International Energy Agency

Guideline for Design Professionals and Consultants

Part 1: Basics for the Assessment of Embodied Energy and Embodied GHG Emissions

Energy in Buildings and Communities Programme

September 2016

EBC is a programme of the International Energy Agency (IEA)

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September 2016

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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 (*)

Management Summary

This guideline summarizes selected results and recommendations of the IEA-EBC project Annex 57 dealing with the "Evaluation of Embodied Energy and CO_{2eq} for Building Construction". The specific mission of Annex 57 was to develop and provide the necessary methodological bases, tools, calculation rules, data bases and application examples for incorporating the aspects of embodied energy and GHG emissions into the decision-making of relevant stakeholder groups. The results are published in the form of thematic sub-reports and specific guidelines for selected groups of stakeholders in order to cater their differentiated needs and requirements.

Annex 57 includes the following series of guidelines:

- Guideline for design professionals and consultants - part 1: Basics for the assessment of embodied energy and embodied GHG emissions
- Guideline for design professionals and consultants – part 2: Strategies for reducing embodied energy and embodied GHG emissions
- Guideline for SMEs of construction product manufacturers
- Guideline for policy makers, including recommendations for public procurement
- Guideline for educators and university professors

Table of content

Scope of the guideline

This guideline is targeted specifically to *design professionals and consultants* with the aim to inform them on the subject of embodied impacts, to present the starting points for the integration of embodied impacts assessment into the design process and to provide access to related information sources and tools. The group of *design professional and consultants* includes architects, engineers and quantity surveyors among others. Specifically in this document, the term embodied impacts refers only to the primary energy consumption and the adverse effects on the climate resulting from GHG emissions that arise in the life cycle due to the production, maintenance and end of life of the construction works.

In this guideline, essential results of IEA EBC Annex 57 *"Evaluation of Embodied Energy & CO_{2eq} for Building Construction"* are summarized and specific recommendations are presented, accompanied also by supporting information.

This publication is part of a series of guideline publications targeted to specific groups of actors working within the construction industry (construction product manufacturers, policy makers, procurers), and the education sector (educators).

Detailed information on basics, as well as background information on system boundaries and indicators is available in a full report developed as part of the Subtask 1 (ST1) of IEA EBC Annex 57 describing the "*Basics, Actors and Concepts*". This report can be found here: http://www.annex57.org/.

Embodied impacts – an additional design aspect

The design of buildings and constructed assets in connection with new construction and refurbishment projects is a complex task. The starting points are, inter alia, the fulfilment of requirements on the functional and technical quality, the effort towards a high aesthetic and urban quality and the necessity of abiding by a budget for the construction costs. At the same time, designers seek to contribute to the conservation of resources and to reduce adverse effects on the environment.

In the past, the attempts of design professionals and consultants to respond to the need for conserving the resources and reducing the adverse effects on the environment were often focused only on reducing the operational energy consumption and the resulting GHG emissions. Nowadays, in particular in connection with the implementation of principles of sustainable development (e.g. relevant standards have been published under the responsibility of ISO/TC 59/SC 17 group), it is becoming increasingly necessary to understand and assess in a targeted manner the impact of design decisions on these important environmental issues taking into account the full life cycle of construction products and buildings. This includes the embodied impacts associated with the production, maintenance, and eventual end of life treatment of buildings and building systems as a result of the production, installation, use and disposal or recycling of construction products.

In this sense, the identification, assessment and influencing of embodied impacts (here embodied energy and embodied GHG emissions) becomes an additional design task. It is often feared that a complete life cycle assessment has to be performed by the designer and thus, an extensive and highly elaborate research for data compilation and analysis must be carried out by the design teams themselves. The quantification of embodied impacts, however, is a task that can be easily integrated into the design process and combined with traditional design tasks. Doing so is not as complicated as it may seem. In practice, the design professional or consultant is not required to perform an LCA for a complete building manually, but to apply the results of LCAs for construction products and building services from other sources, e.g. available in databases. Namely, it is sufficient for a designer to quantify the building products and materials to be used for the building (this is a common design task) and to link the determined material quantities with values from databases or to use tools with integrated databases. This provides information on embodied impacts that need to be interpreted and can serve as a basis for the improvement/ development of building designs. At the same time, the processing of such questions contributes to the competitiveness of the design professionals and consultants and becomes a source of additional revenue.

Therefore, for design professionals and consultants, it becomes increasingly important to deal with these embodied impacts, to quantify and evaluate them, as well as to influence them with design decisions taken in a targeted manner. Specifically, the importance of investigating this aspect lies in the following reasons:

- In regions with a prolonged cooling and/ or heating period the efforts of recent years have led to a significant reduction of operational energy consumption and GHG emissions. In an overall appraisal, this has as a result an increase in the relative importance of embodied impacts due to the production and maintenance of buildings, unlocking here further the potential of savings.
- In regions without a heating or cooling period as well as in engineering structures the energy consumption for the stages of manufacture and maintenance will prevail. The embodied impacts become an additional criterion for the optimization of structures.
- In selected countries, the task of reducing embodied impacts has already been identified as a goal in the national strategies for sustainable development.
- In selected countries and organizations, the goal of reducing embodied impacts has become part of the task and the requirement for certification or purchase of a building.
- UNEP-SBCI has developed since 2012 a new Task Force on "*Greening the Building Supply Chain*" (Technical Report: http://www.unep.org/sbci/pdfs/greening_the_supply_chain_report.pdf), with the aim to draw attention, even more than has been the case, on embodied impacts.
- In the area of sustainability assessment a transition from predominantly qualitative to predominantly quantitative methods is present. In addition, methods of life cycle assessment are increasingly used to describe, evaluate and influence in a targeted manner the use of resources and the adverse effects on the environment. These methods are no longer used only at the end of the design process but also during the early design stages to assist in the evaluation, optimization and comparison of different design alternatives. The embodied impacts are important and indispensable aspects of this process.
- Parts of the real estate industry focus on the aspect of carbon footprint. This is an approach for describing, evaluating and influencing the GHG emissions in the life cycle. Therefore, GHG emissions caused by the production and maintenance of construction works are an essential partial aspect.
- The demand for net zero energy and net zero emission buildings or net positive concepts grows. In connection with the assessment of the environmental benefits of such approaches, it is necessary to analyze the consequences for the embodied impacts. In addition, more and more the life cycle perspective is introduced in the energy and emission balances.

It is clear that design professionals and consultants have to face the challenge of dealing with issues related to the description, evaluation and management of embodied impacts already in the early design stages. The ability to fulfil such a task

- enhances the image and competitiveness of the designers or design firms
- demonstrates the personal commitment to, and acceptance of responsibility for the environment and society

However, the embodied impacts should not be analysed independently. These are only partial aspects of a complex debate on the issue of overall performance and sustainability of construction works. The consideration of the full life cycle and a complete calculation of resource consumption and environmental effects are important. However, for designers who already work their way into these complex issues, the engagement with issues related to embodied impacts in terms of primary energy consumption and GHG emissions is a perfect start.

Role of design professionals & consultants in the information flow & supply chain

Today, more than in the past, architects and engineers are confronted with requirements related to resource conservation, environmental protection and sustainability already from the early design stages. These requirements need to be taken into account and managed in addition to the traditional requirements for buildings.

Design professionals and consultants can encounter along the design and construction process issues related to the description, calculation and treatment of embodied impacts. On the one hand, clients are moving over to formulating requirements for sustainability as an addition to the requirements for technical, functional or design quality. This includes the setting of targets for the reduction of embodied impacts due to the construction and maintenance of construction works either in a direct way (by providing clear statements of targets for reducing embodied impacts or even setting specific target values) or an indirect way (by setting a specific sustainability level to be achieved). On the other hand, owners and investors, who have not yet started including this issue on their agenda, can and must be appropriately advised and actively supported by design professionals and consultants. The group of design professionals and engineers, in its attempt to accept its responsibility for environment and society, can use its power of influencing the design through for example the choice of specific materials and products, so as to minimize the amount of embodied impacts. These choices should be taken into account in the evaluation and selection of design alternatives.

Design professionals and consultants need to collaborate and exchange information with other groups of actors in order to fulfill their tasks. These groups are, among others:

- **Investors and building owners –** they make all decisions and take responsibility for the final result. In case they do not have the knowledge to formulate concrete requirements in relation to embodied impacts, they must be accordingly advised and supported by design professionals and consultants. They have to be informed regarding the nature and extent of the impact of design decisions on the amount of embodied impacts and also to be supported to include this additional aspect in their decisions.
- **Manufacturers of construction products –** they inform the decisions of designers by providing information on the environmental characteristics, service life and maintenance cycles of their products, in the form of EPD's or standard LCAs.
- **Contractors and builders** – they provide information to the design professionals and consultants on the type and scope of construction processes, selected technologies and supplies and partially communicate EPD's of building products to them.
- **Special design professionals and consultants/ auditors –** they advise and assist in the preparation of detailed estimates and/ or LCA.

Between these groups of actors the exchange of information must be organized and carried out in an appropriate manner. Other actor groups with which design professionals and consultants collaborative relationships may form are:

- **Tool and database developers** – they provide appropriate tools to support the work of the design professionals and consultants
- **Policy makers –** they formulate, for example, objectives and requirements in relation to embodied impacts and, if necessary, these are taken into account in respective funding programs.
- **Organizations promoting sustainability assessment and certification –** they request the data related to embodied impacts in order to include these in the assessment. In turn, they also make available data and tools.
- **Procurers –** they integrate requirements to reduce embodied impacts into the invitation to tenders, contracts and other documents. In this context, design professionals and consultants need to provide data and metrics/benchmarks for the embodied impacts of the project to this actor group.
- **Valuers –** they have started integrating more and more into their work the ecological value of the property. In most cases, they obtain information directly from the investor/client to form an opinion on the future value of the asset. In this case, it is advantageous if the design professionals and consultants have provided the clients with information on the embodied impacts e.g.

in the form of a “building file”. Valuers also work on behalf of **financiers** and **insurers**, who have an interest in the assessment of environmental impacts (including embodied impacts) and risks.

FIGURE 1 presents the main actor groups participating in the design process and how the information exchange between them and design professionals and consultants is realized.

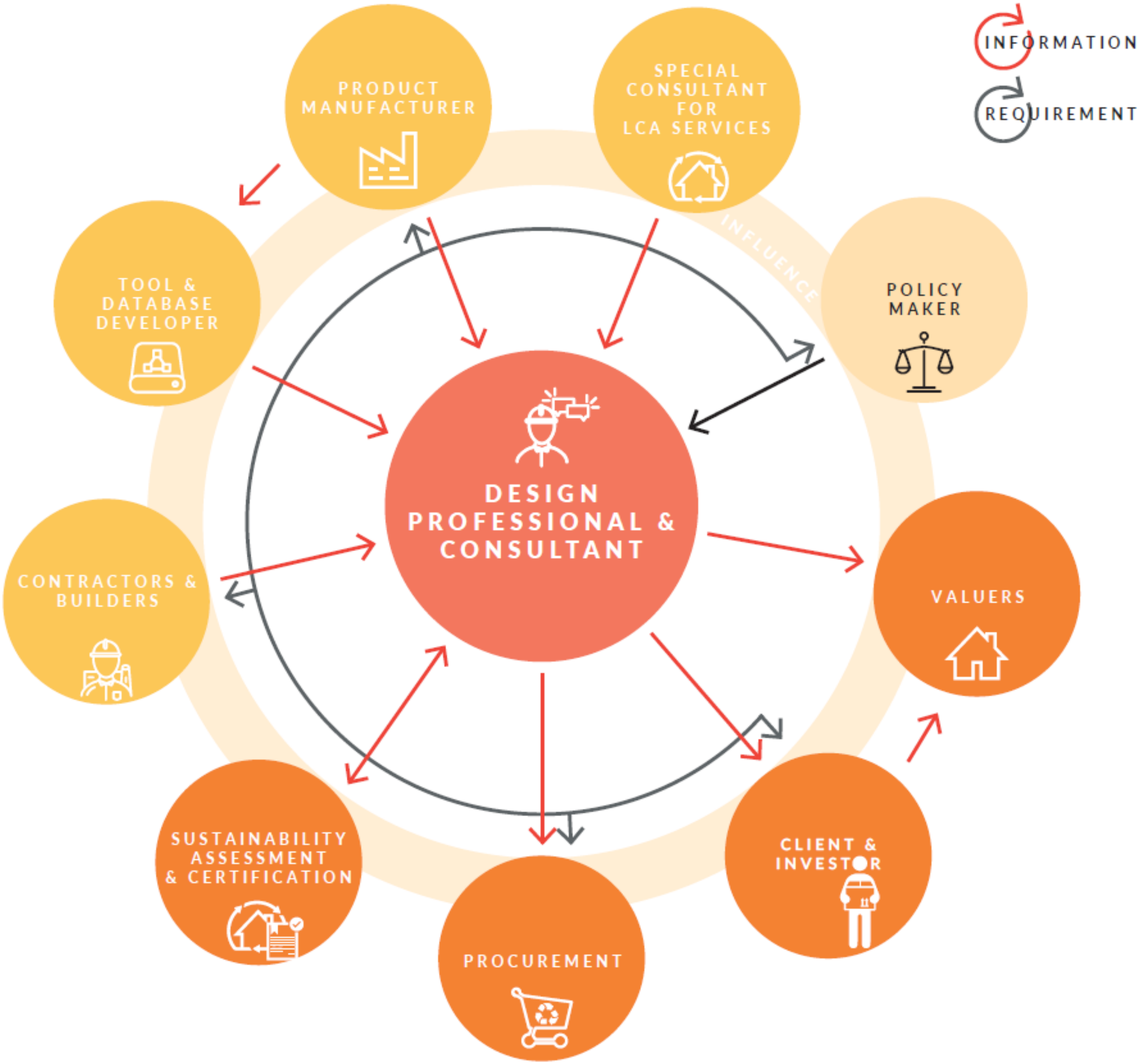

FIGURE 1: List of main actor groups and the flow of information between them and the design professionals & consultants

Integration of embodied impacts assessment into the design process

The importance of early intervention

RECOMMENDATION: The assessment of embodied impacts should start early in the design process. Target setting for embodied impacts should be done by the client already at the pre-design phase. Design professionals and consultants can support the client towards this direction.

The assessments of embodied energy and embodied GHG emissions are not one-off analyses but inform the design and decision-making process by highlighting areas that need action.

The assessment process of embodied impacts has a lot in common with the cost planning process that provides an inventory of all the materials, products, assemblies and elements within a building (e.g. using methods like Life Cycle Costing (LCC)). In the same manner as cost estimates, an embodied impacts assessment should start off with a target of embodied energy and embodied GHG emissions, which is usually estimated at an early stage and assessed and refined as the design evolves. Assessments should progress along the design process and should contribute to the appraisal of different design solutions, as well as to better informed decisions and procurement choices.

Again, it is important the different choices to be combined into an effective design strategy for achieving reductions in embodied impacts from the earliest design stages, as the opportunities for influence diminish during the development process, as well as the cost of changes becomes potentially higher.

So what designers can do about the situation?

In the early design phase the available information is often not sufficient for making a detailed assessment of embodied impacts. **TABLE 1** demonstrates in simple steps the potential for design professionals and consultants to influence the embodied impacts of a building along the project stages. Specifically, it lays out the key work stages of the design and construction of a building project and the most common decisions and tasks of design professionals and consultants associated with these project stages. Particularly, the third column of table 1 provides the recommended by Annex 57 course of action throughout the different phases, specifically related to the calculation and reporting of embodied impacts, and the forth column the type of instruments that can be used to assist design professionals and consultants in the fulfillment of their tasks.

TABLE 2 shows in more detail the choices that influence the embodied impacts in the course of design and tendering process with the most important and relevant for embodied impacts assessments being highlighted in orange. The final column includes embodied impacts 'checkpoints' to better incorporate specifically embodied impacts considerations into the process.

It should be noted that the project (management) life cycle begins already at the Concept/ Design Stage (Ao), thus earlier than the physical building life cycle (A1-C4) – check **FIGURE 2**. Planning and designing a building project taking into account the impacts of the entire building life cycle already from the initial phase of Ao (early design stages) is crucial for achieving reduced embodied impacts in subsequent life cycle stages. Especially the potential embodied impacts from the use stage and end of life stage are often neglected during the design process. Here, it is important to highlight that the environmental impacts of the design process itself (design stage), such as the energy consumption due to the operations in the architectural firm are not included in the assessment of embodied impacts.

TABLE 1: Steps on how design professionals and consultants can influence the embodied impacts of a project according to the stage of the design

PHASE	DESIGNER'S TASK	COURSE OF ACTION IN RELATION TO EMBODIED IMPACTS	TYPE OF INSTRUMENT
Pre-design stages (Client's brief)	Definition of general project goals and requirements, as well as formulation of building performance targets	Provision of assistance to clients via a discussion or checklist for the setting of project-specific targets, either more quantitative (e.g. "budgets" for EC and/or EG in the same manner as economic budgets or benchmarks) or more qualitative (e.g. specifications for the selection of construction products and methods), for the reduction of embodied impacts;	Benchmark values (e.g. sourced from within the design team/firm or the public domain/national standards) or validated rules-of-thumb/empirical values at building level
	Selection of assessment methods	Provision of assistance to clients in terms of reviewing options for formal assessment of embodied impacts (and other sustainability aspects)	National/international standards or building assessment/certification systems
	Decision on new construction or refurbishment	Provision of assistance to clients via a comparison and assessment of the two variants based on embodied impacts considerations along with operational impact considerations to support them in their decision-making	Reference values for building structures, construction methods, construction products, construction processes or case studies
Preliminary design stages (concept/ schematic design)	Decision on the underground construction/ size of the foundations	Examination of alternatives **at the building level** including considerations of embodied impacts	Systems providing average values of embodied impacts for various types of foundations and construction method
	Decision on the construction method and main building materials		
Design development (detailed/ coordinated design)	Optimisation of structural and environmental performance of building components	Examination of alternatives **at the component level** (e.g. load bearing structure, facade, windows) including the consideration of embodied impacts (e.g. web-based element catalogue)	Web-based element catalogue
	General material selection	Examination of alternatives **at the product groups level** including the consideration of embodied impacts (e.g. web-based information on building products and databases)	Product comparison tools Product databases
Preparation of contracts/ Tendering	Preparation of tender documents	Integration of requirements to reduce embodied impacts into the tenders for individual works; Demand for product and manufacturer specific EPDs or LCAs from manufacturers and suppliers	
Construction monitoring	Supervision of works	Determination of the actual installed products according to the type, quality and quantity Collection of specific EPDs or LCAs, quality assurance	Information on the type, quality and quantity of the installed products, EPD's
Object documentation	Preparation of building documents	Compilation of information on the type and quantity of installed materials including also information on the respective embodied impacts into a final document, as well as compilation of instructions for inspection, servicing and maintenance, as well as instructions for deconstruction and recycling	

TABLE 2: Main design tasks and embodied impacts checkpoints during the design and tendering process

PHASES	MAIN TASKS	CHECKPOINTS
PRELIMINARY DESIGN STAGES	**1. Choice of project (demolition, new construction, refurbishment)** 2. Choice of site and local interfaces (climate, utilities) **3. Choice of design concept (relation to the site, geometry, configuration of the premises, zoning, glazed parts)** **4. Choice of constructive systems** **5. Choice concerning the building's durability and adaptability** 6. Choice of the thermal performance of the envelope 7. Choice of energy supply systems	- Consider the embodied impacts of decisions 1-7 - Consider embodied impacts trade-offs - Set embodied energy and emissions target ("budget")
DESIGN DEVELOPMENT	**8. Choice of construction principle** **9. Choice of main building materials** **10. Choice of building components** 11. Choice of building concept (arrangement of rooms) 12. Choice of energy systems concept (e.g. optimization of façade) **13. Assessment of the consequences of end of life scenario** **14. Assessment of the consequences of maintenance cycles** **15. Choice of materials for surfaces and finishing elements** 16. Choice of building site equipment **17. Choice of construction and transport processes**	- Consider embodied impacts of choices 8-14 together with technical, commercial and other environmental criteria holistically to produce an overall design - Include embodied impacts assessment in all significant appraisals of design options - Update embodied impacts assessment based on the final cost plan - Incorporate embodied energy and embodied GHG emissions assessment into sustainability assessment
PREPARATION OF CONTRACTS/ TENDERING	**18. Choice of specific products (e.g. specification, sourcing)** 19. Choice of contractors (credentials)	- Determine procurement requirements with respect to embodied impacts - Check material specification, sourcing, documentation, etc. - Assess the credentials of contractors against the requirements for embodied impacts

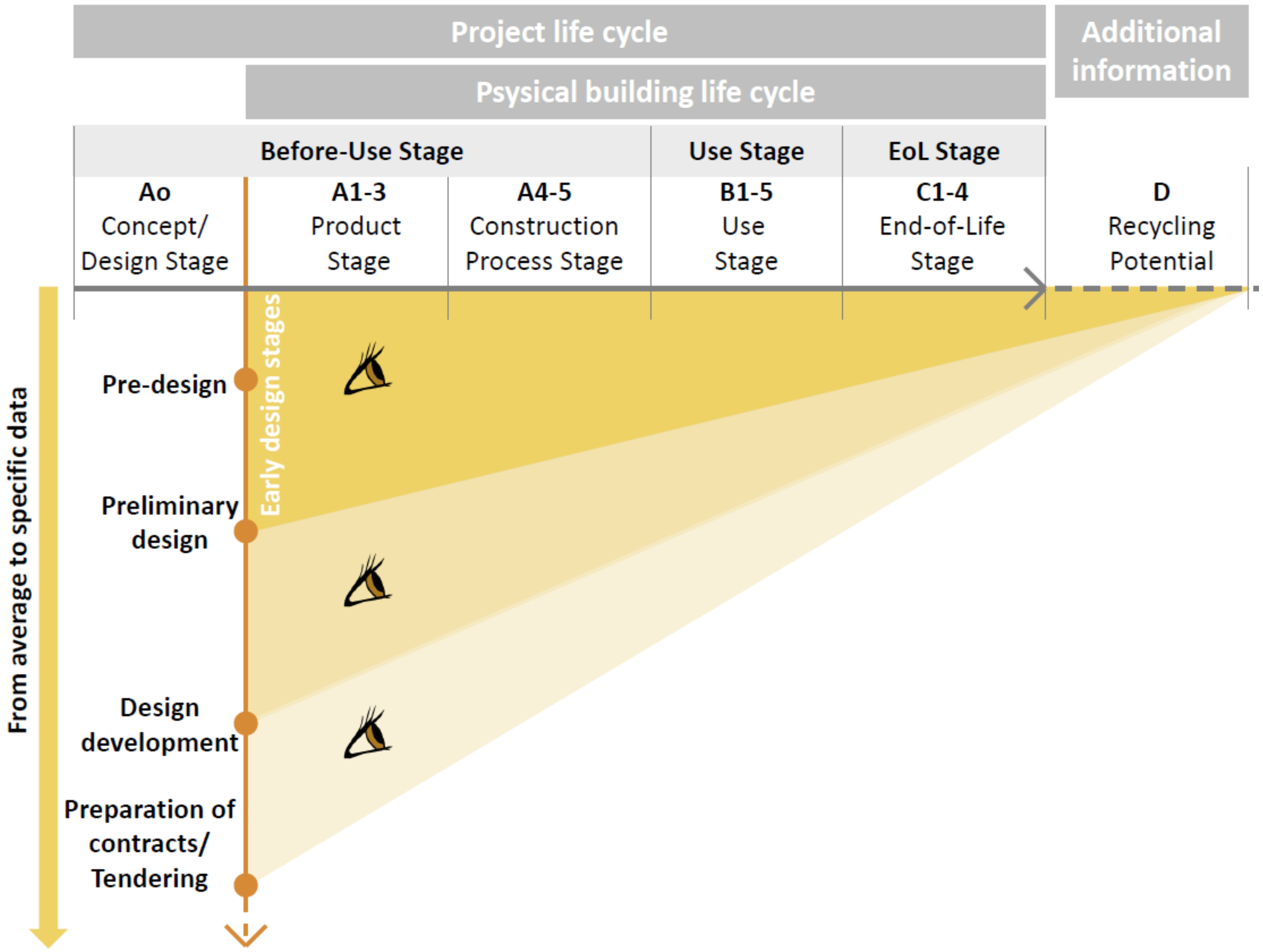

FIGURE 2: Relationship between project life cycle and building life cycle. The designer should consider the entire building life cycle in all phases of the Ao (Concept/Design) project stage – from the early design stages up to the final integration into contracts/tendering

What level of services designers can offer?

When dealing with LCA data one can differentiate as to whether the designer a) uses this for internal work, or b) prepares sustainability assessment reports that are delivered to the client or third parties.

a) Consideration of the embodied impacts in the selection of construction products and the comparison/ improvement of design variants

Currently a number of clients (e.g. developers, banks, investors, public authorities etc.) have started including requirements for the quantification and mitigation of embodied impacts in their projects. This is done mostly for competitive reasons, e.g. as part of their Corporate Social Responsibilities (CSR). Clients need to decide on the aims of EE and/or EG assessments they are commissioning, as well as to ensure that these aims are clear to the whole project team. In this sense, one of the most important services of the designer is to help clients in better target-setting and decision-making and show them how to improve and demonstrate the reduced embodied impacts of the project.

Additionally, inherent to the design process is comparative analysis among design options. Architects are required to answer specific design questions related to embodied impacts and make those comparative decisions on behalf of their clients. Such decisions can be facilitated by the use of LCA. Based on the level of decision and the required skills, a designer can be either a provider of building related LCA information or a user of LCA information and LCA-based assessment results. In this case, the designers are often supported by specialist consultants.

When dealing with LCA data a distinction can be made between the material/product level and the building level:

At the material/product level, designers are likely to be the users of product related environmental (LCA) information; thus, they may use this information to guide in their material and product selection process.

At the building level, designers may themselves be the LCA practitioners, using building-specific LCA tools to create LCAs that characterize the embodied impacts (among others) of proposed projects. However, EE and EG assessment services are currently largely separate from the design process and performed by external specialists. This can present challenges both to clients commissioning assessments and to design teams working on the buildings. If such assessments are only carried out by a specialist after the design has evolved/has been completed, the biggest opportunity to make decisions that could reduce embodied impacts is lost. Even if a specialist is appointed during the design phase, the possible lack of appropriate collaboration between the design and assessment teams may cause delays and misinterpretations.

b) Creation of assessment reports for the environmental or sustainability performance of buildings for the clients/third parties

The following section aims at helping designers to become more informed about the assessment process of these impacts, and encourage them to perform these types of assessments as an extra service to the client or to third parties. The benefits are that since this currently is not a common practice, it could give an architecture firm an edge over the others and increase its market value.

The preparation of assessment reports regarding the environmental performance or sustainability performance has become a task that may also be processed by a designer. Often, the calculation and assessment of embodied impacts is a subtask. Within the scope of this service an auditable report should be prepared. Special requirements shall apply for these reports according to ISO 21931-1:2010:

The report regarding the environmental performance of a building may be presented as documents and visual aids. The findings of all results shall be traceable and transparent. The assessment report shall include, but not be limited to, the following information and/or assumptions regarding:

a) general information:
   - purpose of the assessment;
   - identification of building (address, etc.);
   - client for assessment;
   - assessor;
   - assessment method, including version number and reference;
   - time of assessment in the building's life cycle;
   - life-cycle stages covered in the assessment;
   - period for which the assessment is valid;
   - date of assessment;
   - sources of information used in the assessment;
   - year of construction of building;
   - year(s) of refurbishment of building;

b) building:
   - functional equivalent;
   - general description of building;

c) assumptions and data limitations (It shall include details on assumptions made, and should document data quality issues);

d) Result (It shall include the results for the different indicators, including reasons for any information specifically excluded.)

e) Evaluation (it shall include the result of the evaluation process. Information on the methods for quantifying results shall be described);

f) Statement (A statement shall be given indicating the assessment method, e.g. in accordance with ISO 21931-1)

Both for the purpose of an internal use of the results and for the purpose of delivering the results to third parties, the following steps and guidance for the Assessment Process should be considered.

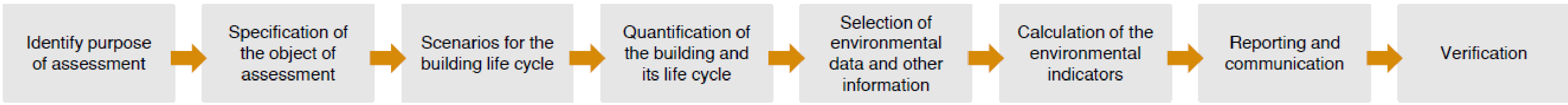

FIGURE 3: Illustration of assessment process (as defined in EN 15978:2011)

Assessment process

This section provides specific guidance on calculating and reporting the embodied impacts following the process for setting up the calculations required for the assessment as described in ISO 21931-1:2010 and EN 15978:2011 (**FIGURE 3**).

Identification of the purpose of assessment

RECOMMENDATION: The purpose of assessment should be clearly stated, as it defines the type, object and scope of the analysis.

As a first step of the assessment process of embodied impacts it is important to specify clearly the purpose of the assessment. This will influence and determine the type, object and scope of the analysis.

The purpose of an assessment may be among others:

- to compare the performance of different design alternatives in relation to embodied impacts – e.g. comparison between steel and timber frame;
- to identify the most impactful components in a building and the least energy and carbon intensive manufacturing and construction activities;
- to understand the trade-offs between embodied impacts and operational impacts;
- to determine the energy and GHG emissions offsetting, when for example, a net zero concept is applied;
- to report and communicate information on embodied impacts for the purposes of labelling, certification, marketing, etc.

Specification of the object of assessment

RECOMMENDATION: The object of assessment and the included lifecycle stages should be clearly described. It is recommended that the assessment includes all life cycle stages (cradle to grave) and additional information about the recycling potential is reported separately. Where the consideration of all stages is not possible, the "product stage" and "construction process stage" should be covered at the minimum (cradle to handover).

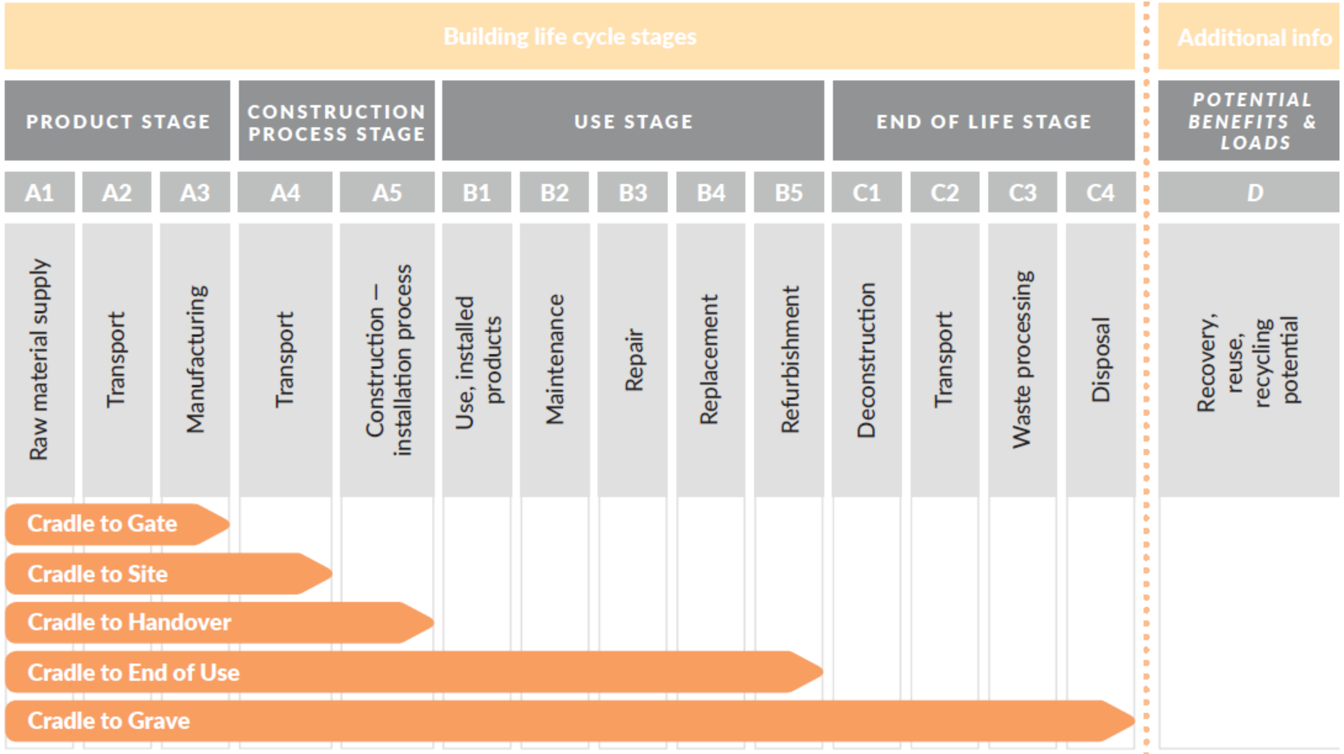

FIGURE 4: Illustration of the building life cycle stages in a modular structure (adapted from EN 15978:2011).

The spatial boundary specifying the part of the physical building that is included in an assessment may range from single building elements to neighbourhoods. This is referred to as the 'object' of an assessment. This should be clearly described and reported. Here, it is recommended that the object of assessment is only the building.

Where possible embodied impacts from all life cycle stages should be considered (*Cradle to Grave* approach – see **FIGURE 4**); if this is not possible, the system boundary *Cradle to Handover* should be used at the minimum, as it represents the initial embodied impacts of the building. More information on the different system boundary types is given in the detailed report "*Basics, Actors and Concepts*" that can be found here: http://www.annex57.org/.

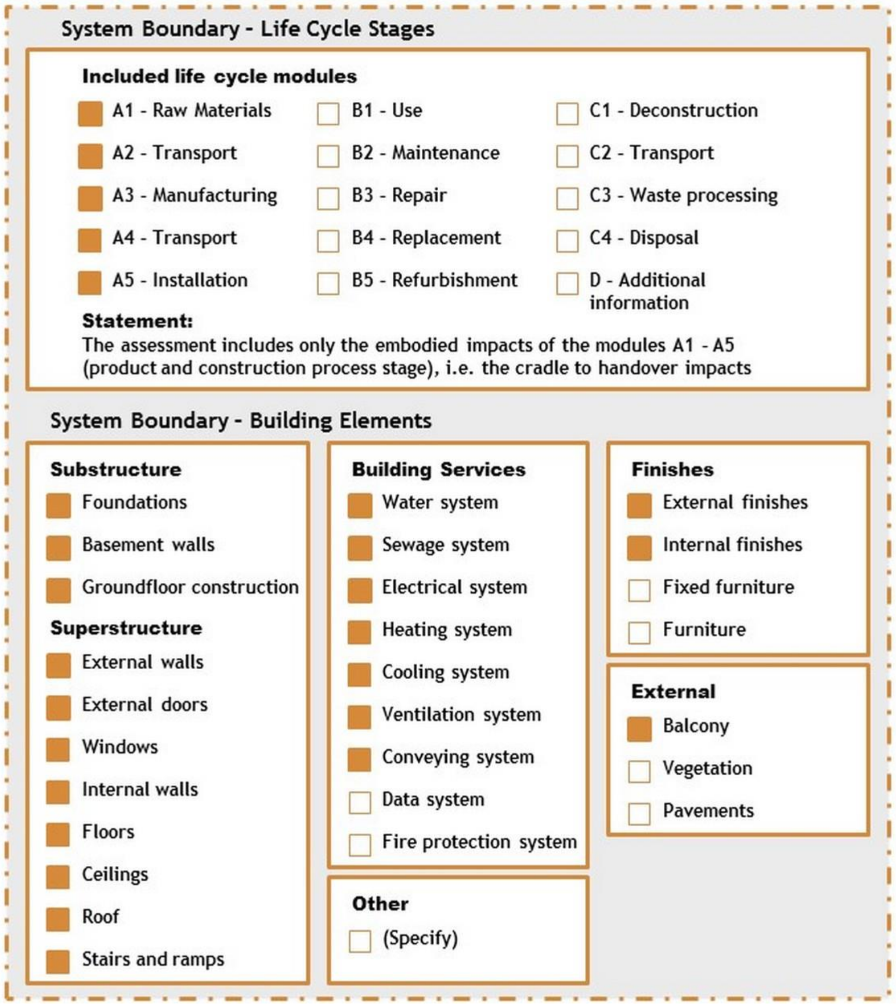

FIGURE 5: Example of a checklist to describe and report the system boundaries used in a study in terms of the covered life cycle stages and building elements

The *net benefits and impacts beyond the system boundary* (e.g. savings accruing to a second user from the use of recycled steel) may be quantified and if so they shall be reported separately as additional information. This is covered by module D in EN 15978:2011 (the same concept is also followed by

ISO 21929-1:2011). **FIGURE 4** provides an overview of what processes/modules to include in each life cycle stage specifically in terms of embodied impacts. Further guidance is given in EN 15978:2011 (a similar modular structure is also followed by ISO 21929-1:2011).

A clear statement is needed in order to define which building elements and building life cycle stages are included in the studied system and to allow comparisons between studies. **FIGURE 5** is an example of a transparent indication of the system boundary. The case studies template, as presented in chapter “Reporting”, also provides an example of such an indication.

The description of the object of assessment must also include, but not be limited to, the following information:

- Location/climate;
- Building type;
- Pattern of use (e.g. occupancy);
- Relevant technical and functional requirements;
- Required service life or design life;
- Reference study period

Scenarios for defining the building life cycle

RECOMMENDATION: The assumption and scenarios for future embodied impacts applied in the assessment should be robust and clearly described.

According to ISO 21931-1 and EN 15978 the scenarios should be fully described and documented as part of the assessment and should be based on currently used, technically and economically viable solutions.

Already from the early design stages scenarios should include:

- Description of the cleaning, maintenance, repair and replacement cycles for all building products and components taking into account the clients requirements, the service life of components, the pattern of use and manufacturer recommendations.
- Description of the end of life scenario – how the building will be deconstructed and how the various waste products, elements and materials will be treated after this point. These can be reused, recycled, combusted for energy recovery or landfilled.

Quantification of the building & modelling of its life cycle

RECOMMENDATION: The determination of quantities of products, materials and components should be based on the best available data at the time of assessment

The determination of the quantities of construction products, materials, components and elements constituting the building should be based on the best available data at the time of the assessment. These may range from rough estimates based upon the design description of the object of assessment (drawings) to predicted, or even actual, bills of materials. In all cases the assessment should consider the gross amounts of materials and products including all possible types of losses.

Depending on the point of the time of the assessment there are different types of data and information representing the object of assessment that can be used. Based on the analysis done in EN 15978:2011, these can basically be distinguished between:

- *generic data* that is typical of the types of structure and materials used;
- *average data* combined from different manufacturers or production sites for the same product;

- *product collective data* established for a type or a category of similar products (e.g. EPD or LCA at the association level);
- *product specific information* for the manufacturers' components or products used in the construction (e.g. EPD or LCA at the manufacturer level);
- *specific detailed information* (e.g. bill of quantities) for the actual products and components used and directly measured information for impacts "as built".

The data and information may be provided in an aggregated form either for the object of assessment as a whole (e.g. volume, height, floor area, energy consumption) or for major components (e.g. walls, floors, roofs) or in a disaggregated form for specific materials or components (e.g. bricks, plaster, flooring, windows, fixtures and finishes).

FIGURE 6 shows the type of data that may be used at different stages of the design and construction process of the building.

	Point of the time of the assessment		
Type of data	Pre- design stages	Design stages	Construction process stage
Aggregated data	■	■	□
Generic data	■	■	■
Average data	■	■	■
Product collective data	□	■	■
Product specific data	□	■	■
Detailed specific data/ measured data	□	□	■

FIGURE 6: Type of data for the quantification of the building and its lifecycle that is more likely to be used at different stages of the assessment

In early design stages, when the information on material quantities is limited, it is recommended to first source data for energy and emissions intensive materials or elements. A priority list of materials based on their wide spread use and high energy and emissions intensity can be found in the "*Construction CO_2e Measurement Protocol*" published by ENCORD (2012).

In addition, it is important to define the replacement frequency for all components and elements. This value is determined by dividing the design life or reference study period of the building by the estimated service life of each component that may be repaired or replaced. The value obtained should be always rounded up.

Note that Building Information Modelling (BIM) can assist already from the preliminary design stages of a project in determining the quantities of primary building materials. More information is given in chapter – "deciding which tools to use".

Selection of environmental data and other information

Once the data of construction materials and products quantities have been secured, the next step is to select appropriate databases, as well as energy and emission factors. This process is described in the respective chapter specifically dedicated to databases *“deciding which datasets to use”*. A general summary of the information requirements for the calculation of the embodied impacts across the different building life cycle stages (as described in **FIGURE 4**) is provided in **TABLE 3**.

TABLE 3: Summary of information (inputs) required for the embodied impacts calculation

BUILDING LIFE CYCLE STAGES		INFORMATION REQUIRED
A1-3 Product stage	**Raw materials supply**	- Quantities of construction materials and products (kg, m^3 or tonnes)* - "Cradle to gate" energy and emissions coefficients/factors for the different materials and products (MJ/kg and $kgCO_2eq/kg$)
	Transport	
	Manufacturing	
A4-5 Construction Process Stage	**Transport**	- Transport mode (litre/km) and distance (km) from factory gate to construction site - Energy and emissions coefficients/factors for different fuels used (MJ/litre and $kgCO_2eq$/litre)
	Construction - Installation Process	- Energy/electricity (kWh) and fuel consumption during construction (litre) - Emission coefficient for electricity ($kgCO_2eq/kWh$) - Energy and emissions coefficients for different fuels used (MJ/litre and $kgCO_2eq$/litre)
B2-5 Use Stage	**Maintenance**	- Energy/ electricity used for cleaning and inspections (kWh) - Emission coefficient for electricity ($kgCO_2eq/kWh$)
	Repair	*Similar as replacement but for smaller parts (see below)*
	Replacement	- Quantities of materials for replacement (m^3, kg or tonnes) - Energy and emissions coefficients for the different replacement materials and products (MJ/kg and $kgCO_2eq/kg$) - Service lives of materials/ components for replacement (years) - Transport mode and distance (km) from factory gate to site - Energy and emissions coefficients for different fuels used (MJ/litre and $kgCO_2eq$/litre) - Energy/electricity (kWh) consumption during installation - Emission coefficient for electricity ($kgCO_2eq/kWh$) - Transport mode (litre/km) and distance (km) from construction site to waste processing facility or landfill - Energy and emissions coefficients for different fuels (MJ/litre and $kgCO_2eq$/litre)
	Refurbishment	*Similar as replacement but at an extended level (see above)*
C1-4 End of Life Stage	**Deconstruction/ demolition**	*Similar as construction/installation process, but for deconstruction/demolition process*
	Transport	- *Similar as transport in construction process stage, but from construction site to waste processing facility or landfill*
	Waste processing	- Fuel consumption for processing and disposal of waste materials (litre) - Energy and emissions coefficients for different fuels (MJ/litre and $kgCO_2eq$/litre)
	Disposal	
D Benefits and Loads	**Recycling**	- Quantities of recycled construction materials and products to be recycled(kg, m^3 or tonnes)* - "Cradle to gate" energy and emissions coefficients/factors for the recycled materials and products (MJ/kg and $kgCO_2eq/kg$) - Remaining life as a percentage (%) of the predicted service life of the material to be substituted
	Energy Recovery	- Quantities of construction materials and products to be incinerated(kg, m^3 or tonnes)* - Calorific value of construction materials and products to be incinerated (MJ/kg) - Energy recovery rate (%)

**quantities of some materials not always have to be converted into weights as their embodied energy and carbon factors are often provided in other units (e.g. per brick, per m^2 or kWh for PV modules, per m^2 for paints and carpets, etc.)*

Calculation of the environmental indicators

RECOMMENDATION: The indicators used for the quantification of embodied impacts should be primarily the consumption of primary energy non-renewable, accounted in MJ, and the global warming potential, accounted in $kgCO_2eq$. The character and the scope of each indicator should be clearly described.

It is recommended that the quantified embodied impacts are represented by the following indicators:

ASPECT	CORE LIST OF INDICATORS	ADDITIONAL INDICATORS
EMBODIED ENERGY (MJ)	Consumption of primary energy fossil [PE_f]	Consumption of fossil fuels as feedstock
	Consumption of primary energy non renewable [PE_{nr}]	
	Consumption of primary energy total (renewable + non-renewable) [PE_t]	Consumption of biomass as feedstock
EMBODIED GHG EMISSIONS ($kgCO_2eq.$)	Global Warming Potential [GWP 100]	F-gasses as identified in Montreal Protocol
		Stored Carbon

However, it should be noted that different sources of energy can be included in the recommended indicators quantifying embodied energy, as well as different GHG emissions can be included in the $kgCO_2eq$.

A clear statement is needed in order to determine the exact character and scope of each indicator and allow comparisons between data. **TABLE 4** is an example of the parameters that need to be given for describing the character of each of the recommended indicators in a transparent way – specifically, PE_t and GWP are described here.
The exact description of the different indicators as recommended by Annex 57 is given in the detailed report "*Basics, Actors and Concepts*" that can be found here: http://www.annex57.org/.

The values of each of the recommended indicators should be calculated for each module and life cycle stage and be aggregated at the maximum level into cradle to handover impacts and cradle to grave impacts. As mentioned in previous chapters, benefits and loads beyond the system boundary should be reported separately. A summary of the typical calculation process to establish these values is given in **FIGURES 7 & 8**.

More detailed guidance on how to determine embodied impacts related to the individual stages of the building life cycle is given in **ANNEX A** of this guideline document.

TABLE 4: Example of a way of defining the character of the indicators used for the quantification of embodied impacts

CHARACTER OF THE INDICATOR PE_t	
Included non-renewable energy resources	Fossil fuels as energy Fossil fuels as feedstock (separately reported) Nuclear fuels
Included renewable energy resources	Biomass Biomass as feedstock (separately reported) Solar energy Geothermal energy Hydropower Wind power
Type of system boundary	Cradle to Grave + Module D (only as information)
Unit of measurement	MJ/reference unit/year of the RSP (e.g. 50 80, 100 years)
Reference unit	Gross Internal Area (GIA)
CHARACTER OF THE INDICATOR GWP	
Type of GHG emissions	Fuel related Non fuel related – process related emissions Non fuel related – F-gasses (separately reported)
Type of system boundary	Cradle to Grave + Module D (only as information)
Unit of measurement	$kgCO_2eq$ /reference unit/year of RSP (e.g. 50, 80, 100 years)
Included GHG emissions in CO_2eq.	GHGs as identified in the 5th IPCC report Freon gases as defined in Montreal protocol
Reference unit	Gross Internal Area (GIA)

Specifically, **FIGURE 7** summarizes the process of calculating cradle to handover embodied impacts. The first step is to calculate the total quantity of different materials and then multiply each by the relevant Embodied Energy (EE) and Embodied Carbon (EC) coefficient – often derived from databases (details are provided later in this guidance) – to obtain cradle to gate values. To estimate the cradle to handover value, allowance must be made for site and fabrication wastage, transportation from the factory gate to the site and construction activities associated with installing the material or product. This can add between 5-20% of the total, depending on the type of materials used, where they are sourced from and the level of construction activity. All the values for each material or product are added together to give the cradle to handover values for the building.

After calculating cradle to handover embodied impacts, **FIGURE 8** shows the continuity of the calculation routine in order to obtain cradle to grave values of embodied impacts. In case quantified information on net benefits of recycling or energy recovery needs to be reported, a typical calculation process is presented in **FIGURE 9**.

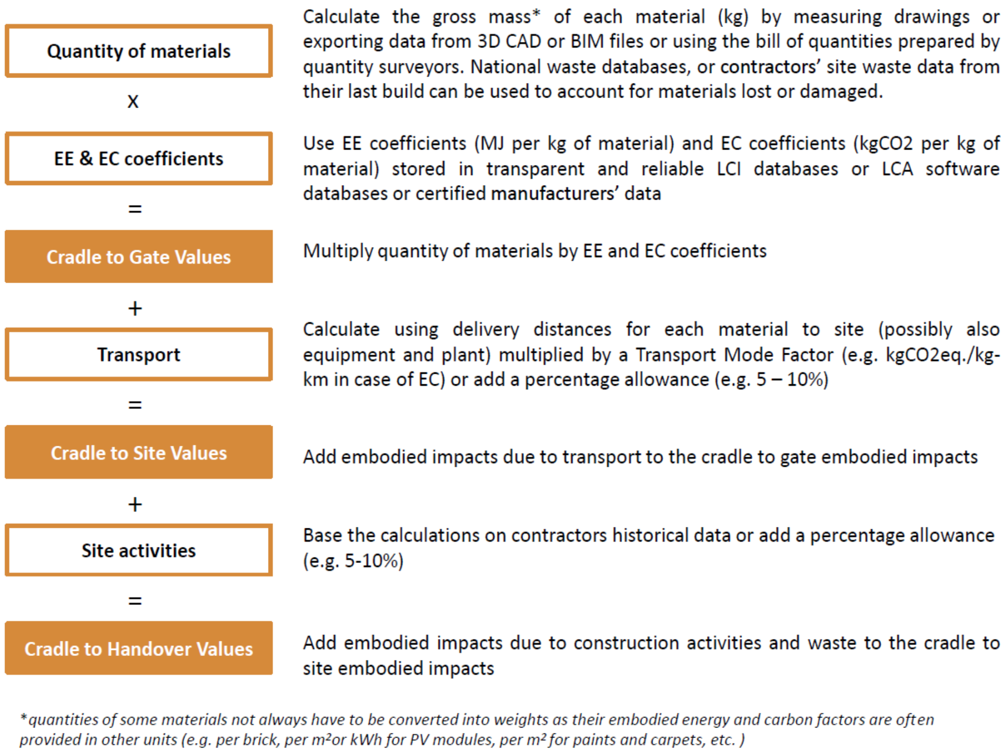

FIGURE 7: Typical process to calculate cradle to handover values of embodied impacts

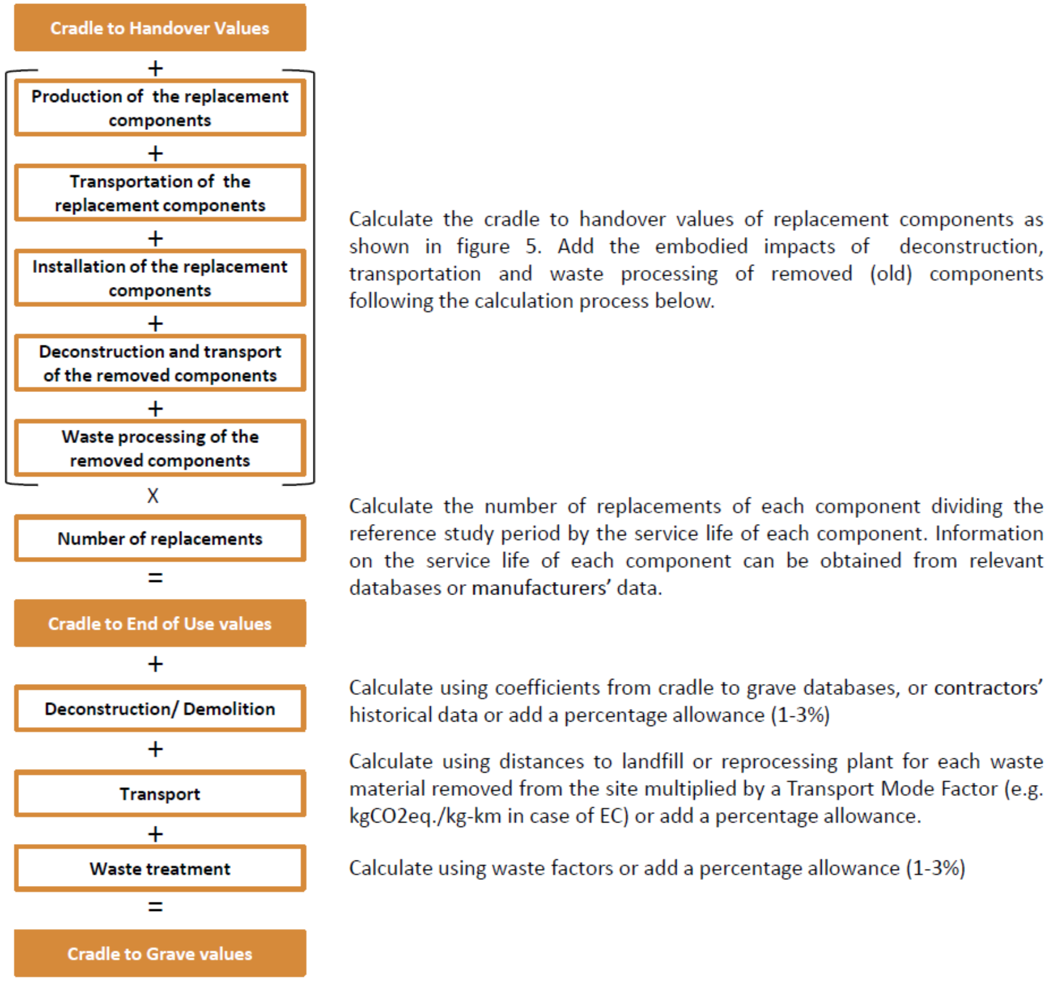

FIGURE 8: Typical process to calculate cradle to grave values of embodied impacts

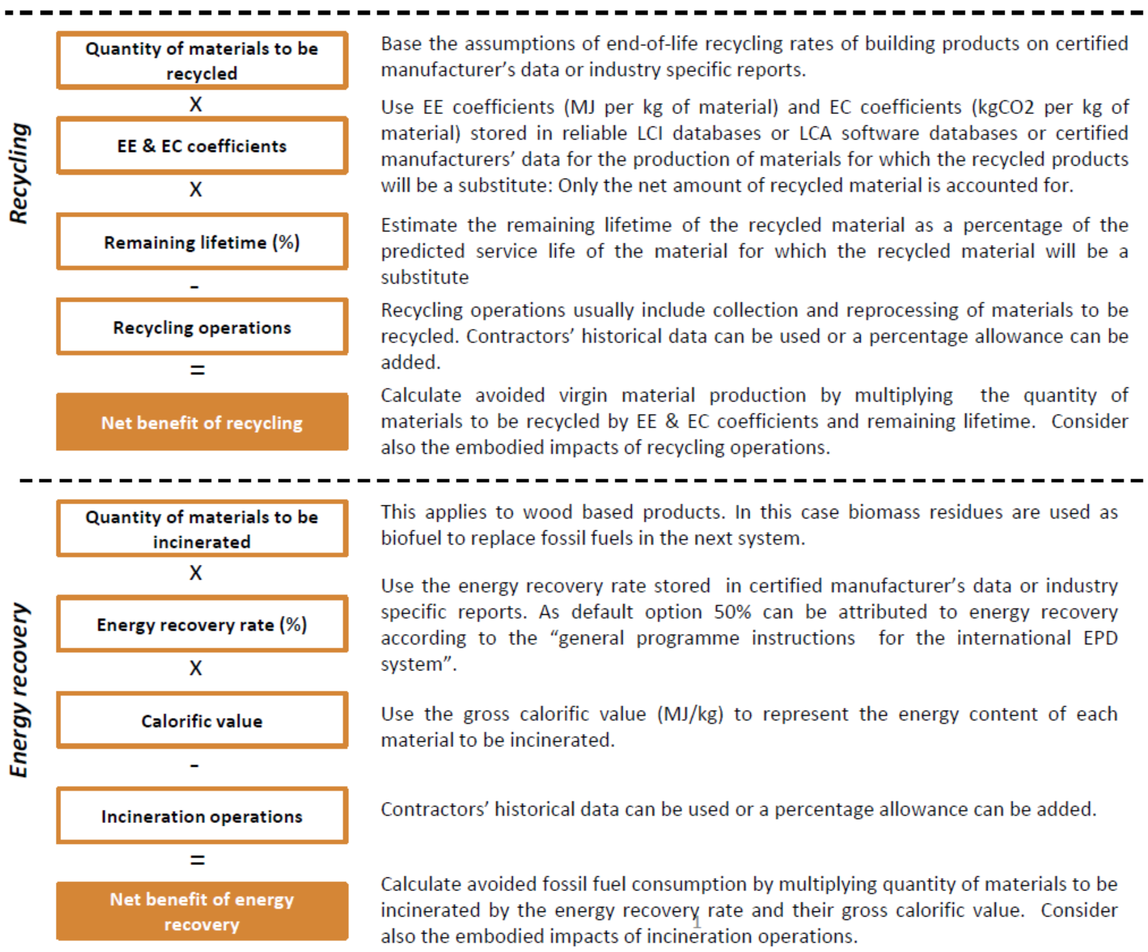

FIGURE 9: Typical process to calculate net benefits of recycling and energy recovery

Reporting and communication

RECOMMENDATION: The reporting and communication of the embodied impacts assessment results should be in accordance with the outline suggested here.

So far this guideline document has given emphasis on the documentation of the object of assessment, the assumptions, the character of the indicators used for the calculation and the data sources. A reporting template has been designed (**TABLE 5**) to promote a consistent reporting and communication of results and better comparability of results coming from different case studies.

Comparability of the assessment results

In many cases, the assessment results from different case studies cannot be directly compared with each other, as the methodologies and calculation principles applied are influenced by the purpose and scope of the assessment. Standards alone do not enable fully comparable results, as they do not define detailed principles especially for the assessment of embodied impacts. Some of the most important factors that affect the comparability of the embodied impacts assessment results are summarized here:

Embodied energy and GHG emissions database for materials

In any case, the most appropriate data sources are transparent LCAs established using the same protocol (modelling rules) or, if not available, EPDs of construction products prepared with ideally the same product category rules. When this is not possible, relevant data from general databases should be used. Note that data, calculation methods, tools and benchmarks are strongly linked and can lead to reasonable assessment results only when used together as an inseparable unit.

System boundary

As mentioned before, one consistent way of defining the system boundary in terms of life cycle stages is by referring to the stages defined in EN 15804:2012 and EN 15978:2011. The coverage of the assessment in terms of building-related constructions and technical equipment can be defined with the help of the items given in **FIGURE 4** of this guideline.

Method for quantifying the embodied impacts

The most appropriate indicators for the quantification of embodied impacts are the primary energy consumption of non-renewable resources and the global warming potential. As described previously, this alone is not sufficient to guarantee comparability of results. Additional information on the character and scope of each indicator is required (**TABLE 4**). Furthermore, information is required about the service life of the different building components and products.

Note that in any case, the functional equivalent of the buildings and building parts compared with each other should be the same.

TABLE 5: Reporting template – minimum documentation requirements for better communication and comparability of results (developed by T.Lützkendorf, M.Balouktsi, A. Passer, & R.Frischknecht)

PARAMETER	DESCRIPTION OF THE CHARACTERISTICS OF THE OBJECT AND ITS ASSESSMENT
Location/ climate and or heating degree days/ cooling	e.g. Germany/ moderate climate
Building/ Usage type/ intensity of use	school building, 200 students, hours of operation 08.00 –18.00, includes a sport hall
Energy-standard	(“net positive” during the use phase, expressed in “primary energy equivalents”)
Gross floor area/ Net floor area	e.g. 726 m^2/ 615 m^2
Gross volume/ Net volume	
Reference area for EE/EC	e.g. energy reference area … 535 m2
Construction method	e.g. Structural steel frame supporting precast concrete floor slabs
U-values of the building envelope	
Ventilation system	
Heating and cooling system	
Final energy demand electricity	Appliances, lighting, services, etc. (kWh/m2a)
Final energy demand for heating and hot water / energy carrier(s)	(kWh/m2a)
Final energy demand for cooling	(kWh/m2a)
Purpose of assessment	e.g. to determine the energy and GHG emissions offsetting, when a net zero concept is applied
Assessment methodology	e.g. according to EN 15978:2011 guidance
Reference Study Period	e.g. 50 years
Included life cycle stages	e.g. cradle to handover (use a checklist, as the one shown in figure 5, to describe in detail which modules/ processes are included
Included parts of the building	e.g. use a checklist, as the one shown in figure 4, to describe in detail which parts of the building are included

PARAMETER	DESCRIPTION OF THE CHARACTERISTICS OF THE OBJECT AND ITS ASSESSMENT
Scenarios and assumptions used for construction process stage	....
Scenarios and assumptions used for use stage	....
Scenarios and assumptions used for EoL stage	e.g. recycling at the end of life
Databases used (if any)	e.g. KBOB-recommendation 2009/1:2014, ökobau.dat or EPD of program ...
Other data sources	e.g. EPD’s from manufacturers
LCA Software used (if any)	e.g. LEGEP
Method of materials quantification	e.g. BIM Architecture
Name/type of the indicator(s) used	use table 4 for reporting the character of the indicator used
Additional indicators assessed	

Practical considerations

Carbon sequestration in wood-based products

One of the special characteristic of wood-based building products (and other bio-based products such as straw or hemp) is biogenic carbon contained in them. Biogenic carbon refers to the carbon absorbed from the atmosphere and stored in a growing tree via photosynthesis. The accumulation of stored carbon is known as carbon sequestration. Carbon sequestration is an often-claimed benefit of using wood-based products in construction.

Claiming this benefit is dependent on many assumptions; for example, that at the end of service life these materials will not be buried in landfill, breaking down into greenhouse gases (carbon dioxide and methane). Due to this uncertainty, some practitioners choose not to include sequestration in their embodied carbon reports.

According to EN 16485:2014, in case the biomass used can be assumed to originate from sustainable forest sources, biogenic carbon emissions can be regarded as zero based on the idea of biogenic carbon neutrality. In fact this is balanced during natural decay or incineration of the products. However, it can be included in the assessment result as additional environmental information (EN 16449).

Here it is recommended the reporting of carbon sequestration, but not their inclusion in the overall embodied impacts analysis as “credits”.

New construction vs refurbishment

Every existing building “represents” embodied impacts related to its product, construction and maintenance. Through the refurbishment, modernization or reconstruction of existing buildings their useful life can be extended and so their embodied energy can be utilised for a longer period of time. This can contribute to the reduction of energy and material flows that would be consumed in a different case for the replacement of an existing building by a new one. However, the overall impact of the decision of replacing an existing building on the life cycle energy and emissions depend much on whether the new building provide a significant improvement in operating energy efficiency

Thus, note that when comparing the two variants, (refurbish or demolish and replace) the both – the demand for additional embodied energy and the specific energy consumption for operation should always be included in the calculation.

High thermal mass materials

Adding large thermal mass materials in the design may increase the impacts of production stage, while lowering at the same time the impacts of operational stage due to reduced cooling/heating demand. For this reason, the impacts of design decisions should always be considered on embodied and operational impacts together rather than separately.

Imported materials

In case imported materials are planned to be used in a building, a designer should either:

- try to investigate the origin of the material, estimate the transport distance between the importing and exporting country and ask for EE and EG data from the manufacturer, or
- apply appropriate data from national databases

No matter what the selected approach is, designers should ensure this is documented and declared in a transparent way that allows comparability. The examination of import-export flows from a macroeconomic perspective is not considered as an option here.

Deciding which standard to use

RECOMMENDATION: The calculation and reporting of embodied impacts should be based on ISO 21929-1:2011 or EN 15978:2011.

There are already various national and international standards that can be used for “embodied energy” and “embodied GHG emissions” assessments. For example in Europe voluntary standards have already been developed by the CEN/TC 350 committee related to Sustainability of Construction Works. The standards aim to encourage a harmonized approach within construction industry for describing and assessing the life cycle environmental, economic and social performance of buildings. The respective international standard is ISO 21929-1:2011. It is therefore recommended specifically in this guidance for building designers the standard EN 15978:2011 or ISO 21929-1:2011 to be used at the building level for the purposes of assessing embodied impacts as part of the total environmental performance.

FIGURE 9 maps out all the existing international and national framework, building and product related standards.

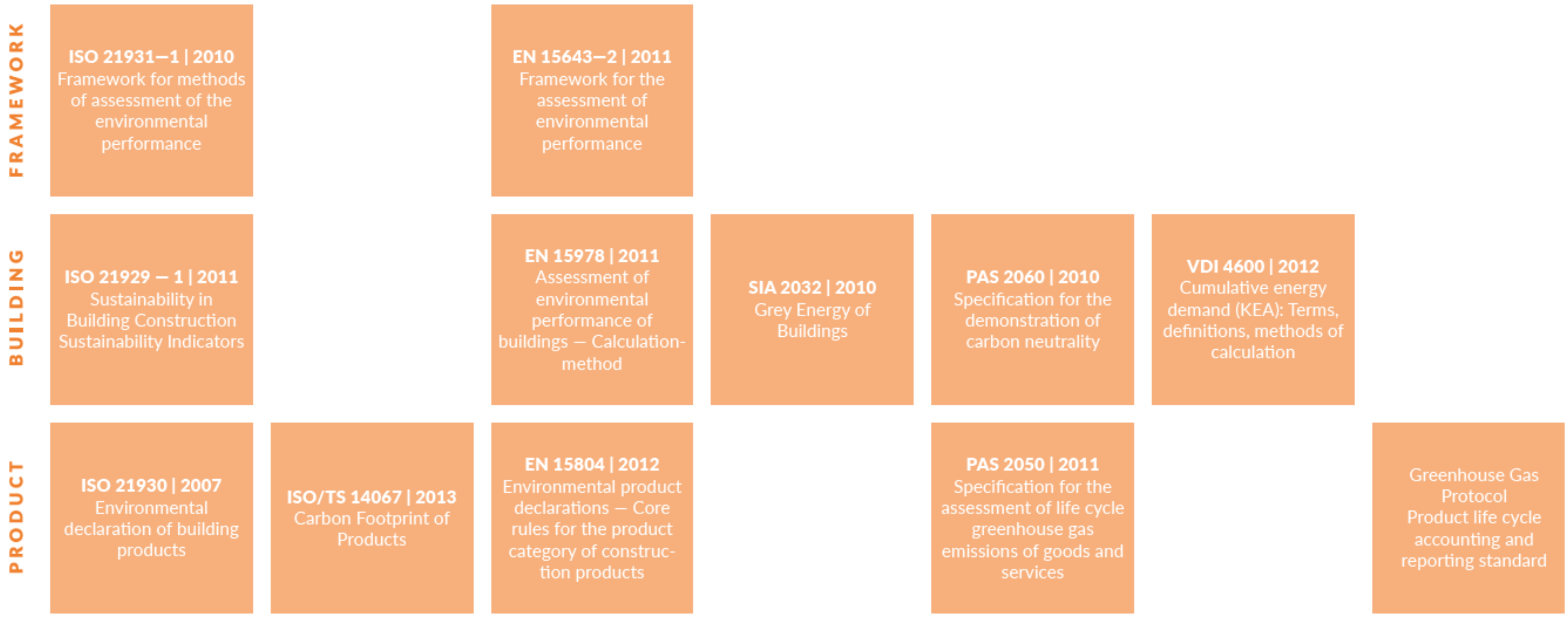

FIGURE 9: Mapping of existing standards related to embodied energy and emissions calculation and reporting (selected examples)

Deciding which dataset to use

RECOMMENDATION: Transparent databases, complete LCAs, or if not available, quality checked EPDs should be used as the main source of data. When not possible, the selection of databases and data (energy and emissions factors) for use should be subject to a quality assessment. The quality of data that have a large impact on the results should be reported.

The most important prerequisite for the assessment of embodied impacts of a building is that relevant information is available on embodied energy and GHG emissions of building materials. However, this information should be reliable to allow useful comparisons between building products, or between building materials.

At present, not all construction product data are collected using consistent boundaries of assessment, and product specific data from manufacturers are not always comparable with the more generic product data. This is also due to the different data sources. A distinction can be made between

- data and databases for scientific purposes that comply with high quality standards
- data from the literature with unclear origin
- freely accessible databases that were created and are being maintained with public funds, and therefore they are subject to a quality control (e.g. ökobau.dat)
- commercial databases with/without (external) quality control (e.g. Ecoinvent, GaBi)
- information published by professional associations with/without (external) quality control
- information published by individual manufacturers with/without (external) quality control

The transparency and traceability of the available published data cannot always be sufficiently ensured. One example of consistent generic and manufacturer specific LCI data is the KBOB-recommendation 2009/1:2014 in use in Switzerland.

In general, many countries are in the process of developing or have already developed embodied energy (EE) and embodied GHG (EG) emissions data for building products. Most of data exist as life cycle inventory (LCI) data format rather than EE or EG itself.

As databases are continually being developed and updated, it is not possible to provide an explicit list in this guidelines document. Some examples are provided in the Annex 57 ST3 report. However, here

guidance is given to find and select databases, as well as to assess the data from the chosen databases.
A list of online LCA databases is provided by the Greenhouse Gas Protocol http://www.ghgprotocol.org/Third-Party-Databases, as well as by the Joint Research Centre of the European Commission http://eplca.jrc.ec.europa.eu/ResourceDirectory/databaseList.vm

In case national LCI data are not available, another source of product data is an Environmental Product Declaration (EPD). EPDs are independently verified, robust and cover generic and product-specific data. Environmental product declarations are worked out according to a standardized process defined in EN 15804:2012 and EN 15942:2011, and present information on the GWP, primary energy resource use and other environmental aspects based on the life cycle approach. In EPDs for construction products the inclusion of cradle to gate data is mandatory, while the full life cycle analysis is voluntary (cradle to grave).

To provide comparable information, EPDs must have the same product category rules as set out in EN15804 and are valid for 5 years only. The information should also be relevant for the case. EN 15942 defines a specific structure for the reporting of information and thus requires data transparency.

Some comprehensive examples of construction product related EPDs from different countries can be found catalogued on the web: (International EPD system) www.environdec.com, (Germany - IBU) www.bau-umwelt.de, (France – INIES) www.inies.fr, (UK – Green Book Live) http://www.greenbooklive.com/search/scheme.jsp?id=9.
It is important to note that usually there are no process based LCI data for complex product systems, such as equipment and machinery. Thus, in case there are no EPDs available for these systems (e.g. examples can be found in Ökobau.dat or EPD International) input-output based data can be used. As there is a trend towards net-zero energy buildings, it is important especially for PV systems to have good quality data.

The assessment of the quality of the data set to be used is very important. A few questions to use in the selection of a database are listed in the report of GHG Protocol "*Product Life Cycle and Accounting and Reporting Standard*":

1. Are the process data from a collection of actual processes or estimated/calculated from other data sources?
2. Were the data developed using a consistent methodology?
3. For agricultural and forest products, are land-use impacts included in the LCA emissions data? If yes, what impacts are included?
4. How long has the database existed, and how extensively has the database been used?
5. How frequently is the database updated?

6. How current are the data sources used for developing the LCA emissions data?
7. Can uncertainties be estimated for the data?
8. Is there any risk that the data will be perceived as biased and, if so, have the data and methodologies been independently reviewed?

Once an appropriate database(s) is selected, design professionals and consultants are required to perform a data quality and "fit-for purpose" assessment also of the individual secondary data chosen from the selected databases. The same report of GHG Protocol identifies 5 important data quality indicators (**TABLE 6**). It is recommended the outcome of any data quality assessment performed to be documented to assist the interpretation of the results and highlight areas for future improvement.

TABLE 6: data quality indicators – adapted from GHG Protocol report "Product Life Cycle and Accounting and Reporting Standard" (2011)

INDICATOR	DESCRIPTION
Technological representativeness	The degree to which the data set reflects the actual technology(ies) used
Temporal representativeness	The degree to which the data set reflects the actual time (e.g., year) or age of the activity
Geographical representativeness	The degree to which the data set reflects the actual geographic location of the activity (e.g., country or site)
Completeness	The degree to which the data is statistically representative of the relevant activity. Completeness includes the percentage of locations for which data is available and used out of the total number that relate to a specific activity. Completeness also addresses seasonal and other normal fluctuations in data.
Reliability	The degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable.

Deciding which tool to use

Nowadays, design professionals and consultants are not required to aggregate data and perform LCAs manually. There are many web-based and software tools that can be used at different stages of the design process to assist them in this task. A diverse range of tools is available, e.g.:

Interactive databases or web-based element catalogues
They usually contain a database and a simple calculation web-based tool (no software installation is required). For example 1 m² of a specific element can be calculated just by inputting the thickness of each layer. Different material choices for layers are provided. With very little effort and time different solutions can be compared with each other. However, note that the background information (data quality) needs to be transparent. Examples of such tools are Bauteilkatalog developed by SIA (Swiss Society of Engineers and Architects) and LEGEP, a tool for integrated life cycle analysis developed by Ascona.

LCA-based design tools
They measure environmental performance of products using LCA data and usually allow users to create and model their own custom assemblies and configurations. Note that in many cases they are tied to specific dataset(s) and/or calculation methodologies.

Building information modelling (BIM)
The software-based BIM organizes and relates physical or financial information to the building. For example, CAD developer like Autodesk included BIM in the software product Revit. LCA data are mass related so BIM softwares can easily include also LCA information. The level of support from IFC4 language (Industry Foundation Classes) for different indicators was investigated by the European project SuPerBuildings, where it was found that especially the indicators "consumption of primary energy non-renewable" and "global warming potential" are directly and explicitly supported by the IFC (http://cic.vtt.fi/superbuildings/sites/default/files/D6.3_0.pdf). Although the concept sounds simple, the implementation of LCA data in BIM is not common yet. Lots of new applications are expected to be developed towards this direction over the next years (e.g. plug-in softwares that be used for adding embodied impacts data to a 3D model to carry out calculations).

Note that the selection of calculation tool is less important than the choice of data, standard or methodology, as the latter are more likely to cause variations and lead to inconsistent results. A quick overview of the tools that are currently available can be found in IEA Annex 31 (http://www.iisbe.org/annex31/pdf/M_directory_tools.pdf).

A few questions to consider when choosing a tool are listed in the "*AIA Guide to Building Life Cycle Assessment in Practice*" published in 2010:

1. What is the configuration of the tool? Does it embed a LCI database and impact assessment method within or are these two required separately?
2. What type of tool is it? Material/Assembly/Whole-Building LCA tool?
3. What life-cycle stages are accounted for in the tool?
4. What is the level of expertise required for using the tool?
5. What inputs are required? What is the method of input?
6. What are the outputs obtained from the tool? What are the options to view the outcome/results?
7. How capable is the tool in terms of interoperability? Will it accept databases from other sources? Are the outcomes of the tool compatible with other analysis and documentation tools?
8. What kind and number of building assemblies and materials that can be evaluated by the tool?
9. What impact categories can be evaluated if the tool has an impact assessment model embedded within?
10. Does the tool provide normalized results?
11. What is the latest version of the tool?
12. How much does the tool cost?

Conclusions and discussion

In the recent years building-related standards and regulations have concentrated mainly on reducing operational impacts without much consideration of embodied impacts (energy and GHG emissions). As a result, buildings are becoming more and more efficient in terms of energy and emissions during their operation. The interest has now been shifted towards embodied impacts where the reduction potential has not been investigated yet to such an extent.

Unfortunately, there is still no consensus on exactly how embodied energy and GHG emissions should be defined, calculated and assessed. Different assumptions and boundary conditions are used which leads to widely differing results. Undertaking such assessments is not as straightforward as it may seem and without a standard methodology, agreed rules and available data, clients cannot be assured of consistent and evidenced results.

In this guideline, a basic understanding about the assessment of embodied impacts at the building level for participants in the building industry – particularly design professionals and consultants – was established.

Operational and embodied impacts work hand in hand. Acquiring a complete understanding of both aspects allows design teams to create the best possible design solutions and specifications for a low energy and emissions building.

Design recommendations to achieve reductions in embodied impacts have been included in a special guideline document.

Glossary

BIM	Building Information Modelling – a detailed 3 D model of a building including data on all of the components
Cradle to Gate	This boundary includes only the production stage of the construction products integrated into the building. Processes taken into account are: the extraction of raw materials, transport of these materials to the manufacturing site and the manufacturing process of the construction products itself.
Cradle to Site	Cradle to gate boundary plus delivery to the site of use.
Cradle to Handover	Cradle to site boundary plus the processes of construction and assembly on site.
Cradle to End of Use	Cradle to handover boundary plus the processes of maintenance, repair, replacement and refurbishment, which constitute the recurrent energy. This boundary marks the end of first use of the building.
Cradle to Grave	Cradle to handover plus the use stage, which includes the processes of maintenance, repair, replacements and refurbishments (production and installation of replacement products, disposal of replaced products) and the end of life stage, which includes the processes of demolition, transport, waste processing and disposal.
CO2eq.	CO2 equivalent - a unit of measurement that is based on the relative impact of a given gas on global warming (the so called global warming potential).
Embodied Energy	*Embodied energy* is the total amount of non-renewable primary energy required for all direct and indirect processes related to the creation of the building, its maintenance and end-of-life. In this sense the forms of embodied energy consumption include the energy consumption for the initial stages, the recurrent processes and the end of life processes of the building.
Embodied GHG emissions	*Embodied GWP* is the cumulative quantity of greenhouse gases (CO_2, methane, nitric oxide, and other global warming gases), which are produced during the direct and indirect processes related to the creation of the building, its maintenance and end-of-life. This is expressed as CO_2 equivalent that has the same greenhouse effect as the sum of GHG emissions.
GHG	Greenhouse gases - they are identified in different IPCC reports
Global Warming Potential	A relative measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is measured against CO2e which has a GWP of 1
IPCC	Intergovernmental Panel on Climate Change

Sources of further information

Guidelines and initiatives from various organisations

American Institute of Architects (AIA) – AIA Guide to Building Life Cycle Assessment in Practice, United States, 2010, http://www.aia.org/

Australian Government – Information paper part of Your Home Australia's Guide to environmentally sustainable homes: *Materials – Embodied Energy*, Australia, 2013, http://www.yourhome.gov.au/materials/embodied-energy

Construction Products Association (CPA) – A guide to understanding the embodied impacts of construction products, UK, 2012, http://www.constructionproducts.org.uk

European Network of Construction Companies for Research and Development (ENCORD) – Construction CO_2e Measurement Protocol: A Guide to reporting against the Green House Gas Protocol for construction companies, 2012, http://www.encord.org/

Royal Institute of Chartered Surveyors (RICS) – information paper: *Methodology to calculate embodied carbon of materials*, 2012, http://www.rics.org/Documents/Methodology_embodied_carbon_final.pdf

RICS guidance note: *Methodology to calculate embodied carbon in a building's construction life cycle*, draft of 2013, https://consultations.rics.org/

UK Green Building Council (UK-GBC) – Tackling Embodied Carbon in Buildings, UK, 2015, http://www.ukgbc.org
UK-GBC Practical how-to guide: *Measuring Embodied Carbon in a Project*, UK, 2015, http://www.ukgbc.org/

Waste and Resource Action Programme (WRAP) – Information sheet for construction clients and designers: *Cutting Embodied Carbon in Construction Projects*, UK, 2011, http://www.wrap.org.uk,
WRAP guidance for low-carbon building projects and estates management: *Procurement requirements for carbon efficiency*, UK, 2011, http://www.wrapni.org.uk/

Standards

ISO/TC 59/SC 17 is series of voluntary standards for assessing the sustainability in buildings and civil engineering works.
http://www.iso.org/iso/home/standards_development/list_of_iso_technical_committees/iso_technical_committee.htm?commid=322621

CEN TC350 is series of voluntary standards for assessing the sustainability of construction products at building level which are currently being developed by the European Commission, www.cen.eu/cen/Sectors/Sectors/Construction/SustainableConstruction/Pages/CEN_TC350.aspx

Greenhouse Gas Protocol - Product Life Cycle Accounting and Reporting Standard. World Resources Institute – WBCSD, http://www.ghgprotocol.org

PAS 2050 is a Publicly Available Specification (PAS) for a method for measuring the embodied greenhouse gas emissions from goods and services.

Tools and data sources (publicly available)

ATHENA Impact Estimator for Buidlings is a whole-building tool used by design teams to explore the environmental footprint of different material choices and core-and-shell system options. It was first released in 2002. It is regionally customised www.athenasmi.org/our-software-data/impact-estimator/

KBOB-recommendation 2009/1:2014 contains a list of environmental indicator results of building materials, building services, energy supply, transport services and waste management services related to buildings. It quantifies the embodied energy (total and non renewable), the greenhouse gas emissions (IPCC 2013) as well as the overall environmental impacts expressed in eco-points according to the ecological scarcity method 2013. It covers manufacture and disposal. Background data are accessible ensuring as much transparency as possible.

BRE"s Green Guide to Specification. The UK construction products sector has worked with BRE over the past 15 years to develop a LCA database for nearly 2,000 of the most significant and common products used in constructing buildings. This database includes information on all stages of the life cycle, including disposal, and has been developed to a consistent methodology (BRE Environmental Profiles Methodology) based on data provided by industry. The data are being made available at www.bre.co.uk/greenguide.

BuildCarbonNeutral is a Construction Carbon Calculator that helps developers, builders, architects and land planners approximate the net embodied carbon of a project's structures and site. www.buildcarbonneutral.org

CapIT Carbon and Cost Estimator is an online system allowing users to estimate cost and embodied carbon values for construction activities. www.franklinandrews.com/publications/capittool/

The Environment Agency has developed a free calculator for estimating the carbon footprint from construction materials and activities on site. www.environment-agency.gov.uk/business/sectors/37543.aspx

ECOproduct is a method and a database assisting in environmental selections of materials and products within a project. ECOproduct was developed by a co-operation between SINTEF Building and Infrastructure, Norsk Byggetjeneste and NAL-Exobox.

www.sintef.no/home/Building-and-Infrastructure/Buildings/Climate-and-Environment/ECOproduct---Environmental-selection-of-building-materials-and-products/

INIES. Consulter les Fiches de Déclaration Environnementaleet Sanitaire (FDES) des Produits de construction.

http://www.inies.fr/IniesConsultation.aspx

Institut Bauen und Umwelt e.V. (IBU) Environmental product declarations (EPD). http://bau-umwelt.de/hp481/Environmental-Product-Declarations-EPD.htm

Learning legacy: Lessons learned from the London 2012 Games construction project Olympics 2012 is a report that sets among others benchmarks for embodied carbon for different types of sporting venues, based on best practice results, www.learninglegacy.independent.gov.uk

Ökobau.dat database in Germany – only available in German http://www.nachhaltigesbauen.de

openLCA a free, professional Life Cycle Assessment (LCA) and footprint software with a broad range of features and many available databases, created by GreenDelta http://www.openlca.org/

SNARC is a system developed by the Swiss national association of engineers and architects (SIA) for the assessment of environmental sustainability of architectural projects at the initial design concept stage www.eco-bau.ch/resources/uploads/SNARCD.pdf

The European Life Cycle Database (EU Joint Research Centre). The ELCD comprises Life Cycle Inventory (LCI) data from front-running EU-level business associations and other sources for key materials, energy carriers, transport, and waste management.
http://eplca.jrc.ec.europa.eu/ELCD3/

ANNEX A. Guidance for the determination of embodied energy (EE) and embodied GHG emissions (EG) related to the individual stages of the building life cycle

MODULE	PROCESSES USUALLY INCLUDED ACCORDING TO THE STANDARDS	PROCESSING INSTRUCTIONS	SOURCE OF INFORMATION
A1-3 PRODUCT stage	"Cradle to gate" processes for the materials and services used in the construction	Information on type and amount of used products is gathered at building level. The quantities of used building materials and products are estimated (in early design stages) or calculated (during design) by the designers. In all cases the assessment should consider the gross amounts of materials and products including all possible types of losses (e.g. due to transport (A2)). The estimated/calculated quantities of average/ specific products are multiplied by energy and emission factors or by product-related EE- and EG- data.	Materials quantities can be sourced from: Reference cases Empirical Estimations Architectural Drawings Bill of quantities Tender documents REVIT/BIM National waste databases or contractors' site waste data from their last building can be used to account for materials lost or damaged at this stage. Energy and Emissions factors/coefficients or product-related EE- and EG-data are obtained from sources like databases, I/O-tables, EPD's, manufacturer declarations, etc.

A4 – Transport	A4 - Transportation of products and materials from the factory gate to the construction site A4 - Transport of construction equipment (e.g. cranes, scaffolding, etc.) to and from site	It has to be decided and declared whether this module is: *neglected *estimated * or accurately determined When using EPD's and databases it can be checked whether data for the transport share (A4) is included. A general estimation can be made on the basis of: *a percentage allowance (e.g. % of A1-A3) *average transport distances For an accurate determination of this module assumptions must be made about the type and distance of transport. The already determined materials quantities for A1-A3 (in some cases also equipment and plant) must be multiplied by characteristic values for transport.	Table for average transport distances Energy and Emissions factors or EPD's for different transport modes and transport services
A5 – Construction/ Installation Process	A5 - Storage of products, including the provision of heating, cooling, humidity control, etc. A5 - Waste processing of the waste from product packaging and product wastage during the construction processes up to the end-of-waste state or disposal of final residues.	It hast o be decided and declared whether this module is: *neglected *estimated * or accurately determined	Tables with EE and EG related information for construction processes EE- und EG-factors or data for electricity, different types of fuels, etc.

	A5 - Installation of the product into the building including manufacture and transportation of ancillary materials and any energy or water required for installation or operation of the construction site. It also includes on-site operations to the product.	When using EPD's and databases it can be checked whether data for the construction/installation process share (A5) is included. A general estimation can be made on the basis of a percentage allowance (e.g. % of A1-A3) For an accurate determination of this module assumptions regarding the type and scope of the required construction works /construction processes to be carried out must be determined and be multiplied by values describing EE and EC. Alternatively, the consumption of energy on the site can be estimated and multiplied by EE and EC-factors or data.	
B1 – Use ***Note: Please do not mix up the modules "Operational Use" (B6) and "Use" (B1) – B1 has to do with the dangerous substances emitted to indoor air from building materials***	Release of substances from the facade, roof, floor covering and other surfaces (interior or exterior), which may have an impact on the climate and thus, they must be part of GWP.	This information is usually not included in the determination and evaluation of the embodied impacts. Only in exceptional cases , when e.g. F-gasses are used for the insulation (as blowing agents) and refrigeration systems, this can be taken into account It must be determined whether construction products are used, which emit greenhouse gases in the use phase. If yes, information on these individual products is gathered at building level. It must be further examined whether these emissions have already been assigned to A1-A3.	Information is obtained from: • Specific Product Manufacturer Information • Databases with construction product data • Empirical values

B2 – Maintenance ***Examples: painting work of the window frames, doors, etc., the annual inspection and maintenance of the boiler, etc.***	All processes for maintaining the functional and technical performance of the building fabric and building integrated technical systems, as well as aesthetic qualities of the building's interior and exterior components.	It has to be decided and declared whether this module is: *neglected *estimated * or accurately determined The designers have to make assumptions about the products and processes for maintenance Including cleaning. (e.g. cleaning/ maintenance cycle, default average transport distances, etc.)	Energy and Emissions factors for different materials/ products and processes can be sourced from: National databases Commercial databases EPD's Manufacturer declaration
	All cleaning processes of the interior and exterior of the building.		
	The production and transportation of the components and ancillary products used for maintenance.		
B3 – Repair ***Example: For a window with a broken pane, this includes waste generated by the pane, production, transportation of a new pane and all impacts due to the repair process (rubber seal, etc.).***	The production of the repaired part of component and ancillary products.	When describing EE and EG (embodied impacts) repair, replacement and refurbishment should not be neglected. The distinction between B3, B4 and B5 cannot always be accurate. The information included here can be • roughly estimated, or • accurately determined. B3-5 information can be determined either on the basis of percentages or by using specific information on individual products and systems. In a concrete calculation the impacts of transport (A4) and installation processes (A5), as well as deconstruction processes (C1), transport (C2), waste processing (C3) and disposal (C4) for the repaired/replaced/new building components must be considered. (If recycling is possible/ likely to happen, a recycling potential can be specified separately in module D).	Service life of building parts and components can be sourced from national databases or be calculated according to national or international standards Energy and Emissions factors for different transport modes and services, energy sources and fuels are sourced from: National databases EPD's for electricity EE- and EG- data for the installation and deconstruction processes EE- and EG- data for transport (from the factory gate to the site and from the site to the waste processing plant)
	The transportation of the repaired part of component and ancillary products, including any losses of materials during transportation.		
	The repair process of the repaired part of component and ancillary products.		
	Waste management of the removed part of the component and of ancillary products.		
	The end of life stage of the removed part of the component and of ancillary products.		
B4 – Replacement ***Examples: Replacement of a partition wall, replacement of a***	The production of the replaced component and ancillary products.		
	The transportation of the replaced component and ancillary products, including any losses of materials during transportation.		

heating system or boiler, replacement of a window (frame, glass), etc.	The replacement process of the replaced components and ancillary products.	The designer or consultant has to make assumptions/ use scenarios formulated for repair /replacement/ refurbishment. Information on type and amount of individual products (repaired parts for B3, replaced components for B4 and new building components for B5) is gathered at building level. The number of replacements of each component has to be calculated by dividing the reference study period by the service life of each component.	For B3-5 at the building level detailed calculation of (repaired/replaced/new) construction products are required for the modules: A1-A3, A4, A5, B1, B2, C1-4 Or alternatively: Averages/ percentages
	Waste management of the removed component and of ancillary products.		
	The end of life stage of the removed component and of ancillary products.		
B5 – Refurbishment ***Examples: A major change of the internal layout (partitioning) and/or the building envelope, change of the HVAC technical systems, modifications for the purposes of a planned or expected change of use.***	Production of the new building components.		
	Transportation of the new building components (including production of any materials lost during transportation).		
	Construction as part of the refurbishment process (including production of any material lost during refurbishment).		
	Waste management of the refurbishment process.		
	The end of life stage of replaced building components.		
C1 - Deconstruction	On-site operations and operations undertaken in temporary works located off-site as necessary for the deconstruction processes after decommissioning up to and including on-site deconstruction, dismantling and/or demolition.	It has to be decided and declared whether this module is: *neglected *estimated * or accurately determined For the processing of C1-C4 modules scenarios for deconstruction, transport, waste processing and disposal of the building must be described.	Energy and Emissions factors for different transport modes, energy sources and fuels, as well construction products are sourced from: National databases EPD's for electricity EPD's for products (usually values for C3-4)
C2 - Transport	Transportation to disposal and/or until the end-of-waste state is reached, including also transport to and from possible intermediate storage/processing locations.		

<table>
<tr><td>C3 – Waste processing</td><td>Collection of waste fractions from the deconstruction and waste processing of material flows intended for reuse, recycling and energy recovery.</td><td rowspan="2">On this basis, end-of-life assumptions can be made

Information on the type and scope of deconstruction and the quantities of materials to be recycled and to be landfilled is provided at the building level

Where data are not available, a percentage allowance can be applied (e.g. % of A1-3)</td><td rowspan="2"></td></tr>
<tr><td>C4 - Disposal</td><td>Neutralisation, incineration with or without utilisation of energy, landfilling with or without utilisation of landfill gases, etc.</td></tr>
<tr><td rowspan="3">D – Net benefits and loads beyond the system boundary</td><td>Recycling</td><td rowspan="3">Module D contains optional information about recycling potential. It applies only when the scenarios defined in C1-C4 allow recycling.

Information on individual products are gathered at building level

In the case of recycling, the avoided virgin material production may be calculated by multiplying the quantity of materials to be recycled by EE & EG factors and the remaining lifetime (a percentage of the predicted service life of the material for which the recycled material will be a substitute). Recycling may also be modelled with the recycled content approach.

In the case of energy recovery, the avoided fossil fuel consumption can be calculated by multiplying the quantity of materials to be incinerated by the energy recovery rate and their gross calorific value.</td><td rowspan="3">EPD's for products
Industry reports
Contractor's historical data</td></tr>
<tr><td>Energy recovery</td></tr>
<tr><td>Sequestration</td></tr>
</table>

In summary, it can be stated that the following information is required for an accurate calculation of embodied impacts:

- type and quantity of used products
- characteristic values for the used products regarding their production
- characteristic values for the products regarding their requirements for cleaning and maintenance, as well as their service life
- characteristic values for the products in terms of greenhouse gases emissions occurring during the use stage
- Characteristic values for the products in terms of recycling options
- transport processes (to and from the construction site)
- construction processes (installation process, deconstruction process and disposal)

Assumptions are required in relation to the:

- type and intensity of use
- service life
- Type of construction/installation (in situ or prefabrication & installation)
- Cleaning, maintenance cycle
- Repair, replacement and refurbishment cycle
- Deconstruction scenario
- Recycling Scenario

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EBC is a programme of the International Energy Agency (IEA)

iea Energy Technology Network