with concrete manufacturers, to produce an optimized concrete solution, resulting in a product with 30% lower embodied carbon than mainstream concrete.

This case demonstrated that developers were starting to be aware that reducing embodied carbon was becoming important during this period. It also showed that, with the right leadership, it was possible for a client to set up procurement requirements which could really lead to product development. And finally, it showed that the concrete and cement industry were clearly aware of the threat to their business from the developing interest in reducing embodied carbon discussed earlier, and therefore had an incentive to demonstrate the potential for low embodied carbon concrete. The study provided an opportunity to market this claim, and has since become a well-used debate tool for the concrete and cement industry.

8.2.3 Access to data supported development of knowledge through UK industry, with later success pushing for policy

In the UK separate initiatives were following a fairly similar timescale. In 1996 the Building Research Establishment (BRE) introduced the first version of the Green Guide, which rated different construction materials for their environmental sustainability. This introduced industry professionals to the concept, although without making visible individual embodied impact data. However a political focus on ‘zero carbon’ emerging in the new century deliberately excluded embodied impacts, despite industry pressure. Schools were to be ‘zero carbon’ by 2016, but with zero carbon only incorporating operational impacts. Industry task groups were set up by the Government showing they were keen to be seen to consult; however membership and terms of reference were tightly controlled, and as a result the wider industry stakeholders (who had been pressuring for the inclusion of embodied impacts) appeared to have little power. The strong rejection of embodied carbon by the left-wing Government potentially had a political incentive, allowing the key political aim of increasing housebuilding while being seen to be environmentally progressive by achieving ‘zero carbon’.

In parallel, between 2006-2011 the Inventory of Carbon and Energy (ICE) was being created at Bath University. This was published as the first open access database on the embodied impacts of construction materials, and was rapidly taken up by academics and industry practitioners in the development of their own tools.

In 2010 Government industry funding supported the development of design support tools including for whole life (operational and embodied) impacts of buildings, and in the same year the UK Green Building Council ran an event on embodied carbon in London. Industry interest in embodied impacts continued to grow, with a country-wide 'Embodied Carbon Week' in 2014. However despite the publication of the European Standards on 'Sustainability of Construction Works' in 2011-12, industry methods for calculating embodied carbon were very varied at this point. Further Government funding was released in 2014 and an industry-led, academic-supported team developed a methodology which was published in 2017 by the professional body RICS. The project lead had also discussed the methodology with the BRE and in 2018 the BRE introduced full LCA as an option within BREEAM, replacing the Green Guide with explicit inclusion of embodied impacts of materials, and aligning their methodology with that of the RICS. Local Government also started to diverge from national policy, with the new London Plan in 2020 including for the first time a requirement to measure embodied carbon in construction projects, using the RICS methodology.

In 2021 a Government consultation by an influential Select Committee heard evidence from across industry and academia on the importance of embodied carbon. They will publish their report in 2022, and are likely to advise that embodied carbon is included within UK regulation. Government is also directly funding the revision and update of the RICS methodology, and have funded the update of the original ICE database, still open access.

8.2.4 Change in practice led by knowledgeable inividuals and contractors who identified co-benefits

As in Sweden, embodied carbon was already being demonstrated in building projects. For a new school building designed and constructed between 2008-2010 the structural engineer suggested that instead of steel frame the team should use cross laminated timber (CLT) as a low embodied carbon solution. To the engineer, BREEAM at the time was lacking this focus, and the innovation came directly from his own knowledge, and his use of the free data from the ICE database as part of an in-house Excel tool His firm were also developing a niche of expertise in CLT design, and were therefore prepared to spend extra resources on this project to demonstrate the low embodied carbon credentials of timber. The contractor then appointed through a traditional post-design procurement route found CLT to be quick to erect, saving time and money. The contractor transferred the technology (and the structural engineer) to a second school building they had already been contracted for through a design and build procurement. CLT has since spread wider through construction in the UK. There are ongoing debates about the use of more timber, although in Wales this is now strongly promoted by the Welsh devolved Government.

9. Conclusions and recommendations

9.1 Overview

This report of subtask ST3.4 of Annex 72 has explored how the transition to lower-impact buildings happens within countries, construction firms, and building projects, and therefore how LCA and assessment approaches built on LCA might best be introduced for greatest effect. The hypothesis was tested that transition is affected by four mechanisms, and the interactions between them: (1) the role of individuals in projects; (2) the tools and artefacts that are used in design; (3) the industry and organizational context; and (4) the national policy and regulation landscape.

A number of qualitative case studies to explore each of these potential impacts were conducted by the five authors in Sweden, Cyprus and the UK and these have been outlined in the previous chapters 3-8. Qualitative case study was chosen as the most appropriate research design due to the recognized complexities of real world decisions, and the importance of exploring them in their context.

The case studies included: multi-family public housing projects in Sweden, Cyprus and the UK, discussed in chapters 3-5; single housing developers in Sweden in chapter 6; individual in-house LCA tool designers in the UK, chapter 7; and development of regulation in Sweden and the UK in chapter 8.

9.2 Discussion

9.2.1 Individuals (1) and artefacts (2)

First of all, a strong relationship was found between artefacts and individuals. In the public housing projects artefacts, including regulations, directives, plans and green building standards, were shown to mediate the work of individual designers, both enabling and restricting their decisions towards sustainability in the case studies of public housing projects in Sweden and Cyprus. Compliance with requirements was shown to be a major driver of design choices, meaning that individuals and groups external to the project, such as policymakers, planners and developers, could therefore steer building sustainability by setting minimum performance requirements.

The study also showed that certification systems, environmental databases and sustainability assessment tools act to hide or reveal various aspects of sustainability, providing reference points for what it means for a building to be “sustainable”. These artefacts therefore act as ‘boundary objects’, following the theory developed by Susan Leigh Star, who describes these as ‘objects that are plastic enough to be adaptable across multiple viewpoints, yet maintain continuity of identity’ (Leigh Star, 1989). These facilitate decisions around design by providing (and proposing) a common understanding of sustainability, with a common agenda, language and reference points. These roles are necessary to translate the ambiguous concept of sustainability into practical criteria and enable cooperation between actors. However, the artefacts were also shown to have the potential to limit the definition of sustainability, silence important issues, and restrict ambitions.

In the UK individuals who had developed in-house tools (another artefact) found the process had been useful to the development of their own knowledge of embodied carbon. Many still mentioned the importance of using intuition and guiding principles in their work, which were based on prior knowledge and experience and aligned with typical recommendations for reducing embodied carbon. Nevertheless in several cases studied in this report, participants drew attention to the difficulty of “one size fits all” solutions for embodied carbon and discussed counter-intuitive results they had seen, emphasising the need to measure embodied impacts to assess whether the intuitive solutions really were lower carbon.

Beyond their developers, the tools had also increased the engagement with embodied carbon of both professionals and clients, educating and informing them about embodied carbon. For some tools this was an intentional purpose, while for others improved understanding of users had been unintentional. They were thus seen acting in a similar way to the (non-LCA) tools and artefacts discussed in the Swedish and Cypriot social housing case studies.

9.2.2 Industry and organizational context (3)

Secondly it was apparent that different industry contexts change significantly who the main stakeholders and decision makers are. In Sweden, strategic planning and the development of new projects arise from the municipality, while in Cyprus there was greater individual autonomy, with fewer criteria enforced through regulation and other artefacts and greater individual power over the design and the sustainability aspects. In Cyprus therefore the interpretation and realization of sustainability was highly dependent on the varied knowledge of individual designers. In the UK there was more design independence seen than in Sweden, but also more industry awareness of and practice in LCA than in Cyprus.

Decisions also vary with the project type. For the single family house builders studied the designs are predetermined and built offsite in factories, and therefore the design changes only occasionally, with little opportunity for reducing environmental impacts. The large public housing projects, meanwhile, were characterised by tight time and budget limitations. There was therefore also a need, acknowledged by the practitioners involved, for additional streamlined procedures and organisational tools to help handle large amounts of requirements and information.

9.2.3 Individuals (1), artefacts (2), industry context (3) and their impact on national policy (4)

Finally all four of the mechanisms hypothesised to affected transition, were seen to interact with the studies of the development of policy in Sweden and the UK. Examples from both countries demonstrated the ways in which power works through policy formation and industry interests, and the differing powers of both loose ‘issue networks’ within the construction industry, and more controlled ‘policy communities’, formed of industry individuals but closely linked to political agendas.

In Sweden embodied carbon was swiftly moved onto the political agenda from 2014, due to the work of a small but powerfully connected group of individuals with industry backgrounds and strong political networks, and supported by credible and independent academic analysis. In the UK in the early years of the century embodied carbon was specifically <u>ex</u>cluded by Government. However the development of the open access ICE database from 2006 was instrumental in spreading knowledge throughout the industry, and many organisations started developing their own tools which in turn further spread understanding. The existence of professional institutions in the UK enabled the publication of an accepted methodology in 2017 by a broad representative body from industry and academia led by an individual, again, with a strong political and industry network. This has since been adopted by the municipal London Plan, and accepted across the UK. In 2022 embodied impacts of buildings finally appear to be about to be included in UK regulation.

Both in Sweden and the UK therefore a charismatic individual could be identified as having had a key role in the introduction of life-cycle based assessment into regulation, combined with a strong network which included industry and political actors and supported by independent academic analysis and by industry bodies. Meanwhile the release of open and reliable data in the UK was instrumental in allowing the development of industry expertise and knowledge across the country, well ahead of that in Sweden. Only much later was credible and contextual open access data launched in Sweden, perhaps explaining in part the limited industry focus before it gained political interest. Despite this difference, embodied carbon is now included in Swedish regulations, while the UK regulations still omit it.

9.3 Recommendations

The purpose of this analysis was to consider the most appropriate and effective route to the introduction of LCA and life-cycle based assessments built on LCA, with the ultimate aim of reducing embodied (as well as operational) impacts from buildings. From the three countries studied it is clear that the answer will vary country to country. However there are some messages which are common.

1. The early publication of open access data in the UK, with additional Government funding for tool development, has led to widespread industry knowledge and concern. Meanwhile in Sweden, starting from much the same basis, a database was only made open access very recently. While regulation in Sweden is now ahead of the UK, industry knowledge appears to be less advanced.

   It is recommended that nations support the development of open access databases for their own context.

2. While developing in-house LCA tools was a learning exercise for the individuals involved, the tools themselves have gone on to educate other users. This characteristic of artefacts to have an effect much wider than their context of use, and not always the intended effect, was also seen within the Swedish and Cypriot public housing case studies.

   It is recommended to use LCA tools well adapted for the national context.

   It is recommended that designers of sustainability assessment tools and standards are open about what definitions and understandings their tools embody, allowing scrutiny of any internal calculations rather than a ‘black box’ design.

As LCA is implemented more widely, this raises the question of where and when it could be most efficiently implemented. The studies show that this will vary depending on the project, national industry context, and power of the designers to make changes.

3. In Sweden LCA assessment could be implemented at a municipal/regional level, as this is the level at which standards are developed. Within Cyprus, national authorities could enforce the use of such evaluations to be submitted with planning applications, or require LCA at organizational level.

   It is recommended that industries and countries conduct assessments of relevance for their own context.

4. In projects with tight budgets and high degrees of standardisation, LCA is unlikely to be used within the project unless it is explicitly required by the client or public authorities. However, LCA could be used outside the project to help develop standardised handbooks, design directions and typologies. The process of defining these standardised solutions could be a critical point for the introduction of design practices to better consider environmental sustainability.

   For industries where there is high repetition, with prefabricated and standardized designs, LCA should also be introduced at industry rather than project level. Some important design choices can be simplified and standardised through guidelines, checklists and default options.

It is recommended that LCA is used to minimise environmental impacts for all standardised solutions in any context in which these exist.

5. This also suggests that moving towards offsite manufacture to reduce waste might have negative consequences for the rapid transition towards reducing embodied impacts, due to the lock-in nature of prefabrication.

   It is recommended that further research is needed to assess the long term environmental impact of prefabricated designs before this approach is encouraged further.

6. In countries where there is already greater LCA literacy and designers have considerable autonomy, such as the UK, LCA or life-cycle based assessments could be required at a project level including at the feasibility stage, to assess high level decisions such as adaptation or demolition, during the detailed design stage to assess the choice of various materials and systems, and at the end of construction to assess the complete LCA for the final building.

   It is recommended that LCA is used at the project level in situations where there is the autonomy and knowledge to make significant changes.

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ANNEX 72

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