Life Cycle Assessment for Taller Timber Buildings

Summer School

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June 2024

COST Action CA20139 - Holistic design of taller timber buildings (HELEN)

COST Action CA20139 - Holistic Design of Taller Timber buildings (HELEN) – organized its 2nd Training School that took place in Zagreb, Croatia, from the 19th to the 21st of June 2024. The HELEN Action Training School represents an important endeavor that promises to reshape how insights are shared and collaborative networks are cultivated within the HELEN Action community. Designed primarily for early career investigators, Ph.D. students, and post-doc researchers, the Training School focuses on providing practical insights from WG4 Sustainability topics to foster their scientific and professional growth. At the heart of the Training School is an engaging learning environment that encourages active participation. Through a balanced mixture of discussions, presentations, exercises, and lectures, participants were introduced to new ideas and practical LCA techniques. This approach not only introduces novel concepts but also offers a platform to apply these insights through real-world case studies, promoting a hands-on understanding.

THEME

Timber constructions are a sustainable building option for a climate-neutral built environment. However, they also raise questions regarding their embodied GHG emissions calculations, life expectancy, and forestry management. They are more susceptible to design mistakes due to their complexity. They are also less durable when untreated or glued and not properly maintained, possibly leading to negative environmental impacts associated with landfilling or incineration. This Training School investigated the issues dealing with taller timber buildings' environmental footprint and their longevity based on the design details and life cycle assessment perspective.

The Training School aimed to educate students on the Sustainability of Taller Timber Buildings through the leading international experts in the field. In addition, students got the opportunity to learn more about timber building durability, environmental key performance indicators, and the evaluation and validation of timber data.

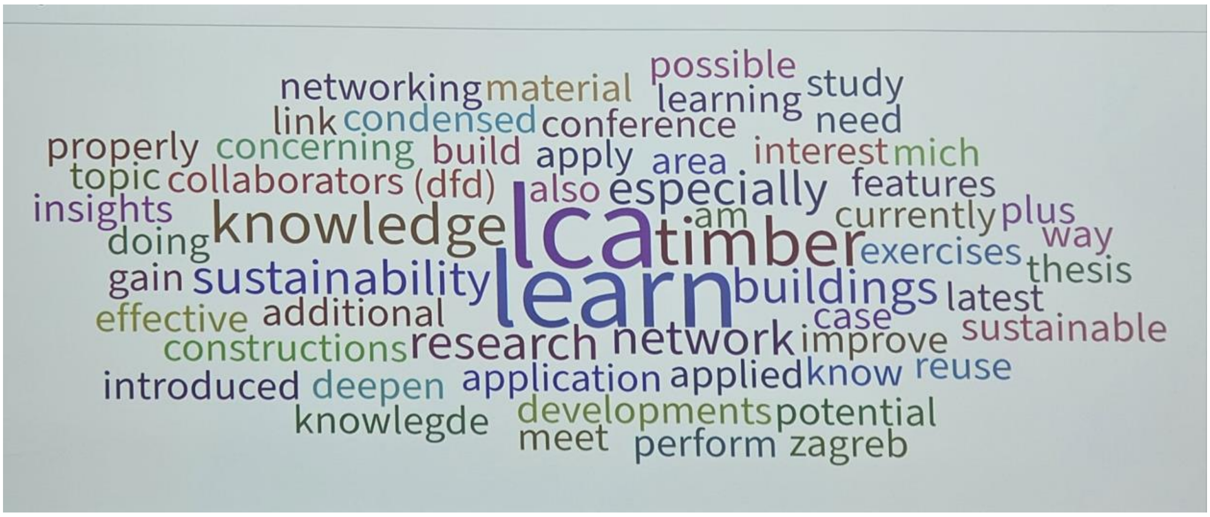

Figure 1, workshop themes and concepts

PROGRAM DESCRIPTION

Lecture 0: COST HELEN

The basic goals of the COST Action HELEN were presented. A short overview of finished activities with future objectives of the action was given. All technical and administrative aspects of the training school were explained.

Lecture 1: Towards Zero Emissions Buildings (Decarbonisation paths, Scenarios (Steel, Concrete and Timber)

The lecture presents the legal EU framework for carbon neutrality of the building sector by 2050. The presentation explored the pathways for zero carbon emissions buildings and the implications of GHG emissions reduction for new construction and renovations (Attia & Gobin, 2020). The choice of building materials and construction materials were presented in a comparative way involving timber, steel, concrete, and hybrid construction. The presentation presented the key concepts of sustainable construction with a focus on embodied and operational GHG emissions and the end-of-life of buildings.

Lecture 2: What is mass timber? Building type, construction method, or product?

The lecture presents a concise framework for understanding mass timber, discussing the building, construction, and product viewpoints. The presentation begins by noting the rise of mid- to high-rise mass timber buildings over the past two decades, highlighting a few groundbreaking buildings. It then addresses the main question of what exactly mass timber is. First, the presenter walked through a selected number of different mass timber building types (low to high-rise residential, office, commercial, and institutional) to demonstrate the variety of applications and products available under the mass timber umbrella. The lecture then delves deeper into modern mainstream mass timber construction methods (panelized and modular) as opposed to more traditional methods (timber frame, wood framing, heavy timber frame), clarifying the key characteristics of what constitutes mass timber from material use ratio and load bearing characteristics. After, the presentation discusses the genealogy of wood products with a focus on modern engineered wood products (glulam, PSL, LVL, CLT, NLT, DLT) that form the core of mass timber applications.

The presentation concludes with an answer to the question by proposing a framework for defining mass timber as an interaction of all viewpoints - building type, construction method, and products: A mass timber building can be of any typology but typically contains more than 0.35 m3 of wood per unit area; a mass timber construction method uses a high degree of prefabrication, from panelized elements to fully modular; a mass timber product refers to modern load-bearing structural components (linear and planar) that are well suited for heavy load transfer.

Lecture 3: Whole Life Carbon Calculation for Sustainable Construction: Unlock the Key to Decarbonizing the Built Environment

This intensive lecture dives into the critical concept of Whole Life Carbon (WLC) calculations – a vital tool for understanding and minimizing the environmental impact of buildings throughout their entire lifespan. We looked at:

“Different” carbon like Embodied Carbon vs. Operational Carbon and Fossil Carbon vs Biogenic Carbon: Understand the distinct carbon emissions associated with materials, construction (the rucksack), and a building's day-to-day operations (like energy use).

CEN 15804 and Modules A-D: Master the European-standard framework for comprehensive WLC assessments.

Calculation Methodologies: How to quantify carbon emissions at each stage of a building's life, from production to demolition.

Sustainable Design Strategies: Explore how WLC insights inform material selection, construction methods, and energy-efficient building systems.

This matters, as the construction industry needs to meet ambitious climate goals, and WLC expertise is in high demand. This summer part empowers you to make informed, carbon-conscious decisions in architecture, engineering, and urban planning, taking into account the “different” carbon.

Lecture 4: Whole Life Carbon Calculation (Timber Materials LCA: Tools and Databases)

The presentation gives an insight into the complexity of modeling anthropogenic and biogenic carbon flows related to timber materials when performing a Life Cycle Assessment (LCA). Specific attention was paid to the LCA of timber materials in buildings. The presentation referred to international standards, such as CEN 15804 (CEN, 2019), CEN 15978 (CEN, 2025), and EN 16485 (CEN, 2014, p. 16). All life cycle stages were considered. For each life cycle stage, different modeling approaches for anthropogenic and biogenic carbon were explained. Certain aspects were discussed in detail, for example, the biogenic carbon content, the impact distribution of multi-functional processes, the electricity production scenarios, and the loads and benefits from reuse, recycling, and energy recovery of timber materials. Furthermore, information on the most common tools and databases for the life cycle inventory and impact assessment (e.g., Ecoinvent, ÖKOBAUDAT, etc.) was provided. The final goal of the presentation is to provide knowledge about the most common modeling and inventory techniques based on scientific literature, to increase awareness about the influence of those techniques on the final results of an LCA study, and to sensitize the importance of transparent LCA studies.

Exercise description

The exercise was performed through a quiz. The participants answered a series of questions by analyzing existing tools, discussing possible modeling schemes, or developing simple calculations. Part of the questions referred to a concrete case study, which was briefly presented at the beginning of the session (see Piccardo& Gustavsson, 2021 (Piccardo & Gustavsson, 2021)). The trainer provided the basic material needed to answer the questions. It might be useful to use electronic devices (e.g., laptop, tablet) to navigate online.

Lecture 5: Whole Life Carbon Calculation (Timber Building Life Expectancy)

This lecture presents a survey conducted in 2023 that aims to reply to the following questions: 1- What measures are essential to ensure a high-rise timber building has a lifespan of 150 years? 2- How can we accurately predict the service life during the planning process? The creation of the survey was rooted in the necessity of responding to the second question. The primary objective was to define the actual service life for medium-raise (3 to 8 stories) and tall (above 8 stories) timber building components based on estimations provided by the experience and knowledge of timber building industry professionals. Your expertise contributes immensely to the success of this initiative. This survey is prepared by Tomasso Verdier, Shady Attia, and the COST Action HELEN Sustainability group members.

Lecture 6: Sustainability of the forestry wood industry chain and timber buildings

Sustainable forestry, or sustainable forest management, is the practice of managing forests to meet the current needs and desires of society for forest resources. When sourcing sustainable timber or bio-based building materials in general, this can be instrumental in combating climate change as they store vast amounts of carbon. Timber and engineered wood products based on a range of wood species can contribute to easy and cost-effective construction. Service life about the prevention of biodegradation, as well as fire safety aspects, needs to be considered, and property enhancement treatments can be part of the sustainability approach. The forestry wood industry chain provides excellent opportunities to create jobs, boost the economy, and underpin both healthier living and working environments. There are different options to produce bio-based building materials, ranging from extracting trees from semi-natural forests to tree plantations and agricultural production. The many resource options available also impact the suitability of different commodities. As such, they are all contributing to the transition from linear fossil-based systems to circular and bio-based systems, representing opportunity and a suitable pathway for achieving several SDGs.

Exercise description: Strategies for sustainable bio-based building components

The quality of trees, as well as the wood properties, not only challenges us but also provides opportunities to prioritize processing strategies, taking into account the sustainability aspects of both forestry and the construction sector. Several case studies were used to discuss and quantify some variables. The focus was on the production of long-lasting harvested wood products, integrated wood processing strategies for local short supply chains, and optimization of the 9R framework.

The building and construction sector plays a vital role in mitigating climate change. Consequently, the use of wood and bio-based materials as a strategy for reducing the environmental impact of buildings is increasing. However, along with realizing the potential environmental benefits of biomass, the focus on assessment methods and their inherent uncertainties increases. Typically, Life Cycle Assessment (LCA) is used to quantify the environmental performance of buildings but is often criticized for not considering temporal factors related to emissions. Therefore, dynamic LCA (D-LCA) approaches have been developed. The lecture showed how climate change impacts on the building and construction sector are calculated with the help of D-LCA. The difference between the climate change impacts calculated with the static approach and D-LCA was highlighted. Moreover, an extensive focus on the assessment of biogenic carbon in timber elements was presented.

Lecture 7: Dynamic life cycle assessment (Biogenic carbon in timber buildings)

The building and construction sector plays a vital role in mitigating climate change. Consequently, the use of wood and bio-based materials as a strategy for reducing the environmental impact of buildings is increasing. However, along with realizing the potential environmental benefits of biomass, the focus on assessment methods and their inherent uncertainties increases. Typically, Life Cycle Assessment (LCA) is used to quantify the environmental performance of buildings but is often criticized for not considering temporal factors related to emissions. Therefore, dynamic LCA (D-LCA) approaches have been developed. The lecture showed how climate change impacts on the building and construction sector are calculated with the help of D-LCA. The difference between the climate change impacts calculated with the static approach and D-LCA was highlighted. Moreover, an extensive focus on the assessment of biogenic carbon in timber components was presented.

Exercise description

To fully grasp the knowledge of dynamic assessment of climate change impacts and the temporal aspects influencing the results, a case study of an external wall was analyzed. Two scenarios, one mainly from cementitious materials and another composed of biobased sources (timber), were assessed, and the differences were analyzed. The impacts of climate change were calculated using a static and dynamic approach. In addition, biogenic carbon was analyzed, and the implications of the final results were highlighted and discussed.

Lecture 8: Tools for building life cycle assessment: The case of OneClick LCA

The lecture focused on how to utilize One Click LCA software effectively for sustainable construction projects. The session covered:

1. Overview of One Click LCA: Understand the purpose and significance of life cycle assessment (LCA) and environmental product declarations (EPDs) in the construction industry.
2. Software Interface: Familiarize yourself with One Click LCA's user-friendly interface, including navigation tools and key features for LCA calculations.

3. LCA Methodologies: Explore different LCA methodologies supported by One Click LCA, such as ISO 14040/44 and EN 15978, and learn how to choose the appropriate methodology for your project.
4. Advanced Features: Discover the software's advanced features, including scenario analysis and optimization tools, to enhance the accuracy and efficiency of your sustainability assessments.

By the end of this lecture, participants gained the knowledge and skills necessary to leverage One Click LCA software for comprehensive life cycle assessments and environmental performance evaluations in their future projects.

Exercise description

This exercise offers a hands-on opportunity to apply One Click LCA software in evaluating and enhancing the environmental sustainability of building projects. A case study of an office building (t Centrum) in Belgium was analyzed. (Al-Obaidy et al., 2022)A new project was created in the One Click LCA tool, and the necessary data was used as input to get the results of cradle-to-cradle LCA. Scenarios using different materials were made to compare materials and improve the building's environmental performance in the early design phase. The final results were highlighted and discussed, as well as how they were presented and how to download the LCA final report.

Lecture 9: Case Study 1 (InnoRenew CoE building, Izola)

This lecture presented the result of the carbon footprint of the largest wooden building in Slovenia. The case study is the InnoRenew CoE building, Izola. The presentation explores a summary of a full life cycle assessment (LCA) with the EU Environmental Footprint / EN 15804 (A2:2019) method indicators. The discussion focused on the hotspots of LCA, including the end-of-life, with its large amount of biogenic carbon emissions, including methane (2 811 t CO2e), the influence of foundation, with the concrete, partly reinforced (2 273 t fossil CO_2e) and the low impact of heating and cooling during the use phase. The presentation discusses the importance of resource use – minerals and metals and climate change (carbon footprint) are the most important impact categories. The challenge of reaching a climate-neutral building is still high. Therefore, InnoRenew CoE is planting trees to offset the greenhouse gas emissions (not included in the LCA or carbon footprint as outside the scope and system boundaries). The limitation of the LCA report is the lack of including the land use at the building site. Also, the land use of wood should have been a hotspot, but in this study, the land use of the building site is also not to be neglected. However, not yet been taken into account in the climate change (land use) impact category. This was a limitation of this study.

Lecture 10-11: Trainees Project

The summer school project invited participants to perform a life cycle assessment using OneClick LCA for the circular building *'t Centrum* project, a case study for an office building located in Westerlo, Belgium. The provincial Center for Sustainable Building & Living Kamp C of the city of Antwerp developed the first circular building in Belgium. The building is carbon neutral and integrates the circularity principles serving as an accelerator for modular and circular construction. The building's inauguration occurred in March 2022, and the building is planned to be dismantled and re-assembled three times by 2037, every time on a new site next to the original location. The idea of the LCA is to evaluate the adaptability, durability, and ability to reuse the structural elements to reduce waste and facilitate high-quality building element tracking and management.

Lecture 12: Workshop

At the end of day three, the summer school was summarized through a discussion of the workshop outcomes. The team developed common guidelines for the life cycle assessment of sustainable taller timber buildings.

ORGANIZER/VENUE

The workshop location was Kranjčevićeva Street 2, Faculty of Civil Engineering, University of Zagreb. The location is conveniently within walking distance from the city center, taking a maximum of 20 minutes. The classroom was located on the ground floor for easy access.

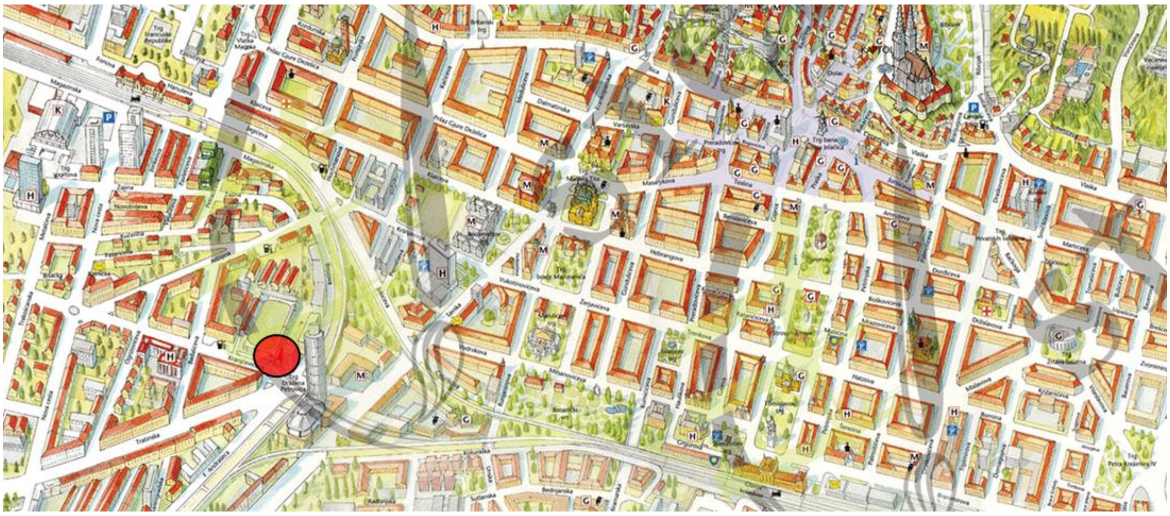

Figure 2: The workshop lasted for three days, starting 19.06.2024, in a face-to-face format in Zagreb, Croatia.

ATTENDEES

Beginning Ph.D. students with a background in Timber Engineering, Architecture, or Civil Engineering. Post-doctoral researchers were also welcome but as a second priority. The workshop hosted 24 students and 8 trainers.

Muheeb	Al-Obaidy
Shady	Attia
Štěpán	Beranek
Joana	Campos
Tatiana	de Oliveira Chiletto
Mansoure	Dormohamadi
Guangli	Du
Song	Ge
Endrit	Hoxha
Bujar	Jashari
Blaž	Kurent
Matthew	Leeder
Jelena	Lovrić Vranković
Emilien	Mary
Fabiana	Moritani
Rafael	Novais Passarelli
Nikola	Perkovic

Chiara	Piccardo
Felix	Quarcoo
Alisa	Resch
Pietro	Rigo
Michael	Salka
Aída	Santana Sosa
Erwin M.	Schau
Katharina	Sroka
Mislav	Stepinac
Marina	Tenorio
Joris	Van Acker
Marko	Veizović
Tianxiao	Yin
Arthur	Duyck
Luka	Vojnovic

Figure 3, Group picture of workshop participants

ORGANIZERS

Shady Attia - Email: shady.attia@uliege.be

Mislav Stepinac – Email: mstepinac@grad.hr

Webpage: https://cahelen.eu/

DETAILED TRAINING PROGRAM

Day 1 – 19 June			
00	REGISTRATION	Mislav Stepinac	8:15
0	Introduction to COST Action HELEN	Mislav Stepinac	8:50
1	Towards Zero Emissions Buildings (Decarbonisation paths and whole life carbon assessment)	Shady Attia	9:00
2	What is mass timber? Building type, construction method or product?	Rafael Passarelli	10:00
3	Whole Life Carbon Calculation (Types of Carbon: embodied and operational, CEN 15804 & Modules A-D)	Erwin M. Schau	11:30
Photo	**Group Photo**	**Photo**	**12:15**
Lunch			12:30
4	Whole Life Carbon Calculation (Timber Materials LCA: Tools and Databases)	Chiara Piccardo*	13:30
Exercise 4			14:30
5	Whole Life Carbon Calculation (Timber Building Life Expectancy)	Shady Attia	15:00
Exercise 5			16:00
Exercise 8	Installation of OneClick LCA	Muheeb Al-Obaidy*	16:30
Day 2 – 20 June			
6	Sustainability of the forestry wood industry chain and timber buildings	Joris Van Acker	9:00
Exercise 6			9:30
7	Dynamic life cycle assessment (Biogenic carbon in timber buildings)	Endrit Hoxha	9:45
Exercise 7			10:30
8	Case Study 1 (InnoRenew CoE building, Izola)	Erwin Schau	11:00
Lunch			12:30
9	Tools for building life cycle assessment: The case of OneClick LCA	Muheeb Al-Obaidy	13:30
Exercise 8	Trainee Project		
Excursion	Technical Museum Nikola Tesla	Mislav Stepinac	15:00
Dinner	School Dinner in City Center	Join Us !	20:00
Day 3 – 21 June			

10	Trainee Project	Muheeb Al-Obaidy	9:00
			12:30
11	Project Presentations	All	13:30
12	Workshop Tall Timber Design Guidelines	All + Attia	15:30
Closing	Closing	All	17:00
Guide Tour	City Center Zagreb Guided Tour	Mislav Stepinac	

*Chiara Piccardo will attend only Day 1.

LCA GUIDELINES & LEARNED LESSONS

The final sessions of the workshop included a larger discussion on the steps needed to perform an LCA and the lessons learned from the workshop. The workshop content was developed based on a framework developed as part of the IEA EBC - Annex 89 - Ways to Implement Net-zero Whole Life Carbon Buildings and IEA EBC Annex 72 - Assessing Life Cycle Related Environmental Impacts Caused by Buildings Activities on Whole Life Carbon Modelling (Attia et al., 2024; Attia & Petersen, 2024; Bertini & Dasse, 2024). The following items reflect the key steps that workshop participants identified as essential for a structured LCA approach based on CEN 15804 (CEN, 2019, 2025).

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1) LCA Method Description

The life cycle assessment (LCA) is an objective process for evaluating the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released into the environment and evaluating and implementing opportunities to improve environmental conditions (ISO, 2006).

1.1 Goals and Scope:

> ***Goals - Determining the purpose of my LCA and achievements regarding the CO_2 release.***
> ***Scope - Determine the type of Construction system or anything else.***

The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials, manufacturing, transportation and distribution, use, reuse and maintenance, recycling, and final disposal (the so-called 'cradle to grave' concept). According to the ISO 14040 and 14044 standards, a LCA is carried out in four phases (see Figure 4) (ISO, 2006, 2016):

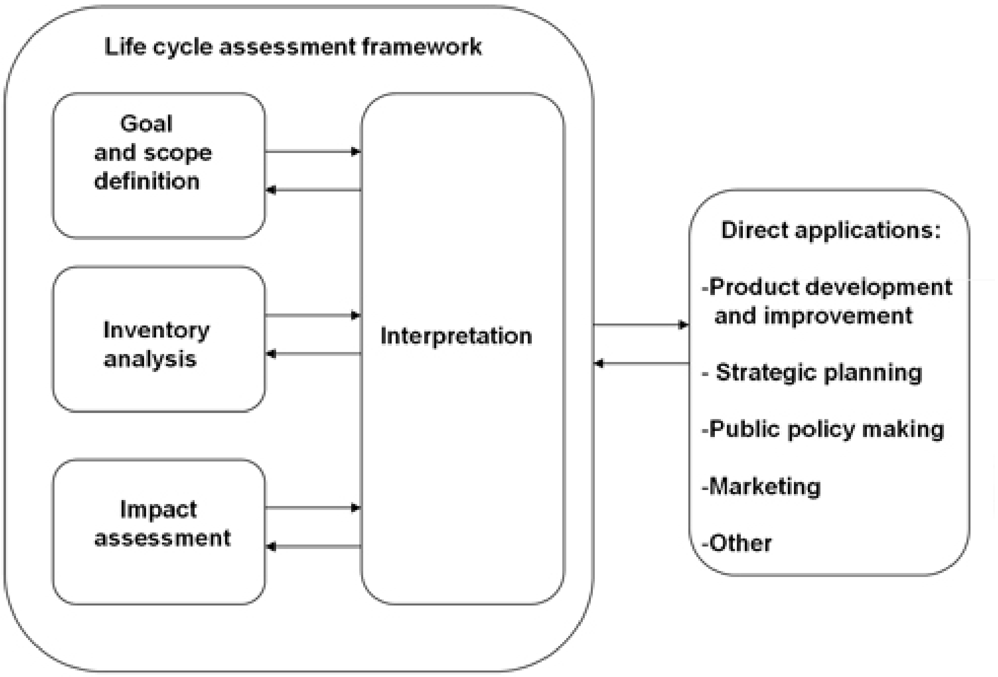

Figure 4. Conceptual Framework on LCA

- Goal and scope definition;
- Inventory analysis: compiling the relevant inputs and outputs of a product system;
- Impact assessment: evaluating the potential environmental impacts associated with those inputs and outputs and
- Interpretation: the procedure to identify, qualify, check and evaluate the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.

1.2 LCA Characterization Method

The characterization method is a crucial step in the impact assessment phase of life cycle assessment (LCA). It involves converting and aggregating the inventory data (i.e., the list of emissions, resource extractions, and energy use) into specific environmental impact categories. This is done by applying characterization factors that reflect the potential impact of each substance in relation to a reference substance for each impact category.

Key Concepts in the LCA Characterization Method

1. **Impact Categories**:

    - Impact categories represent different types of environmental concerns, such as global warming, acidification, eutrophication, and human toxicity.
    - Each impact category aggregates various substances that contribute to the same type of environmental effect.
2. **Characterization Factors**:
    - A characterization factor quantifies the contribution of a specific substance to an impact category relative to a reference substance. For example, in the global warming potential (GWP) impact category, the reference substance is typically carbon dioxide (CO_2), and other greenhouse gases are characterized relative to CO_2 (e.g., methane has a GWP of 28-36 times that of CO_2).
    - These factors are based on scientific models and data that describe how each substance contributes to the impact category.
3. **Calculation Process**:
    - **Inventory Data Collection**: Gather data on all inputs and outputs associated with the product or process being assessed.
    - **Classification**: Assign each inventory item to the relevant impact categories.
    - **Characterization**: Multiply the amount of each inventory item by its characterization factor to calculate its contribution to each impact category.
    - **Aggregation**: Sum up the contributions of all inventory items within each impact category to obtain the total impact.

The characterization method in LCA is essential for translating raw inventory data into meaningful environmental impact categories. It enables the comparison of different substances and processes based on their potential environmental effects, facilitating informed decision-making in environmental management.

1.3 Approaches of LCA:

Life Cycle Impact Assessment (LCIA) Models

- **Characterization Models:** Convert LCI data into environmental impacts using characterization factors (e.g., ReCiPe, TRACI, CML).
- **Normalization Models:** Normalize results by comparing them to a reference scenario, such as regional or global environmental loads, to understand the relative significance of impacts.
- **Weighting Models:** Assign relative importance to different impact categories based on stakeholder values or societal preferences.

Impact Pathway Models

These models link emissions to specific environmental and health outcomes, often using cause-effect chains. For example:

- **Global Warming Models**: Use climate models to predict the effect of greenhouse gases on global temperatures.
- **Toxicity Models**: Predict the impact of chemical releases on human health or ecosystems based on dose-response relationships.

Consequential or Attributional

- **Static LCA** assumes that environmental impacts occur instantaneously and do not change over time. All data is typically aggregated over the entire life cycle, and the analysis is done at a single point in time.

- **Dynamic LCA** incorporates the temporal dimension, allowing for the assessment of environmental impacts as they change over time. This approach considers the timing of emissions, energy use, and other factors throughout the life cycle.

2) Study parameters and models

In a Life Cycle Assessment (LCA), study parameters and models are critical for defining the scope, boundaries, and specific approaches used to conduct the assessment. These elements ensure that the LCA is tailored to the objectives of the study and that its results are meaningful and applicable.

2.1 Key Performance Indicators and impact categories

These are the specific environmental areas of concern that the LCA will address, such as:

- Global Warming Potential (GWP)
- Ozone Depletion Potential (ODP)
- Acidification Potential
- Eutrophication Potential
- Human Toxicity Potential

The selection of impact categories depends on the goals of the study and the environmental issues relevant to the product or process being assessed.

2.2 Study parameters: Outlines the boundaries of the study, including:

- **System Boundaries:** Defines which processes are included or excluded in the assessment (e.g., cradle-to-grave, cradle-to-gate, gate-to-gate).

- **Functional Unit:** A measure of the function of the system being studied, which serves as a reference to which all inputs and outputs are normalized (e.g., "1 kg of product," "1 kWh of electricity").

- **Geographical Scope:** The geographic area that the study covers (e.g., local, regional, global).
- **Temporal Scope:** The time period considered in the assessment (e.g., current year, 50-year period).

2.3 Allocation in LCA

Allocation in Life Cycle Assessment (LCA) is a crucial concept, especially when dealing with systems where multiple products, by-products, or functions are produced in a single process or supply chain. Allocation refers to the process of assigning the environmental burdens (e.g., emissions, resource use) of a shared process or system to the different products or functions it generates.

Allocation Procedures

- **Allocation**: The process of assigning environmental burdens to different products or co-products in multi-output processes.
- Methods include:
  - **Mass Allocation**: Based on the mass of each output.
  - **Economic Allocation**: Based on the economic value of each output.
  - **Energy Allocation**: Based on the energy content of each output.
- The choice of allocation method can significantly affect the results and should be justified based on the study's objectives.

2.4 Biogenic Carbon in LCA

Biogenic carbon storage plays a critical role in LCA, particularly for bio-based products. Accurately accounting for the sequestration, storage, and release of biogenic carbon is essential for understanding the true environmental impact of these products. The inclusion of temporal dynamics, land-use considerations, and end-of-life scenarios further refines the assessment, contributing to more sustainable decision-making.

3) Inventory and Data collection

3.1 Materials quantification and inventory

Creating a material inventory for Life Cycle Assessment (LCA) using Building Information Modeling (BIM) data or a spreadsheet involves several steps. The goal is to extract relevant material quantities from the BIM model and organize them in a format suitable for LCA, where you can then assess the environmental impacts of the materials used in a construction project.

3.2 Life Cycle Inventory (LCI) Models

- **LCI Databases**: Collections of data that represent the inputs and outputs associated with different processes. Examples include Ecoinvent, GaBi, and the U.S. Life Cycle Inventory Database.
- **Process-Based Models**: Represent specific industrial processes or supply chains, detailing all inputs (materials, energy) and outputs (emissions, waste).
- **Input-output models:** These use economic data to estimate environmental impacts by linking industry sectors and their associated environmental burdens.

3.3 Data Source: Primary Data vs Secondary Data

In LCA, both primary and secondary data play vital roles. Primary data offers high specificity and accuracy for the processes being studied but is resource-intensive to collect. Secondary data provides broader coverage and is easier to obtain but may lack the detail and relevance of primary data. A well-conducted LCA often balances both types of data to achieve a comprehensive and reliable assessment of environmental impacts.

Primary data refers to data directly collected from the specific processes or activities being studied. This data is typically gathered through measurements, observations, or direct inquiries from the facilities or companies involved in the life cycle of the product or process under assessment.

Characteristics of Primary Data:

1. **Specificity**: Primary data is specific to the particular system being studied. It reflects the actual operations, technologies, and practices in place.
2. **Accuracy**: Primary data is generally more accurate and reliable for the context in which it is used because it is directly measured or obtained from the source.
3. **Examples**:
    - Energy consumption measured at a manufacturing plant.
    - Emissions data collected from a specific factory's smokestack.
    - Raw material usage reported directly by a supplier.
    - Transportation distances reported by a logistics provider.
    - Environmental Product Declarations (generic or specific)

Secondary data refers to data that is not collected directly from the specific system being studied but instead comes from existing sources such as databases, literature, industry reports, or generic datasets. This data is often used when primary data is unavailable or difficult to obtain or when the study covers a broader scope, which makes primary data collection impractical.

Characteristics of Secondary Data:

1. **Generic Nature**: Secondary data is usually more generic and may not reflect the specific conditions of the system being studied.
2. **Accessibility**: It is typically easier and faster to obtain, often available through LCA databases like Ecoinvent, GaBi, or industry reports.
3. **Examples**:
    - Average energy consumption data from an LCA database for a specific industry.
    - Emission factors for different fuel types sourced from national inventories.
    - Material production data from the scientific literature.

LCA databases play a critical role in assessing the environmental impacts of construction materials and processes. By leveraging these databases, professionals can make informed decisions to enhance the sustainability of building projects. Choosing the right database depends on factors such as data coverage, geographic relevance, integration with LCA software, and the specific needs of the project.

Ecoinvent: While not a modeling tool itself, Ecoinvent is a widely used life cycle inventory database that can be integrated with various LCA software. Its features include Extensive, high-quality data covering a wide range of industries and processes. The data is regularly updated to reflect current industry practices and technologies. Ecoinvent is used in conjunction with LCA software like SimaPro, GaBi, and OpenLCA for accurate data input and analysis.

ICE Database is called the Inventory of Carbon and Energy (ICE) database, developed by the University of Bath, focuses on the carbon footprint of construction materials. Its features include data on embodied carbon for various construction materials. It focuses on energy use and carbon emissions associated with materials. It provides both global and UK-specific data. It is useful for carbon footprint analysis of construction materials and assessing the environmental impact of building projects.

GaBi Database is Developed by Sphera (formerly Thinkstep). It provides extensive LCI data for various industries, including construction. Its features include comprehensive data on construction materials, processes, and environmental impacts. It includes datasets for materials, transportation, and energy use. It is regularly updated with industry-specific data. Its applications are Ideal for modeling and analyzing the environmental impact of building materials and construction processes.

ÖKOBAUDAT is a specialized life cycle assessment (LCA) database focused on the building and construction sector. Developed by the Institute for Building and Construction at the Technical University of Munich (TUM) in collaboration with various industry partners, It provides a comprehensive set of environmental data tailored to the industry's needs.

KBOB LCA refers to the LCA database and guidelines developed by the KBOB (Koordinationsstelle für Bau- und Immobilien-Ökobilanzen)**,** or Coordination Office for Building and Real Estate Life

Cycle Assessments in Switzerland. KBOB is a Swiss organization that focuses on standardizing and promoting life cycle assessment (LCA) practices in the construction and real estate sectors.

INIES (Base de Données INIES) is a French database for Life Cycle Assessment (LCA) specifically designed for the building and construction sector. Managed by the INIES (Information Normative pour l'Analyse du Cycle de Vie des Produits de Construction) organization, it provides detailed environmental data and impact assessments for building materials and construction processes.

3.4 Data Quality Requirements

Specifies the quality and types of data required for the LCA, including:

- **Temporal Representativeness**: How recent the data is.
- **Geographical Representativeness**: The relevance of the data to the location of the study.
- **Technological Representativeness**: How well the data reflects the technologies used.
- **Completeness**: The extent to which all relevant data is included.
- **Consistency**: Ensuring uniformity in the data collection and processing methods.

3.5 Assumptions and Limitations

- Clearly defined assumptions, such as assumptions about product life span, recycling rates, or end-of-life scenarios, are crucial for transparency.
- Limitations, including data availability or methodological constraints, should also be acknowledged to contextualize the results.

4) Modeling LCA

Life Cycle Assessment (LCA) modeling software is essential for conducting comprehensive environmental assessments of products, processes, and services. These tools help users model a product's entire life cycle, from raw material extraction to end-of-life disposal, and assess various environmental impacts, such as global warming potential, resource depletion, and pollution.

Some widely used LCA modeling software is OneClick LCA, SimaPro, INIES and GaBi. Manual LCA Modeling Based on Environmental Product Declarations (EPDs) involves using the information provided in EPDs to perform a Life Cycle Assessment (LCA) for a product or process. This approach is useful when detailed EPDs are available, as they provide standardized, verified data on products' environmental impacts.

4.1 Uncertainty and Sensitivity Analysis Models

Sensitivity analysis in Life Cycle Assessment (LCA) is a technique used to determine how changes in input parameters affect the outcomes of an LCA study. This analysis helps identify which variables have the most significant impact on the results. It can guide decision-making by highlighting which factors are most critical for influencing the environmental performance of a product or process.

Uncertainty Analysis assesses the degree of confidence in the LCA results due to variability and imprecision in data. It helps understand how uncertainties in input data affect the overall assessment results.

- **Monte Carlo Simulations**: A statistical method used to assess uncertainty by running the LCA model numerous times with varied input parameters.
- **Scenario Analysis**: This involves creating different scenarios (e.g., best-case and worst-case) to understand how changes in assumptions affect outcomes.
- **Sensitivity Analysis**: This method identifies which input parameters have the most significant influence on the results, helping prioritize data quality improvements.

5) LCA Visualization

n Life Cycle Assessment (LCA), **visualization** plays a crucial role in communicating results and identifying **hot spots**—areas where environmental impacts are most significant. Effective visualization helps stakeholders understand where to focus efforts for improvement and make informed decisions. Here's a comprehensive guide on how to visualize LCA results and identify hot spots:

Hot Spots in LCA are the stages, processes, or components of a product or system that have the highest environmental impacts. Identifying these areas helps prioritize actions to reduce overall impact.

Comparison Charts are the most famous data visualizations in LCA. They compare the environmental impacts of different products or scenarios, helping in the evaluation of alternatives and making decisions based on environmental performance. For example, a comparison chart showing the GWP of two different building materials.

6) References

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PARTICIPANTS FEEDBACK

See below.

3. University / Organisation / Employer:

1. University of Applied Sciences in Ferizaj
2. Hasselt University
3. University of Bologna
4. Aalborg University
5. University of Mons
6. Linnaeus University
7. University of Mons
8. University of Split
9. ETH Zürich
10. FH Campus Wien
11. University of Galway
12. University of Coimbra
13. University of Ljubljana
14. Mendel University
15. Institute for Advanced Architecture of Catalonia
16. Empa
17. Aalborg University
18. The University of Edinburgh
19. NTNU
20. University of Belgrade - Faculty of Forestry
21. University of Minho
22. University of Bristol

Number of Respondents 22

Number of respondents who skipped this question 0

7. Overall

	Poor	Below Average	Average	Good	Excellent	Number of Respondents
Value of the summer school (time & knowledge)	0% (0)	0% (0)	9% (2)	33% (7)	57% (12)	21
Likelyhood you would recommend this summer school to others (if repeated)	0% (0)	0% (0)	4% (1)	23% (5)	71% (15)	21
Pace of the materials	0% (0)	4% (1)	9% (2)	38% (8)	47% (10)	21
Level of detail for the the summer school content	0% (0)	0% (0)	19% (4)	33% (7)	47% (10)	21
Overall Summer School Evaluation	0% (0)	0% (0)	4% (1)	33% (7)	61% (13)	21
					Number of Respondents	***21***
					Number of respondents who skipped this question	***1***

8. How would you describe your LCA skills after and before the summer school?

	Poor	Below Average	Average	Good	Excellent	Number of Respondents
Before	14% (3)	28% (6)	42% (9)	9% (2)	4% (1)	21
After	0% (0)	0% (0)	23% (5)	66% (14)	9% (2)	21
					Number of Respondents	***21***
					Number of respondents who skipped this question	***1***

Page 3. Open-end Questions

9. Did you hesitate to attend this summer school and did the summer school meet your expectations?

1. I have not hesitated. Summer school met every if my expectstions
2. I did not hesitate to attend as the topic is very relevant to my research and practice. Yes, the summer school met my expectations.
3. Although I wasn't sure it would be a good fit for me at first, I ended up learning a lot about several things that weren't necessarily related to my project, but helped me improve my understanding of biogenic carbon and forestry.
4. completely
5. Yes, it did
6. I look forward to the summer school and my expectations were meet beyond doubt.
7. Did not hesitate + Yes
8. I was excited to participate in the training school and it met my expectations.
9. I am very satisfied
10. No, the summer school definitely met my expectations.
11. I didn't hesitate to attend the summer school and it definitely exceeded my expectations.
12. This summer school fully meet my expectations
13. I was expecting more in detail lectures instead of broad ones about LCA basics. It would have been interesting to see more case study results to get a feel for what would a low carbon building look like as opposed to a high carbon one.
14. It is very good, totally meet my expectations.
15. Yes and no, I think it was really nice but sometimes the time was too short or long for the exercises. I think a bigger focus on the actual exercises would have been nice
16. Yes, it surpassed my expectations.I've learned a new program and met a lot of people who are dealing with timber in their research
17. I had some difficulty with the budget, because transport and accommodation were more expensive than the allowance provided for the participants. However, the summer school met my expectations and I was very satisfied with all the knowledge I learned. I am very grateful for the opportunity to participate and meet highly qualified and renowned researchers.
18. No, quite opposite. I was keen to attend and TS did not only meet but exceeded my expectations.

***Number of Respondents* 18**

***Number of respondents who skipped this question* 4**

10. What specific feature did you like most about this summer school?

1. Cooperation and active groups
2. The most informative component of the summer school was the longer-format exercise in modeling our own LCA.
3. Dynamic LCA, Forestry and sustainably managed forest, Material intensity in engineered wood products, One Click LCA tool
4. presentation of LCA specific to timber, work on the case study
5. Dynamic LCA
6. Learning about the Whole Life Caron Calculation, Dynamic LCA and Use of OneClick LCA. Also, the expert lectures from the facilitators and the network with colleague PhD students.
7. Lectures by trainers
8. Networking
9. Practical work in OneClickLCA
10. Group discussion.
11. Work in the Building LCA program, a visit to the Nikola Tesla museum and a joint dinner.
12. Generally I don't like group work, but in this case one click group work gave me the most knowledge. I think that was the highlight of the training school.
13. Networking and update on the new knowledge in the field
14. Exercises & networking
15. The team project.
16. exercises - trying everything out ourselfes
17. Materials and lecturers were great, also learning new program step by step.
18. Overall, I thoroughly enjoyed every aspect of the summer school. One of the highlights was the team of professors, each highly knowledgeable in their respective fields, and it was a pleasure to meet them. The content covered was extensive and in-depth, providing me with valuable insights into each topic. Additionally, organization and punctuality were commendable, contributing significantly to positive experiences.
19. I liked variety in talks, from detailed LCA to broader forestry topics but most importantly the application using LCAoneClick software. Debates and Q&As were also of great value!

Number of Respondents	***19***
Number of respondents who skipped this question	***3***

11. What did you like least about this summer school?

1. N/A
2. The shorter-format exercises between presentations were not well prepared. The prompts were unclear, the steps necessary to address the prompts had not been demonstrated in sufficient detail prior, and the distinction between which required data to inform responses could be found from the resources provided versus requiring assumptions inadequately explained. The process of finding solutions was also not presented after the fact (written solutions were delivered the next day, but after the opportunity to ask any clarifying questions had passed, so this approach wasn't particularly educational). There was a general state of confusion among the participants, which. considering the average level of intelligence and training, strongly suggests unclear delivery on the part of the presenter.
3. Some of the lectures could be more productive.
4. /
5. Some exercises were done too quickly
6. The Summer school was too short and made the lectures packed , which affected time for discussions and questions.
7. Too much time spent on OneClick LCA explanations
8. -
9. Long time when traveling by bus.
10. I don't think of any part that I didn't like.
11. N.A.
12. Not enough time for exercises, preparation of exercises could have been better to guide us through but let us work on them alone
13. Everything was excellent, so none.
14. Especially in the last part where we did the modelling in our group it could have been a bit more effective to get some main information and then figure it out ourselves instead of step by step following the presenter for each material in each category
15. Nothing
16. I do not think that there are any negative points. Just a quick suggestion for the next training school, we could have had more time to develop practical activities that would have helped us.
17. Too short.

Number of Respondents **17**

Number of respondents who skipped this question **5**

12. Would you recommend this summer school to other scientist or professionals and why?

1. Make more initiatives, keep going.
2. Yes, because LCA is a fundamental tool toward achieveing climate change mitigation goals, which span many disciplines.
3. Absoloutly
4. relevance of lectures and traineers
5. Yes, starting with the basics provides in-depth knowledge of LCA
6. Yes, because of the knowledge that will be acquired and ideas shared during the school
7. Yes - Very intresting
8. Yes! These were days of very valuable content and contact with leading professionals on the subject.
9. Yes, I think that content is good for begginers, but advanced students haveability to ask very competent instructors for additional information.
10. Certainly, if they want to get to know Building LCA, or expand their knowledge in this topic.
11. If repeated, I would put group work sooner (not on the last day). It makes you think more about the topic and it teaches you the most. If it would be done at the beginning, I might have more questions for the lecturers of other topics. It also connects people better. In Erwin's group work I would recommend to have a bit more hands on approach to explaining what was expected from us (I was a complete beginner).
12. Yes, the summer school provides an ideal opportunity for young researchers to contact people in the same field and also learn the newest knowledge
13. Of course, it is valuable.
14. yes
15. Of course I would.
16. Yes, I would definitely recommend this to the entire scientific community. Through my experience, I gained knowledge of both the theoretical and practical aspects of LCA. In addition, networking opportunities were interesting for promoting new initiatives in sustainability and LCA.
17. Yes, I would highly recommend it. Greatly informative and networking as well.

Number of Respondents **17**

Number of respondents who skipped this question **5**

13. General Comments?

1. Thank you guys! Best wishes!
2. Thanks for organizing!
3. Given the large existing building stock in Europe, the next meeting could also focus on LCA for renovations. We might start with renovation principles and circular economy. I know Catherine De Wolf has extensive experience in this area. Then, we can perform an LCA on the renovated building. Given the large number of existing buildings in Europe, it could also focus on LCA for renovations. We might begin with renovation principles and circular economy. Catherine De Wolf, who has extensive experience in this area, could be a valuable contributor. Then, participants can perform an LCA on the renovated building.
4. see you next time for another interesting summer school!
5. No
6. Future summer school period be extended to one week.
7. /
8. Thank you for sharing knowledge!
9. None
10. Shady, you have a wonderful ability to manage a room of students. Also, I felt your answers carry a lot of weight. Keep up the good work.
11. Very much look forward to the next summer school
12. Excellent.
13. In general the summer school was very nice and I liked the mix about learning something and trying it out. However I feel that the sustainability concept of the event could have been a bit better. It seems a bit ironic to talk about sustainability and life cycle of products and then use the nespresso capsulars and one-time plastic cups and plates. So it would be nice to consider that in the future to try to limit the waste as good as possible. But overall it was a really nice experience, thanks a lot for organising
14. Well organised in detail
15. Thank you for organising and delivering this TS. Much appreciated!

***Number of Respondents* 15**

***Number of respondents who skipped this question* 7**