VASEK

Life cycle thinking as a part of design choices

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Summary

Construction and built environments have a significant impact on both the Finnish economy and our environment. Climate change and loss of biodiversity are among the most central challenges of our time, and all sectors of society must implement measures to not only mitigate but to adapt to them.

The choices and decisions made during the design stages of construction projects have a long lasting impact on our environment. Life cycle thinking represents a way that allows us to take all of these impacts into account in a holistic manner. This is done by assessing the impacts of different products and services from the procurement of raw materials up to their deployment. The goal of life cycle thinking is to avoid a situation where the efforts to minimise aderse effects in one part of the process end up increasing them in another. In the context of construction, life cycle thinking may also provide cost savings in addition to environmental benefits, as the costs of different building solutions are assessed in terms of the total lifespan of the building in question instead of simply looking at investment costs.

This workbook provides the reader with a handy guide on their journey into the world of life cycle thinking and teaches them how to apply it in the design and implementation of construction projects. In addition to the most central concepts of this way of thinking, the workbook also presents practical examples of how life cycle thinking can be applied in different projects.

The workbook has been edited by AINS Group experts Salla Saukkoriipi, Leevi Aihos, Maija Mattinen-Yuryev, Roosa Leino and Hannele Ahvenniemi.

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Glossary

Life cycle carbon footprint	Life cycle carbon footprint refers to the climate impact a product or project has during its life cycle. The life cycle carbon footprint of a building is comprised of the emissions generated during the manufacturing of products, the use of the building and the energy used, as well as the demolition work at the end of the life cycle.
Life cycle stage; module	Describes a single activity that generates emissions during the life cycle of a building or part of a building. A stage in the building's life cycle in accordance with standard 15643.
Life cycle assessment (LCA)	Life cycle assessment. A scientific method to analyse and assess the total impacts of a product or service throughout its life cycle.
Life cycle costing (LCC)	The aim of life cycle costing is to reflect the costs incurred by the building owner throughout its lifecycle. Life cycle costs measure the cost arising from the building all the way from land acquisition to demolition.
Carbon budget	The maximum total or limiting value set for all greenhouse gas emissions arising from the building during its life cycle.
Carbon footprint	Describes the climate impact of a product or service. The unit used for carbon footprints is carbon dioxide equivalent (CO2e).
Carbon handprint	The sum of potential climate benefits created by a product or service expressed as carbon dioxide equivalents.
Climate declaration	A standardised and verified way of presenting the positive and negative climate impacts of a product, i.e. both its carbon footprint and carbon handprint.
Climate statement	The Finnish Ministry of the Environment is currently preparing a decree delineating how climate statements for buildings should be prepared and what methodology should be used for determining the life cycle of a product or service as low-carbon. A climate statement would report the carbon footprint and handprint in accordance with the principles specified in the decree.

Greenhouse gas	A gas that absorbs the sun's energy in the atmosphere, thereby accelerating global warming. Greenhouse gases include gases such as carbon dioxide, methane and CFCs.
Convertibility	Preparing to convert the space or building to match future needs through different design and use solutions. Enhancing the multifunctionality of buildings and facilities is a key part of convertibility
One Click LCA	Commercial life cycle assessment software.
Design for deconstruction	Designing buildings to be deconstructed in a manner that enables sorting the resulting materials for materials recovery
Product stage	A life cycle stage that consists of procurement of the raw materials used for the building materials, transport, and the manufacture of the final product (modules A1–A3).
Environmental classification	The environmental classification of a building presents a reliable way to assess and verify the environmental performance of a site and to compare it with that of other sites. Classification systems generally used in Finland include criteria and standards such as RTS, BREEAM, LEED and the Nordic Swan label.
The Ministry of the Environment's method for the whole life carbon assessment of buildings	A method developed by the Ministry of Environment for assessing the carbon performance of buildings. The draft method (2021) is used in parallel with the draft regulation and explanatory memorandum on the climate statements of buildings. The final guidance for the method will be published once the regulation enters into force.
Environmental product declaration, EPD	A standardised and verified way of presenting the environmental impact of a certain product. The impact is assessed based on a life cycle assessment of the product.

1. Background and purpose of this workbook

Key points

- Construction is a significant factor in terms of both the environment and the economy. In order for construction to be sustainable, the whole life cycle of the building must be taken into account from the requirement assessment stage onwards.
- Construction sector operators have so far applied life cycle thinking to reach a competitive advantage in the market.
- Life cycle thinking means assessing the impacts of buildings over their entire life cycle, from the procurement of raw materials up to demolition and disposal of materials.
- When applied during the design stage, life cycle thinking presents an effective way of minimising the environmental and cost impacts of construction projects.
- The cost and environmental impacts of projects can be optimised most effectively during the early stages of the project. In addition to an overall low carbon performance, life cycle thinking also serves to increase the service life and cost effectiveness of buildings.

As humans, our actions impact both our local environment and the world around us as a whole. Nowadays, we are well aware of the extent to which challenges related to mitigating climate change and adapting to its effects and the scarcity of natural resources limit our future actions. Construction has both significant immediate and long term effects on the environment. Choices made during the design stage affect the construction phase, the long use and maintenance phase, as well as the demolition, materials recycling and disposal at the end of the building's life cycle.

Material choices made in this stage of the process affect a number of aspects of the overall process: the thermal insulation capacity of the building, the achieved living comfort, convertibility, maintenance and repair costs, as well as how ecologically or affordably the building can be demolished or renovated. A building that has been designed well and in accordance with the principles of life cycle thinking is a cost effective solution for both the developer and the end user.

In addition to minimising costs, life cycle planning aims to optimise a variety of other characteristics related to the project, and especially to fully utilise any benefits that may be reaped. In addition to cost and environmental perspectives, factors considered in life cycle design may also include matters related to areas such as safety, user health, convertibility and modularity.

1.1 Industry views on life cycle planning

Oskari Jokikokko ja Markus Karhu, Arkta Rakennus Oy

"Decisions made during the design stage have far-reaching effects that span the entire life cycle of a building. The design stage includes significant decisions that affect the carbon footprint, carbon handprint and energy consumption of a building. This is why it really pays off to incorporate life cycle thinking into your building design process. Smart choices during the design stage may, for example, reduce the building's energy consumption, which will directly affect its carbon footprint and housing expenses in the longer run.

Both investors and consumers are aware of the environmental issues at play, and this awareness extends to the construction process itself as well. We need to be able to offer products that are as low carbon as possible, since they are currently considered far more attractive than old housing stock. Wood construction has allowed us to gain better access to plots. Carbon footprints of products and services are becoming increasingly important for all fields of commercial activity. By incorporating carbon footprint, handprint calculation and life cycle thinking into their operations early on, entrepreneurs can improve the future competitiveness of their businesses.

Reports should not be compiled simply for the sake of reporting. It really pays off to take full advantage of the data included in these reports and to integrate them into the company's guidance for designers."

Johanna Saarela, NAL Asunnot Oy

"Construction consumes enormous amounts of energy and natural resources. It is therefore important that we design buildings that have a long useful life and are as high quality as possible. At NAL Asunnot, the properties we construct remain in the company's ownership, which means that we also focus on ensuring that the apartments can be used for a long time and will be able to offer their occupants a high standard of living comfort long into the future. At the same time, we must take into account the maintenance and repair aspects of apartments in addition to their sustainability. Systems must generally be relatively maintenance free and as easy and cost effective to maintain as possible.

Construction and buildings account for about one third of Finland's emissions. The *climate impact of buildings must be taken into account throughout their life cycles. A large part of the emissions that arise from built environments are the result of use phase energy consumption: how buildings are heated, cooled down, lit, and so on. For this reason, the choices made during the design phase have such a large impact on the carbon footprint of a building. Now that we know what the carbon footprint baseline of our new properties is, we aim to incorporate even more low carbon options in our future projects and utilise more low carbon design solutions."*

1.2 Environmental and cost impacts of construction and infrastructure

The construction sector has a significant impact on the economy and the environment: up to two-thirds of our national wealth is tied up in built environments, and currently, just under half of our energy consumption is related to built environments (figure 1).

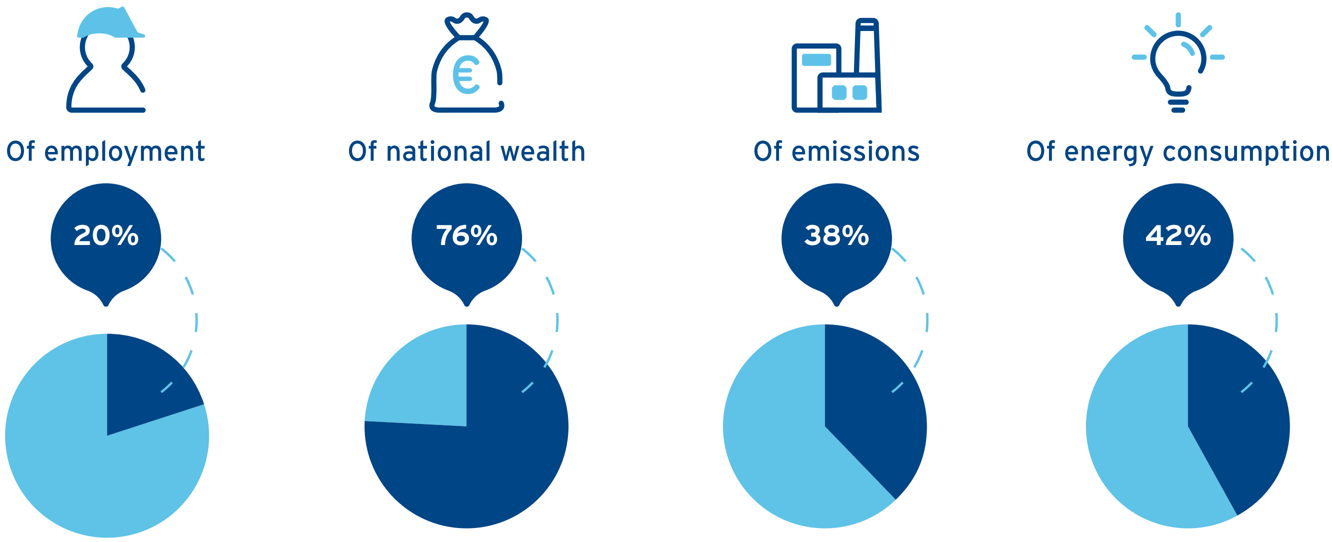

Figure 1. The construction sector's impact on the Finnish economy and environment (source: publications of the Confederation of Finnish Construction Industries RT)

1.3 Principles of life cycle thinking

Life cycle thinking means assessing the cost and environmental effects of products and services throughout their whole life cycle, from procurement of raw materials to their disposal. It aims to assess the effects and impacts of a product or service in a holistic manner at all stages of the life cycle. The goal of this way of thinking is to avoid situations where harmful impacts or material or ener-gy consumption or costs would increase in one part of the product chain as a result of being reduced elsewhere. The key to reducing life cycle impacts is therefore to look at the product value chain and all aspects of this chain. In addition to reducing environmental impacts, life cycle thinking can also deliver significant economic benefits.

The life cycle of buildings begins with raw material procurement, followed by the actual construction process. After the construction process has been completed, the building enters its useful life, during which it is maintained, repaired and renovated. At the end of its useful life, the building is dismantled and the materials used are recycled and, if necessary, further processed and disposed of. This constitutes the final stage of the building's life cycle (C) (Figure 2). When talking about the life cycle of buildings, the different stages of the life cycle are generally divided into modules signified by letters A to C (Figure 2). The modules cover the life cycle of the building from building products (product phase A1-A3) to construction (A4-A5), use phase (B) and end of life (C). The life cycle stages take into account the effects of necessary material and energy inputs and transport.

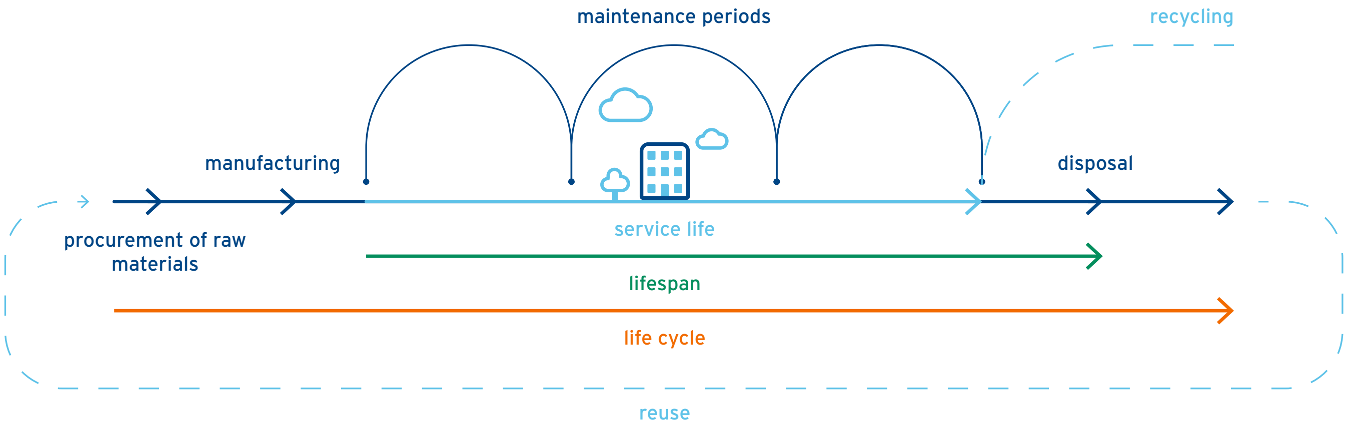

Figure 2. Concepts related to the life cycle of a building.

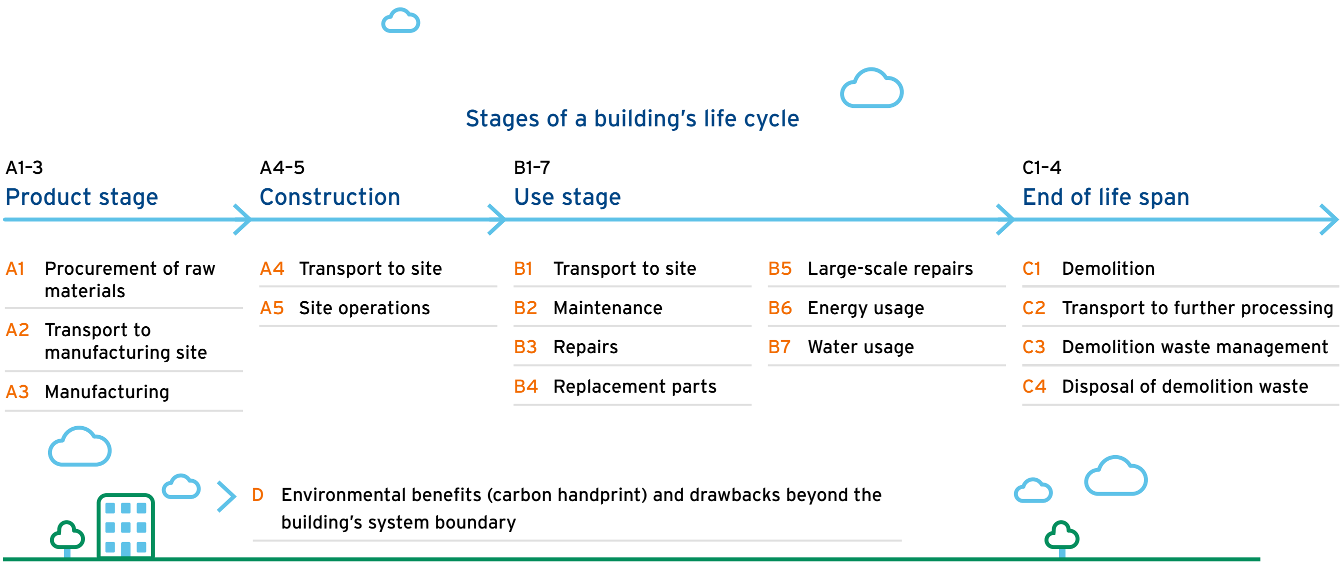

Figure 3. Life cycle stages of a building (also known as modules) (source: Ministry of the Environment).

1.4 Life cycle thinking and its implications for the construction sector

In addition to reducing costs, life cycle thinking also aims to lighten the environmental burden caused by the construction sector. In the context of building design, the application of life cycle thinking is typically called life cycle design and involves designers of different specialties. This is an especially good thing considering that the best results are typically achieved by a multidisciplinary team of designers who can find the best solutions for the project as a whole.

The cost and environmental impacts of projects can be optimised most effectively during the early stages of the project (Figure 4). As the design progresses towards the construction stage, opportunities for managing these impacts become more scarce, as decisions made at earlier stages limit the choices available (the so called path dependence phenomenon). Therefore, the earlier the principles of life cycle thinking are taken into account and existing life cycle design tools are used, the better more effectively environmental impacts and costs may be minimised. In terms of new buildings, life cycle design affects especially the choice of materials, how different work phases are managed, monitoring and quality assurance.

Life cycle costs are a useful metric for optimising the life cycle impacts of a project. Life cycle costs measure the cost arising from the building all the way from land acquisition up to demolition. The aim of life cycle costing is to illustrate the actual costs incurred by

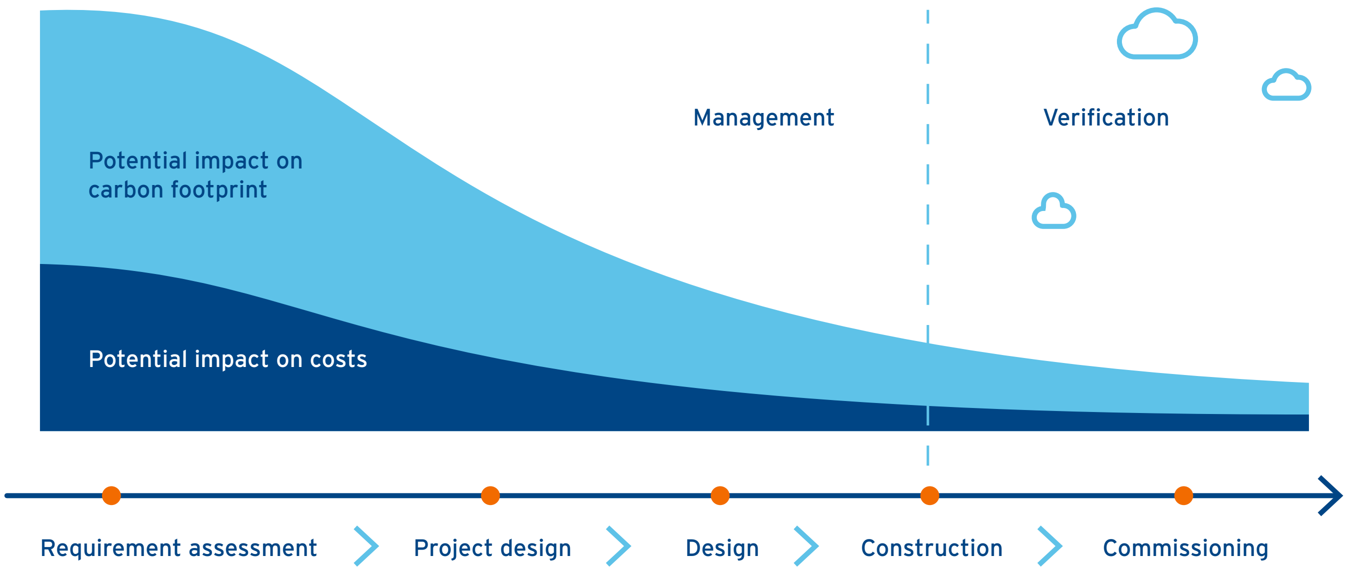

Figure 4. Opportunities to affect the carbon footprint and costs of the project as it progresses.

the property owner throughout the life cycle of the building. The respective value of costs at the time they are incurred is commen-surated to the present value using a discount rate. Managing cost-effectiveness on a life cycle level starts with the property owners, users and developers, who must all demand solutions that are cost-effective not just in the short term, but throughout the entire life cycle of the building. The early stages of a project present the most effective opportunity for managing its life cycle costs. Life cycle costing is based on the same principles as calculating the life cycle carbon footprint of a project.

Methods used in life cycle assessment (LCA) are also used for estimating the environmental impacts of projects. At present, by far the most typical environmental impact assessed is the impact a project has on global warming. These climate impacts are reviewed by carbon footprint assessment, which takes into account the greenhouse gas emissions of the project. In reality, construction projects also generate a number of other environmental impacts, such as impacts on the soil and inland waters, fine particles and other emissions released into the air, which can be taken into account in a more extensive climate assessment.

2. Life cycle thinking in building design

Key points

- In addition to environmental impacts and costs, the use of life cycle thinking in the context of design (life cycle design) helps to control future risks, thus creating added value for property owners and users. However, applying life cycle thinking requires not only expertise but also time and sufficient funds.
- The best results are achieved by managing the life cycle characteristics of the building throughout the project. It is possible to influence the emissions and costs associated with the project at any stage, but the most meaningful opportunities for optimisation are presented in connection with the requirement assessment and project design.
- Setting the right targets is a central factor in terms of optimising the life cycle performance of a project. If an operator wants to incorporate life cycle thinking into one of their projects, it is advisable to make use of the tasks specified in the life cycle expert's task list document ELINK18 (Elinkaariasiantuntijan tehtäväluettelo, available in Finnish).

The systematic management of the life cycle characteristics of a project requires action at every stage of the project, from requirement assessment up to the use and maintenance stages (Figure 5). In addition to optimising life cycle characteristics, setting objectives also ensures that life cycle design can be implemented in the best possible way. By identifying, assessing and comparing the effects that different design solutions have on the life cycle characteristics of the building in question, the parties involved can effectively steer the project towards the mutually set objectives. When evaluating solutions, it is important to identify possible joint effects instead of simply assessing individual impacts separately. It is important to try to avoid just optimising individual subsets and concentrate on the project as a whole instead.

The environmental and cost impacts are determined mainly during the requirement planning and project design stages, although they are mostly realised during construction and use (Figure 6). This is why it is important that life cycle thinking is utilised from the very beginning of the project.

There is a useful task list available for life cycle experts to help take relevant aspects into account at all stages of a construction project

Requirement assessment → Project design → Design → Construction → Use / maintenance

PROJECT MANAGEMENT

Setting objectives for the project

The aim is to assess the emissions arising from the project and reduce them, ensure energy efficiency, a long service life, reasonable life cycle costs, adhere to the principles of the circular economy and utilise recycled materials

Life cycle costing

Assessing the factors that have the greatest impact on the costs arising from the project over its entire life cycle and identifying possibilities to manage them

Optimisation of energy solutions

Ensuring the most energy-efficient and cost-efficient methods are used, taking into account possible on-site energy production on the plot

Managing a low-carbon site

Green deal, ensuring the highest possible recycling rate for waste generated on the site

Expertise required

Project management, design and implementation require understanding of objectives set for the building's life cycle and how they can be achieved

Materials optimisation

Seeking out low-carbon options that are in line with the principles of the circular economy, circular economy planning, reusable components, sustainable building materials

Procurement

Carbon footprint, a long service life, zero maintenance and the principles of the circular economy as procurement criteria

Climate statement

A carbon footprint calculation based on the realised designs

Carbon footprint and environmental impact assessment

Assess the most significant factors and opportunities for reducing the carbon footprint, and set a target footprint

Life cycle objectives

As a part of decision-making compare the life cycle impacts of different solutions, multi-objective optimisation

Guidance and maintenance

Providing user guidance and ensuring planned maintenance measures are implemented, monitoring consumption during use and comparing it to the planned consumption

REDUCING EMISSIONS AND COSTS

Location · **Plot** · **Frame structure material** · **Materials** · **Site emissions** · **Monitoring use and consumption**

Shape of the building · **Potential for repairs and maintainability** · **Recycling rates on site**

Environmental conditions · **Budget** · **Energy solutions** · **Material efficiency** · **Implementation according to plan**

Figure 5. Applying life cycle thinking in the context of project management and opportunities for managing emissions and costs at each stage of the project

– the ELINK18 task list. The list helps experts to define the contents and scope of the relevant tasks and to ensure that all necessary reviews and assessments are performed in a timely manner.

Larger scale or more challenging construction projects typically have a separately appointed life cycle expert. This expert will assume the main responsibility for setting life cycle objectives and help to refine them, as well as ensure that the desired life cycle characteristics are achieved and guide the project towards its goals. If another party involved in the project is familiar with matters related to life cycle design and sustainable building practices, they may also assume the role of a life cycle expert. Sustainable, low carbon construction projects require attention and engagement from all parties. This is crucial to ensure that project objectives are met. However, it is also important that the life cycle related measures are managed by a specific party who is also able to monitor how these measures are implemented.

Typically, the monitored and verified life cycle characteristics include climate impacts throughout the life cycle of the building, i.e. carbon footprint and life cycle costs. Carbon footprint assessment is described in greater detail in the workbook on carbon footprint calculation methods and relevant expertise. It is also important to pay sufficient attention to the airtightness, damp proofing and thermal transmittance characteristics of the designed buildings, as these factors significantly affect the energy efficiency and sustainability of a building.

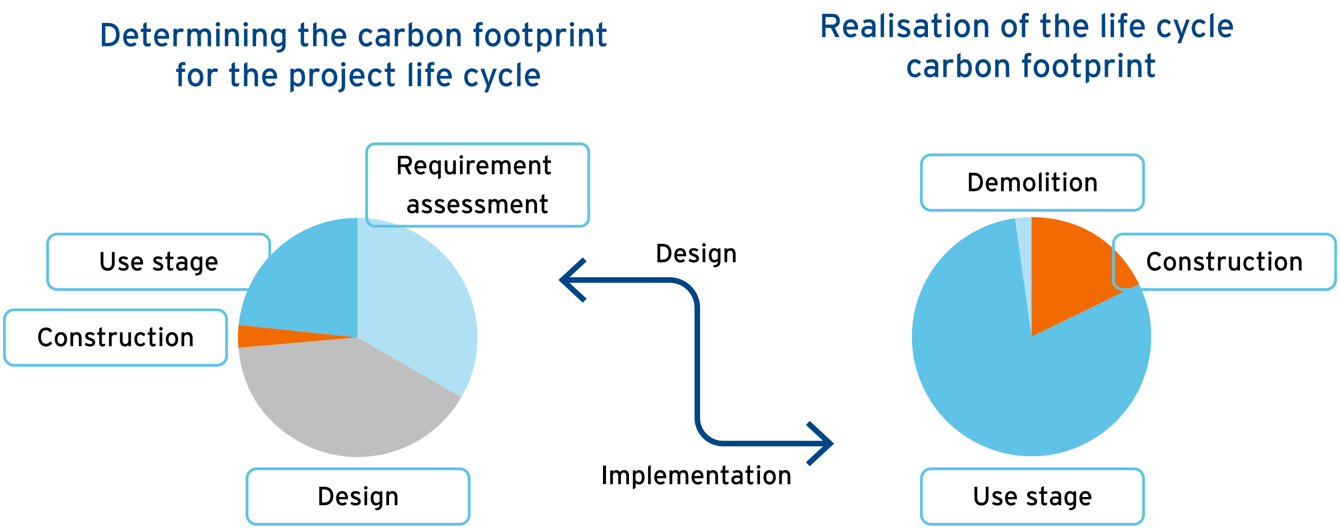

Figure 6. Determination and realisation of environmental impacts at different stages of the project (source: Pasanen, Bruce and Sipari, 2012)

2.1 Requirements assessment

As the life cycle impacts of a building (such as carbon footprint and costs) are generally determined in the early stages of the construction project, it is sensible to also apply life cycle thinking in the context of the requirements assessment. In other words, it is difficult to effectively control life cycle impacts unless they have been taken into account and considered systematically already during the requirement assessment stage, when determining design objectives and during the design stage itself.

In this phase, it is especially important to identify key impacts and opportunities for managing these impacts, as well as think about how they should be taken into account in the project. Key questions for the requirement assessment include:

- What life cycle objectives should we set for the project?
- What are the main environmental impacts arising from the project, and how can we take them into account?
- What purpose will the building resulting from the project be used for?
- Are there already existing buildings/structures that could be used to reduce the need for building new spaces or facilities?
- How can we build the required spaces and facilities and optimise the energy and other resource consumption in terms of the whole life cycle?

It is also important to carry out different assessments to acquire concrete information of the life cycle impacts of different design solutions. These include

- carbon footprint calculation
- life cycle costing
- assessment of the onsite production of renewable energy at the plot (if the future location of the building is already known)
- comparing potential future locations for the building (if the location has yet not been decided)

Operators should compare several different design options in order to find the ones that best serve the construction process and the resulting building over its entire life cycle. Multi objective optimisation, in which several different calculations and assessments are compared against each other, can also be useful to this end.

2.2 Project design

Make sure to implement at least the following measures during the project design stage:

- Update/calculate the carbon footprint
- Update/implement life cycle costing
- Implement a preliminary building energy simulation
- Set concrete life cycle objectives for the project

During the project design phase, the life cycle objectives set for the construction project are refined, and more specific objectives are set in terms of e.g. scope, functionality, quality and costs. It is important to take life cycle perspectives into account at this point at the latest. In this stage, the key tasks of a life cycle planner include refining any calculations and assessments conducted during the requirement assessment phase, as well as reviewing the life cycle and energy objectives based on information received from these sources. It is also advisable to carry out a preliminary energy simulation during the project design stage. This preliminary simulation will outline the eventual energy consumption of the building or buildings in question.

The objectives that are set at the project design stage should be concrete enough so that they may be realised and their progress may be monitored. Concrete objectives may include:

- longevity of load bearing structures (100 years)
- taking into account the effects of climate change in the design process, i.e. considering the adaptation aspects (increased rainfall, winds, and changes in the soil)
- carbon footprint budget
- serviceability and maintenance routes
- energy efficiency and an ambitious target for the total energy consumption of the building
- materials efficiency, maintenance free materials

In order to optimise the life cycle aspects of the building, comparisons of alternative design solutions and multi objective optimisation should be utilised in the project design. This will allow project staff to find solutions that are optimal in terms of the whole life cycle of the building or buildings.

At this stage, it should also be considered if it is sensible to incorporate any environmental classifications in the project. In practice, the project design phase should examine the possible benefits that environmental classification would present to managing the life cycle aspects of the building or buildings. In addition to this, the staff should compare how suitable different environmental classification systems are for the project in question, and assess which classification level the project could potentially reach. The desired classification level can then be determined based on these assessments.

2.3 Proposal design and general design

In the proposal design phase, alternative design solutions are developed in parallel to correspond to the objectives set out in the previous stages of the project. Since this stage includes identifying the possible technical solutions to meet the design objectives, the life cycle expert's central task is to simulate and compare these options to one another and to the life cycle and energy objectives.

So, in practice, this project stage consists of monitoring the implementation of the life cycle objectives by updating the previous carbon footprint calculations and life cycle costing results, for example. In other words, the aim of life cycle related assessments is to help the team members choose the best options by highlighting their different impacts in terms of e.g. costs or climate, thereby ensuring that life cycle objectives are met.

The assessments are used to advise and inform designers of life cycle objectives and the design solutions they require. Key aspects in terms of guidance include factors such as material choices and utilising recycled or reusable materials. The environmental soundness of material choices is ensured using environmental product declarations (EPDs) or climate declarations.

The so called design for deconstruction approach may also be used to minimise the end of life impacts of the building or buildings. A building that is designed for deconstruction can be disassembled piece by piece, after which the structures may be either reused or recycled. As such, the approach focuses on the reuse and sustainable recovery of structures, building components, and materials. DfD is therefore a strategy that must be integrated into the project as early on as possible, preferably at the beginning of the design stage. Timely implementation will ensure that it is still possible to manage and affect all significant factors, such as material choices. This is especially important since the demolition and reuse potential of the building components and materials is influenced by a number of factors that may include complex, potentially hidden or combined structures and systems, non standardised or specially manufactured parts, composite structures, combinations of different quality grades of the same material, or harmful substances or materials.

In addition to striving to curb climate change, it is nowadays generally recommended that building design should attempt to adapt to the changes brought on by the changing climate. This means taking into account the predicted future weather and soil conditions at the building site, and adjusting the structural and technical design of the building accordingly. The most typical weatherrelated predictions are considered to be global warming and increased precipitation.

2.4 Implementation design and construction

At this stage of the project, the life cycle expert's mission is to ensure that the project meets its life cycle objectives. This means updating the carbon footprint and life cycle cost calculations in accordance with the actual material choices and other information from the parts of the project that have already been implemented. Implementation design and construction are crucial in terms of life cycle management, as it is important to ensure that the final plans are both in line with the life cycle objectives and specific enough to guarantee that the materials acquired for the site will possess the right life cycle properties. Further procurement related guidance for the contractor may also be required.

Ensuring that construction is carried out according to plan also ensures that the desired life cycle properties are realised and the project meets its life cycle objectives. Careful construction also guarantees that the building is durable and has a long useful life. For this reason, it is sensible to strive to keep the quality of the entire construction process as high as possible.

Once all of the materials have been procured and the actual energy and materials consumption can be determined, it is important to remember to update any calculations that have been made using estimated values. Sustainable construction and life cycle planning can only be promoted by monitoring the actual emissions of completed construction projects. Using the actual data also allows project staff to verify that the project has truly met its objectives.

2.5 Life cycle thinking and operational risks and opportunities

So far, life cycle thinking has not been studied or developed extensively in either the context of small or large organisations. Integrating life cycle thinking into daily business operations is widely seen to have positive effects on the businesses as well, as it is generally supported by modern market drivers and will be a significant part of the operations of an increasing number of organisations in the future. From a corporate point of view, developing life cycle thinking at a company level can therefore also be seen as a part of future-proofing, as it contributes to mitigating future risks associated with the company's operations. However, operators should recognise that as new ways of working are introduced, life cycle thinking can make their production more cost-effective in both the short and long term. The strengths, weaknesses, opportunities and threats associated with applying life cycle thinking are presented in Table 1.

In the context of the construction business, risk management is also linked to the quality delivered to the client or the people using the facilities. High-quality work ensures a longer useful life and minimises future risks associated with the building or buildings. Life cycle thinking can therefore be seen as a form of quality assurance that allows operators to identify and control future requirements and challenges at the design stage before they are actualised. Sustainable, maintenance-free buildings support the continuity of occupant operations and enable lower rental or maintenance charge costs. In contrast, if a building is constructed as quickly as possible only using standard solutions, costs arising from energy use may change significantly during the building's life cycle, which will in turn affect the continuity of occupant operations. Occupants' and users' understanding of the (either strategic or practical) effects that the premises have on their operations is constantly improv-ing. Therefore, leaving life cycle thinking out of the equation during the design stage of the project may also create potential threats associated with renting, selling or using the premises, or the living comfort of the building.

S (strengths)	W (weaknesses)	O (opportunities)	T (threats)
A well established, science based approach	Applying life cycle thinking requires time, funds and expertise	Reduced environmental impact and costs, better management -> added value for property owners and users	Potential risks associated with renting, selling or using a building created by ignoring life cycle thinking
Reliable standards, tools and emission databases available for assessing impacts	There are always uncertainties associated with theoretical numbers, so care must be taken when interpreting the results	Life cycle thinking enables risk management and improves quality	Potential cost increases during design, production, and acquiring and maintaining new expertise
Produces numeric, comparable data to support decision-making		Image benefits in terms of environmental sustainability and responsibility	

Table 1. Life cycle oriented approach (SWOT analysis).

3. Examples

Key points

- The ELINK18 task list for life cycle experts has only been more widely applied since 2018. This also means that project level life cycle management activities have generally not been carried out before.
- Including a carbon footprint, life cycle costing and energy expert in the design team will help optimise the life cycle characteristics of the project.
- Typically, projects have applied a workshop approach to make carbon footprint and sustainability management more effective.

The ELINK18 task list for life cycle experts was published in 2018, and the purposeful life cycle management of projects has only become more widespread in Finland since then. For this reason, holistic, integrated life cycle planning has only been implemented for a handful of projects completed so far. There are a number of projects that are still ongoing in 2022 that have been more thoroughly managed in terms of their life cycle aspects.

3.1 Renovation of an office building

The project consisted of renovating a 100-year old office building protected under the Finnish act on the protection of built heritage (498/2010). During the extensive renovation project, many of the preexisting building materials were replaced, the building technology in the premises was upgraded, and a new ventilation plant room was constructed in the attic floor of the building.

During the project design stage, the design team attended guidance workshops on carbon footprint and sustainability. The aim of these workshops was to brainstorm lower-carbon and more energy-efficient solutions to be used in the project. The workshop drew on a carbon footprint calculation identifying the main sources of emissions and factors that could potentially be influenced during the course of the project. The workshops also further assessed the emission, cost and functionality related effects of using low-carbon concrete and different material options for reinforcement structures of the ventilation plant room.

After the sessions were over, the impacts of these solutions were assessed in greater detail in collaboration with the design team. Finally, it was decided that the reinforcement structures of the ventilation plant room would be constructed of wood instead of steel due to the carbon footprint impacts and weight related benefits.

3.2 Renovation of a building used by an educational institution

The project targeted a building used by an educational institution. The building was several decades old, and underwent a major renovation. During the renovation project, potential solutions were assessed from a carbon footprint and energy consumption perspective. A life cycle costing and energy expert were also invited to join the design team early on in the design process. The team also assessed the possibilities for utilising and recycling materials recovered during demolition both outside and within the scope of the current project. They also studied the differences and impacts between various window renovation and replacement solutions.

When both the carbon footprint and energy efficiency gains were taken into account, refurbishing and renovating the windows to achieve an U-value of 1.0 were estimated to have a similar carbon footprint. However, if the U-value was to be improved to 0.8, refurbishment was deemed to produce a slightly smaller carbon footprint than renovation.

The project participants found it challenging that the value produced by preserving materials was not directly reflected in the calculations. Reliably estimating the future repairs required for the renovated windows and the emissions these repairs would create was also seen as a challenge.

3.3 Key lessons from the project cases

Applying life cycle thinking on a project level allows operators to identify the most significant negative environmental impacts arising from the project and offers opportunities for managing their scope and quality. In addition to environmental considerations, life cycle thinking also helps to identify cost relevant factors, allowing operators to optimise and minimise life cycle costs with suitable management, guidance and design solutions. Examining the life cycle as a whole and taking life cycle matters into account early on in the design process can also improve durability in use, along with other quality related matters. This, in turn, supports risk management and promotes sustainable building practices.

4. Summary

Construction activities have a significant impact on the environment and the economy. In order to build sustainably, we must take the whole life cycle of the building into account. As the effects of climate change intensify, the importance of buildings' carbon footprints and handprints, as well as their ability to adapt to the changes in our environment, is highlighted. By applying life cycle thinking early on in the project, operators can identify the most significant negative environmental impacts and find opportunities for managing their scope and quality. The cost and environmental impacts of projects can be optimised most effectively during the early stages of the project. In addition to an overall low carbon performance, life cycle thinking also serves to increase the service life and cost effectiveness of buildings.

Setting the right targets is a central factor in terms of optimising the life cycle performance of a project. If an operator wants to incorporate life cycle thinking into one of their projects, it is advisable to make use of the tasks specified in the life cycle expert's task list document ELINK18 (Elinkaari-asiantuntijan tehtäväluettelo, available in Finnish). Including a carbon footprint, life cycle costing and energy expert in the design team will help optimise the life cycle characteristics of the project.

Table 2 summarises the measures used to ensure the application of life cycle thinking and the most important matters to be taken into account in a construction project stage by stage.

Requirement assessment	• Assigning a life cycle expert to the project (or allocating the tasks of a life cycle expert to other consultants) • Identifying the operational requirements of the construction project and preparing preliminary plans and decisions to meet these requirements (remember to take space and resource efficiency into account!) • Setting preliminary life cycle objectives for the project (useful life, amount of emissions, serviceability) • The project's life cycle guidelines and preliminary assessments (carbon footprint and life cycle cost comparisons) should also be prepared at this stage. • If the project involves both demolition and new construction activities, the operators should assess how much of the materials and structures of the old building can be utilised in the construction of the new one.
Project design	• Update/prepare a preliminary carbon footprint calculation and compare options. Setting a target level for the carbon footprint (carbon budget). • Prepare an energy declaration (and a preliminary energy simulation) and set energy efficiency targets. • Set circular economy related objectives / a circular economy plan. • Carry out life cycle costing and compare different alternatives. In terms of energy, operators should consider the impacts of the shape of the building, solar energy solutions, passive cooling, and window orientation and size. • If the old building is to be demolished, the operators must carry out a demolition assessment. • Define life cycle objectives in greater detail in the project plan. • Assess the impact that the life cycle objectives will have on the project schedule. • When recruiting designers for the project, ensure that they have sufficient knowledge of life cycle thinking. This may be implemented by adding complementary points to the relevant task lists, or paying special attention to skills and experience in quality scoring in the context of public procurement (benchmarking).

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Proposal design	• Compare the life cycle impacts of different design solutions and assess progress towards the objectives set in the project design stage. • In terms of materials, it is essential to take into account any large quantities, frame solutions, and other choices that affect the quantity of materials. However, it is also important to consider the lifecycle characteristics and environmental impacts of other materials. • Materials may also constitute a carbon sink. Therefore, it is useful to consider if they could be used to increase the project's carbon handprint. • Ensure that the target set for the useful life of the building or buildings can be achieved. • In terms of energy, it is important to ensure that the equipment and systems are properly and correctly sized and as energy efficient as possible.
General design	• Update calculations to reflect actual material choices. At this stage, you can still compare the carbon footprint, lifetime and cost of different manufacturers' products for procurement purposes. • Estimate the energy consumption of the new building or buildings and a dynamic calculation of the indoor air conditions to ensure that the chosen solutions will allow the project reach its objectives in terms of measurements as well as energy consumption and environmental impacts arising during use.
Tasks related to the building permit application process	• Prepare a climate statement and attach it to the building permit application. Ensure that the design solutions are consistent with the project objectives.
Implementation design	• Ensure that design solutions remain in line with the carbon footprint and other life cycle targets and objectives set for the project. • Assess the extra time required for building certain low carbon solutions (e.g. the curing time of recycled concrete, which is longer than that of virgin concrete)

Construction	**During the preconstruction stage:** • Record the carbon footprint targets for the project and requirements and conditions for materials efficiency and utilising other materials in the contract specification. Operators should require the contractor to commit to the Green Deal conditions for emission free construction sites. • Prepare a zero emission approach, emissions criteria and circular economy objectives for the site. Record all the aforementioned criteria and principles in the contract specification. • Establish low carbon construction quality criteria to support the contractor's procurement activities as a part of the process of finding a contractor or contractors. • Define incentives and sanctions for the contractor to safeguard adherence to low carbon guidelines and objectives. • Ensure that the contractor is committed to the carbon footprint targets, waste management objectives and sustainability reporting practices set for the project and that they understand the practical side of this commitment. **During construction:** • Site staff will ensure that the low carbon solutions are implemented in accordance with the designs. • At the beginning of the construction process, ensure that the contractor understands the objectives set for the site, carbon footprint requirements and the carbon objectives set for the building's life cycle (including objectives related to energy, the building's carbon footprint and the circular economy). • Review and approve the contractor's circular economy plan, environmental plan, logistics plan, waste management plan and low carbon materials procurement plan.
Commissioning	• Ensure that materials to support low carbon or carbon neutral use and maintenance have been drawn up, and that the future users have been provided with adequate guidance. • Ensure that energy consumption during use is monitored and any deviations from target levels are inspected.

Taulukko 2. Hankevaiheen keskeiset toimet elinkaariajattelun soveltamiseksi.

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