Research Article ISSN 2766-2624

Advances in Earth and Environmental Science

Assessment of Circularity and Minimization of CO_2 Emissions in the Overall Industrial Construction System – The Path to a Sustainable Transformation along the Value Chain: Case Study of a Building Assessment with Madaster

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Submitted: 4 Sept 2026; **Accepted:** 10 Sept 2026; **Published:** 21 Sept 2026

Citation: Kerstgens, J., Kaufmann, M. J., Rieke, L., Schmidt, M., Blanke, C., & Reichardt, J. (2026). Assessment of Circularity and Minimization of CO_2 Emissions in the Overall Industrial Construction System – The Path to a Sustainable Transformation along the Value Chain: Case Study of a Building Assessment with Madaster. *Adv Earth & Env Sci; 7*(3):1-12. DOI : https://doi.org/10.47485/2766-2624.1096

Abstract
The industrial sector is responsible for a large part of the environmental impact. Integrating the circular economy into the planning and operation of industrial buildings can help to reduce resource consumption and environmental impact. This development affects various systems such as the location, the building structure, the building services, the production processes and the logistics. Considering sustainability in each of these areas can help reduce CO_2 emissions and reduce environmental impact. In this context, a study at the Münster School of Architecture (MSA) investigated important aspects of circularity in climate-friendly industrial construction. The preliminary design of a factory building (RMA), evaluation models of circularity and CO_2 efficiency (madaster) as well as factors from production and logistics (IFA, Institute for Factory Systems, Leibniz University Hannover) formed the basis of this study. In this publication, the five active systems mentioned are first roughly outlined. In addition, the aspect of the building structure is considered in more detail in various construction variants. This creates the basis for the overarching goal of evaluating the overall industrial construction system in the context of circularity, taking into account the dependencies between the individual disciplines and subsystems.

Keywords: Sustainability, Circularity, Industrial construction, architecture, factory planning, Assessment.

Introduction

The manufacturing sector is responsible for a large part of the resources consumed and environmental impacts measured by CO_2-emissions. These result both from the factory construction from the building point of view, e.g. in the form of building materials, and from the subsequent factory operation from the process point of view, e.g. in the form of energy and material flows. The levers for the functionality and profitability of a factory are already defined in the planning phase. In operation, only the previously planned concepts are implemented and the design of the building and the production processes can only be insufficiently influenced. For the planning of factories, the IFA and RMA have developed the approach of synergetic factory planning, which links the interior and exterior design of building planning according to the HOAI with the planning of logistical and technical production technology from a process perspective. This planning approach has made a significant contribution to the VDI guideline 5200 for factory planning, which is recognized in industry and research. [1] [2][3][4][5] [2]

At the latest the increasing importance of climate change means that sustainability has increasingly become a central success factor from a building and process point of view in modern industrial construction, in addition to functionality and economic efficiency. Sustainability has become an important megatrend worldwide. In addition to the increasing customer awareness of ecological sustainability, there are also regulatory and economic reasons that increase the importance of more sustainability in companies. The legally fixed prices for emission certificates in the national emissions trading system (nEHS) alone are expected to be €55 in 2024, underlining the financial potential for companies to reduce carbon emissions [2] [6][7][8] emissions in a targeted manner. The framework conditions for a sustainable factory are already defined in the planning phase. At this point, ecological sustainability is significantly influenced by the building materials used in the realization of the factory. However, even during the operating phase, the reduction of losses of energy resources is considered one of the most important goals of ecological construction. [3] [9] [10]

In order to be able to record all environmental impacts holistically and to be able to evaluate different variants at an early stage, a high level of information transparency about the construction and operation processes is required. Complex, manual methods can no longer do justice to the increasing complexity of the ever-increasing amount of data. Building Information Modeling (BIM) as a digital method with a data model at the center provides the technical and methodological infrastructure to document the necessary information and thus to be able to ecologically evaluate the individual elements in industrial construction. [11] [12] [13–16]

Circularity (also known as the circular economy) plays a central role in achieving a sustainable factory. Despite different definitions, it is understood to mean a closed cycle that begins with the environmentally friendly mining of primary raw materials and resource-saving production, enables a long and intensive service life and enables the input materials to be recycled in the best possible way at the end of their service life. At present, however, there are few approaches and instruments for the practical implementation of circularity in industrial construction. The Madaster platform was developed from an international research project for this context, which systematically combines data on components and products with planning data on buildings and can thus make overall statements about the building on the basis of its individual components. In this way, a building resource passport can be created on the basis of an IFC file or Excel file and information on circularity and sustainability can be derived. The aim of this article is to consider different systems of circularity in industrial construction and to apply first evaluation approaches in the context of a study. The aim of the study is to determine sensible building constructions for a mandatory building volume for variable building elements. In addition, further research needs for future approaches are to be derived. In order to consider and analyse a holistic circularity, the industrial building system was divided into five active systems in the life cycle for systematic structuring (see Figure 1). These include the location, the building structure, the building services, production and logistics, each of which will be discussed in more detail below. [17–19] [20].

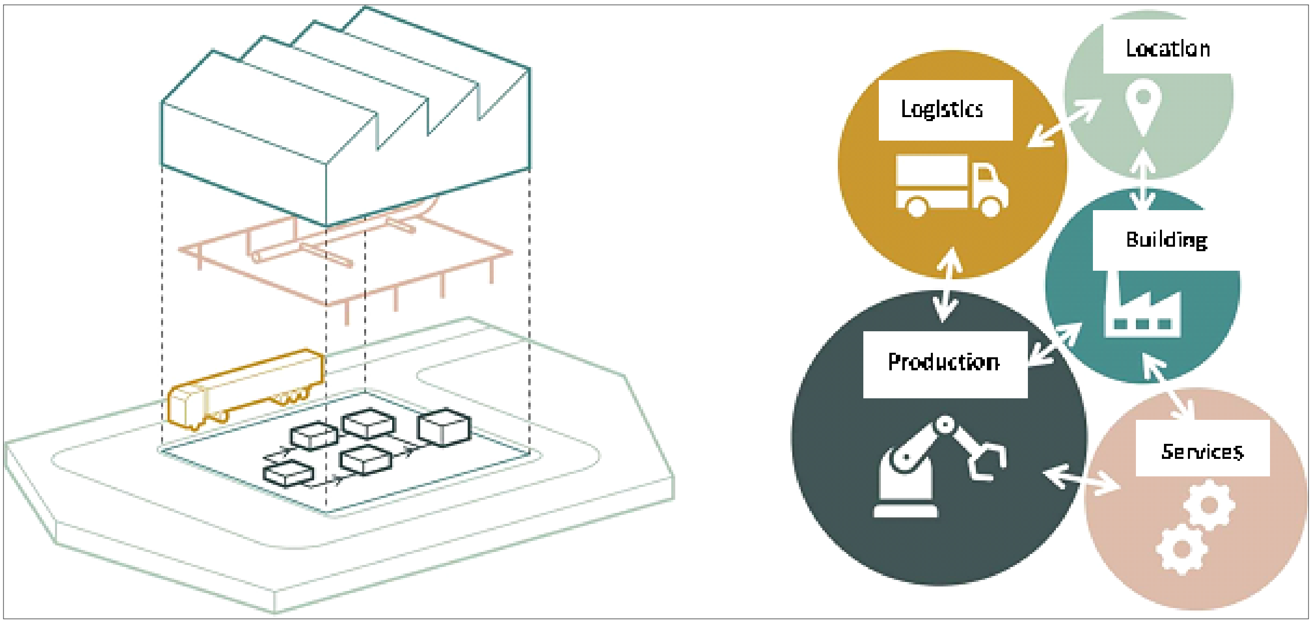

Figure 1: Holistic and synergetic circularity planning and evaluation Holistic Planning / Subsystems of Circularity with Industrial Facilities

Location

The three pillars of sustainability must already be taken into account when selecting the location. These include economic (economic), societal (social) and environmental (ecological) factors. With a focus on ecology, the following generic location factors can be identified for factory planning projects with an influence on CO_2 emissions and circularity: [21]

- Proximity to customers and suppliers: Short transport routes reduce CO_2 emissions.
- The connection to nearby train stations or the possibility of a rail connection: Under the premise of the supply of sustainably generated energy, CO_2 emissions can be minimized even for longer distances. [22]
- The availability of local or district heating through the use of sustainable energy sources: In contrast to natural gas, CO_2 emissions are much lower. If more energy is required for the production processes, another energy source can be switched on at peak times. This reduces the positive effect accordingly. [23]
- Brownfield development: The revitalization of derelict industrial areas reduces land use and supports the reuse of existing infrastructure. Furthermore, the CO_2 emissions caused by a new building exceed those of a conversion many times over. [24]

As part of the study carried out, no location was specified by the client.

Building Structure

Generic factors with an influence on CO_2 emissions and circularity can also be identified for the building structure:

- Modular design: The use of modular, easily detachable components allows for easy disassembly and reuse of materials in future projects. [25]
- Recyclable materials: Choosing building materials that are recyclable at the end of their life promotes the material cycle. [25]
- Adaptability: Building depths, clear heights, the size of contiguous column-free areas as well as the possibility of subsequent internal extensions (e.g. installation of galleries) define the versatility and thus the possibility of possible connection or conversion of a factory building. [2]

These factors were implemented in concrete terms as part of the feasibility study. In order to be able to take into account aspects of sustainability and circularity, the formulation of the building construction, in the modeling software Autodesk Revit, went beyond the usual level of detail for this phase.

The gross floor area of the building is a total of 22,000 m² and is made up of 158 modules with 12 x 12 m axis grids. The primary supporting structure is formed by glulam columns and girders. The main girders are planned as fish-bellied trusses, the other skeletal components have a rectangular profile. Wooden ribbed panels with hemp fibre insulation provide the enveloping building elements - supplemented by vapour barrier and roof waterproofing as a roof, and waterproofing supplemented by waterproofing and wooden façade panels as an outer wall. Partial roof lanterns and vertical aluminium mullion-transom façade strips provide lighting and ventilation and, if necessary, regulate the smoke extraction. Courtyards and the entrance area are glazed over a large area with a view to avoiding excessive solar inputs, taking into account the orientation. Parts of the hall have a recessed gallery floor for later administrative uses, the supporting structure here is also composed of glulam columns and girders. Reinforced concrete floor slabs and stepped point foundations are used as foundations – also due to the lack of alternatives for projects of this scale.

Interface

The model was handed over to the students for subsequent import on madaster in IFC format. In addition to the information already available in the model, such as geometric information and dimensions of the components, the elements were supplemented by other information points, such as the respective cost groups and clear material designations. This enables the unambiguous assignment of the planning elements to the material information on madaster in the further course of work. Since the model was also used for visualizations as part of the feasibility study, a synergy effect was created with regard to the material designations. Only the assignment of the cost groups meant a manageable additional effort in this case.

Valuation Model

Data basis

Product data: Madaster contains material and product databases that are available to madaster users across platforms and by country.

Building data: The madaster platform primarily uses IFC files (4 or 2x3). As an alternative, madaster offers an Excel template. This template is made available on the madaster platform. The source files should contain:

- Geometric properties of CAD objects
- Material description that the madaster system can use to provide information about the materials used in the property.
- Classification coding (DIN 276 is common in Germany), which allows the madaster platform to assign the elements to the building envelope in which the element is located.

In madaster, several source files can be uploaded per object. For example, construction, installation and architecture. You decide which file is activated. If multiple source files are active, madaster will merge them. Madaster obtains all geometric data from the IFC files that are uploaded. This means that madaster itself does not carry out any analyses of environmental impacts, for example, but only scales up existing component effects at building level and finally summarizes them.

Methodology

After the model upload, the enrichment process follows. Madaster retrieves the material data from the imported active IFC files and compares them with the madaster material database. During the import process into madaster, the source files are automatically checked for completeness for important information, such as material description, classification code and geometric data. In addition, based on the material description, the platform links each element in the source file to a corresponding material or product record registered in the madaster database. When the material description of an element is detected, the madaster system automatically links the building element to the product data record. If there is no automatic linking, it is possible to connect the element manually in the platform afterwards ("enrich"). If the planning file does not contain any product-specific information about a building element, for example because it is a public building, the respective building element can be linked to generic product data. These represent industry-standard averages and mean that a building can be fully described, even if specific information is missing.

After uploading, it becomes apparent how complete the information of the object is. If certain elements have not yet been linked to a material, this can still be added manually in the "Enrichment" tab.

The classification of materials and products according to DIN 276 enables madaster to categorize the materials of the products into cost groups. In this way, it is made clear how many materials are located at which point in the object.

Analyses
Mass: By combining the information of building elements with the bulk densities to products and materials, information on the masses of the individual material types can be calculated. This enables a quantification of the building material masses, which is of great importance for the connection to the secondary raw material market.

Circularity: The madaster Circularity Indicator is based on the international open-source material Circularity Indicator (MZI) of the Ellen MacArthur Foundation and was developed to get an idea of how an object performs in the field of circular construction. The madaster CI gives an indication of the degree of recyclability of the object. A fully recyclable property achieves a value of 100%. The circularity indicator evaluates the property under 2 aspects of the life phases:

- the materials used for the construction of the object (ratio of primary raw materials to materials used) and
- how products and materials are processed at the end of their life (ratio of reuse/recycling and waste to landfill or incineration).

Environment: Through the associated product information on the Environmental Product Declaration (EPD) for individual products and also association-wide average values, these effects, which are related to a functional unit of a product system, can be extrapolated to the entire building via the geometries of the building elements. This is possible because EPDs are created for the entire life cycle of a product and thus the phases of maintenance and dismantling are also taken into account. Thus, an overall value for the CO_2 emissions (excluding the use phase (B6)) of a building can be derived.

Financial resource residual values: The known material masses can be linked to known and verifiable market prices for the respective materials in order to derive a current market value. This respective market value is reported on the madaster platform together with the material price source (e.g. London Metal Exchange) and then discounted by flat values for dismantling and transport costs per unit of material quantity. This is intended to generate a realistic value for the builder on the valuation date. This resource residual value is displayed for each material in the respective building layers.

Interfaces
In order to keep the usage effort as low as possible and to further promote the networking of the information value chain of the construction industry, as much data interfaces as possible are integrated. This also increases the user's range of functions. For example, data on environmental impacts from the product EPDs are linked by the respective EPD platforms.

Certification Organizations
The result of this data network, which the client has developed together with architects, planners and other participants in the construction process, is the ability to document the building and its components. Starting with the list of materials, through the connected environmental impacts and possible circularity perspectives of the building fabric, the building owner can use this knowledge for documentation obligations according to ESG and certification requirements.

Commodity Exchange/Material Register
A building is constructed for the period of its functional useful life. Certain building layers are repaired earlier (e.g. interior fittings) than others (construction). It is crucial for the connection of the materials to be exchanged to resource-efficient reuse that there is concrete, reliable information about these materials and that there is an appropriate planning period for the reconnection to the value chain. Information about changes in product and material composition can be added to each documented building at any time. As a result, materials that become available can be presented with a high density of information on the material register and interested market players can secure them from the client. As a result, a financial return from the circular economy comes back to the client.

Variant Comparison
The study project included the comparison of a total of five variants. Four of these will be presented in this context, as they are particularly well suited to show the procedure due to their contrasts. In order to create a manageable frame of comparison, the specified concrete foundation components – foundations, floor slabs, frost aprons and plinth elements – were mandatory for all variants. For the concrete floor slab, an RC concrete with 45% recycled aggregate was chosen. Changeable parameters of the building structure and thus factors influencing the GWP as well as circularity were the components for the skeleton construction, shell and finishing. These were designed by the students in the sense of a steel, wood-steel hybrid as well as wood-straw hybrid construction and wood-hemp hybrid construction and are described in detail below.

In the process of assigning the EPD of the components, different materials with the same properties were compared. The impact of different types of wood and concrete on the CO2 balance was striking here.

If there are several EPDs with different environmental impacts for a material, the EPD with the lowest environmental impact was chosen.

Since an EPD can be assigned to one component at a time in madaster, a product system was created for multi-layer components such as walls and roofs. In the product system, the respective EPDs of the submaterials are added. The product is calculated with the "type" volume, so the materials in the product are given as a percentage of one cubic meter.

Variant A: Steel construction (see also Fig. 2 and Fig. 3)
The structure was constructed using HEB 100, HEB 180 and HEB 260 steel columns and girders. The outer walls are made of ISO panels with a mineral wool core and cover shells made of galvanized sheet steel. The roof is made up of steel girders with trapezoidal sheet metal on top and PIR insulation.

The entire project has a mass of 17.16kt (660kg/m^2).

The circularity indicator output is 83%. 23.7% primary building materials and 76.3% secondary building materials are used. 98.7% of the materials are recyclable. The GWP in the life cycle was calculated as 4.03ktCO_2e.

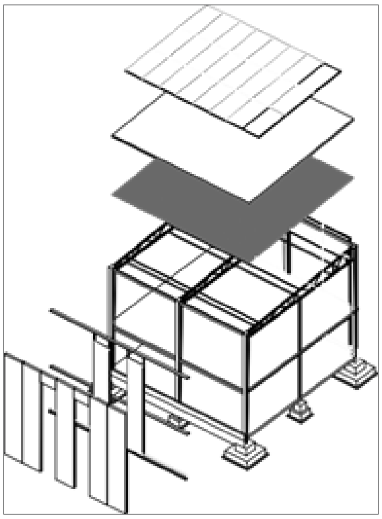

Figure 2: Isometric Building Construction Variant A

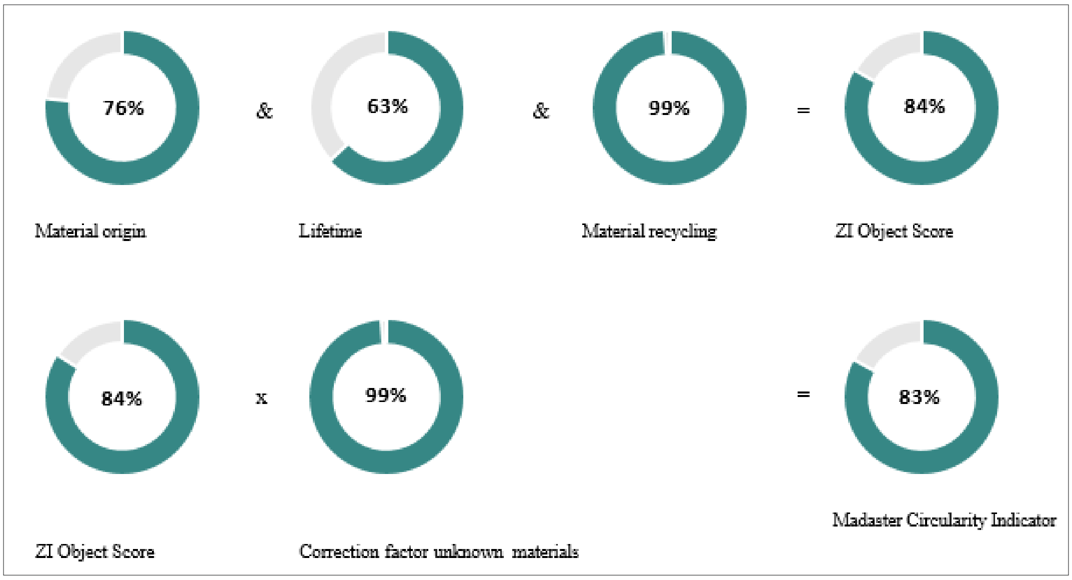

Figure 3: MZI Calculation Components Variant A

Variant B: Wood-steel hybrid construction (see also Fig. 4 and Fig. 5)

The supporting structure was assumed to consist of HEA steel columns 160 to 400 and IPE 300 to 600. The outer walls and the roofs form load-bearing wood sandwich constriction with insulating cores made of mineral wool.

The mass of the project is 16.78kt (645kg/m^2). The circularity indicator is 68%. 59% of the materials are primary building materials and 41% are secondary building materials. The material recycling indicates a reusability of 90.8%. In the life cycle analysis, the building has a GWP of 8.85ktCO_2e.

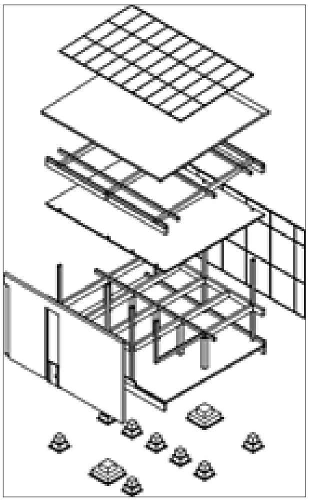

Figure 4: Isometric Building Construction Variant B

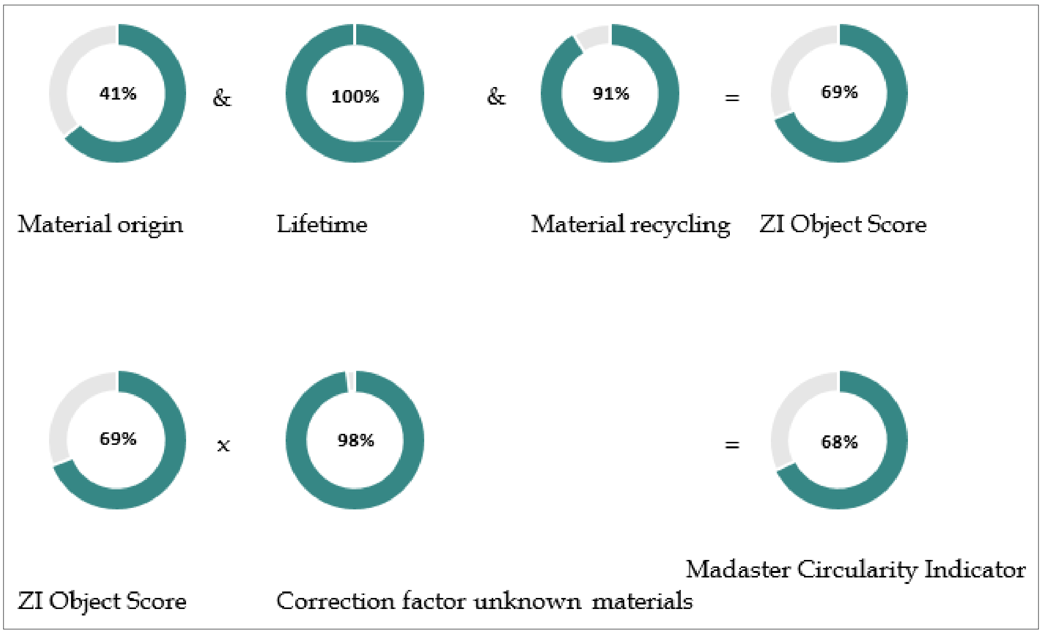

Figure 5: MZI Calculation Components Variant B

Variant C – Wood-Straw-Hybridconstruction (see also Fig. 6 and Fig. 7)

Glulam forms the supporting structure in the wood-straw hybrid construction method. The outer walls are designed as a timber frame construction with infill insulation made of straw bales. OSB boards with straw insulation boards are provided on the glulam beams of the roof structure. The mass of the project is 16.76kt (645kg/m2). The circularity indicator is 29%. The proportion of primary building materials is 95.2%. 4.8% of the materials come from secondary building materials. 89.9% of the materials used are suitable for recycling. The GWP amounts to -0.013ktCO_2e in the life cycle analysis.

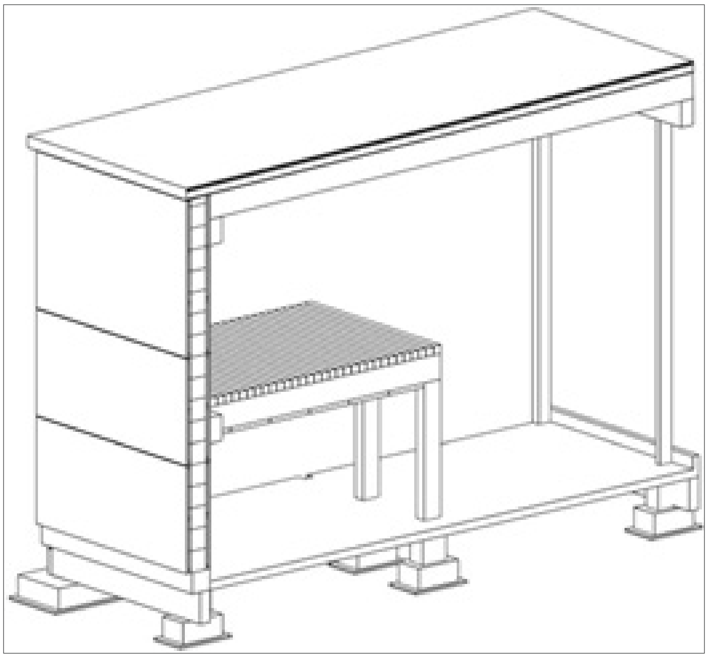

Figure 6: Isometric Building Construction Variant C

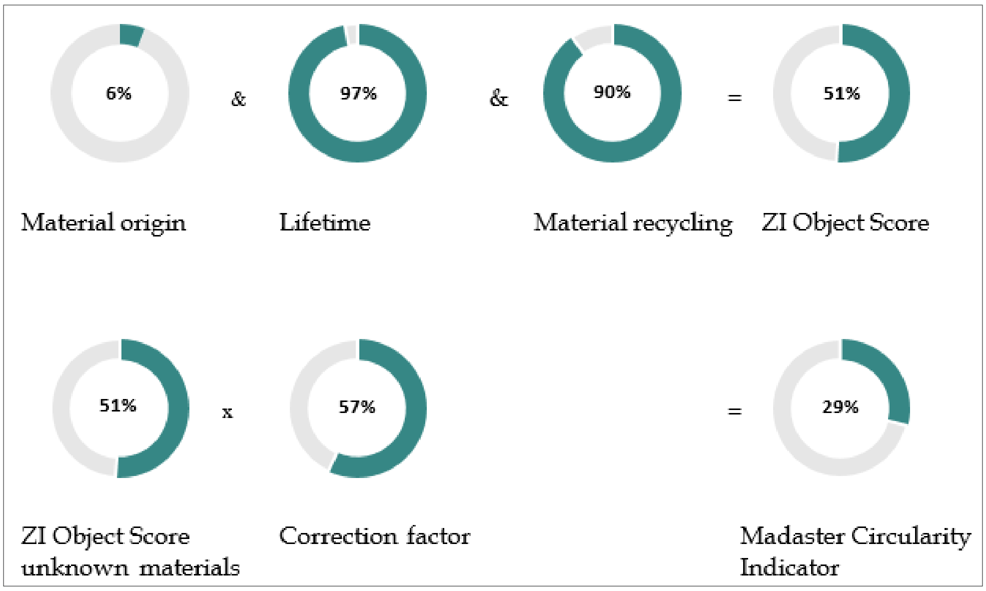

Figure 7: MZI Calculation Components Variant C

Variant D - Wood-Hemp-Hybridconstruction (see also Fig. 8 and Fig. 9)
The supporting structure is constructed with glulam columns and girders. Timber frame construction forms the façade with applied hemp fibre insulation and wooden battens. The roof also has a wooden construction with stuffed hemp insulation in it.

The total mass of the project is 15.54 kt (598 kg/m2). The circularity indicator is 58%. The materials consist of 69.3% primary building materials and 30.7% secondary building materials. 78% of the materials are reusable. The GWP of the life cycle analysis is given as 0.385ktCO_2e.

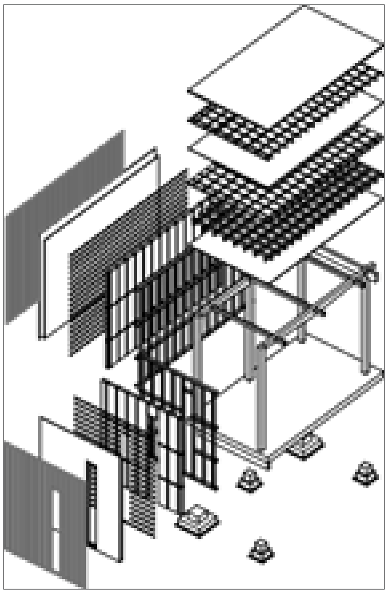

Figure 8: Isometric Building Construction Variant D

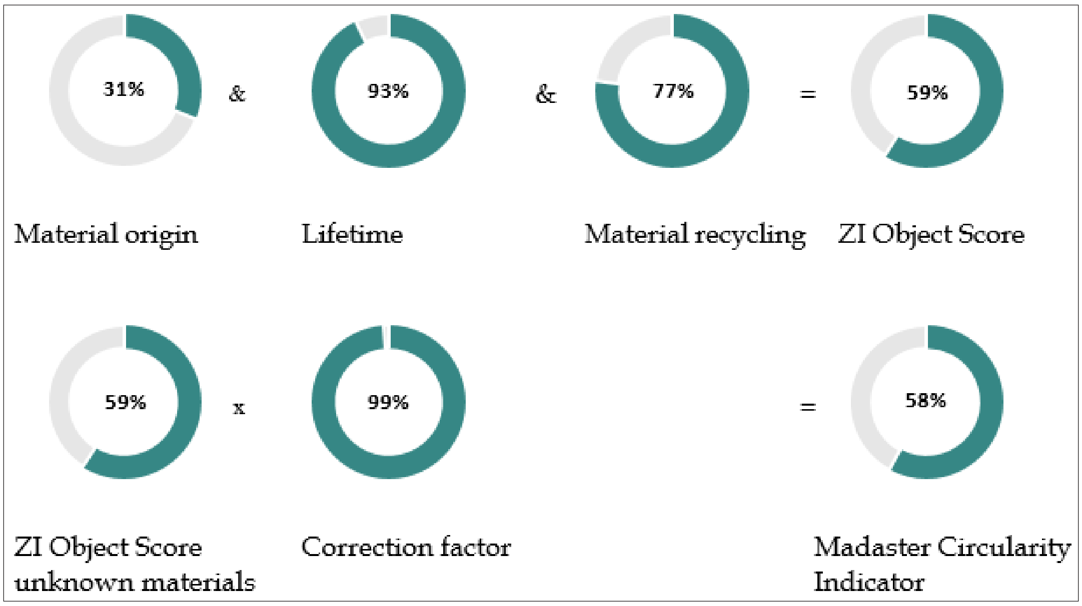

Figure 9: MZI Calculation Components Variant D

Summary Variant Comparison

Mass

The total mass varies between construction methods. The steel construction has the largest mass with 17.16 kt (660 kg/m²). The wood-steel hybrid construction method with 16.78 kt (645 kg/m²) and the wood-straw hybrid construction method with 16.76 kt (645 kg/m²) have almost the same masses. The lowest total mass is the wood-hemp hybrid construction method with 15.54 kt (598 kg/m²).

Circularity Indicator

The circularity indicator varies greatly between construction methods. Steel construction has the highest indicator of 83%, while timber-steel hybrid construction is at 68%. The wood-straw hybrid construction method has the lowest value of 29%, while the wood-hemp hybrid construction method is 58%. The low indicators of variants C and D are mainly derived from the traceability of the materials straw and hemp to nature, as these materials are accordingly not available for use in new buildings.

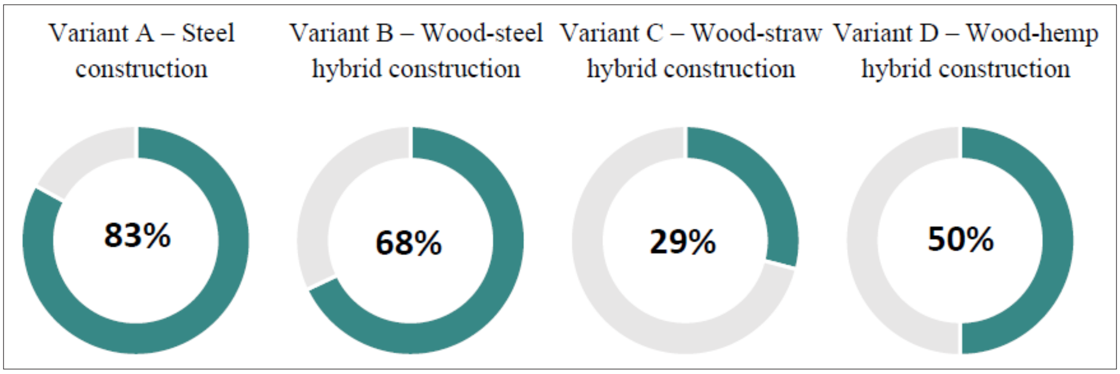

Figure 10: Variant comparison of the madaster circularity indicator

Material origin

The composition of the materials shows differences in the use of primary and secondary building materials. The steel construction method uses 23.7% primary building materials and 76.3% secondary building materials. In comparison, wood-steel hybrid construction consists of 59% primary and 41% secondary building materials. The wood-straw hybrid construction method has a high proportion of 95.2% primary and 4.8% secondary building materials, while the wood-hemp hybrid construction method consists of 69.3% primary and 30.7% secondary building materials. The high proportion of primary building materials in variants C and D can be attributed to the use of organic insulation and the exclusive use of wood for the skeleton components.

Material recycling

Recyclability varies between construction methods. The steel construction shows a high recyclability of 98.7%. Both the wood-steel hybrid construction and the wood-straw hybrid construction have similar recyclability rates of 90.8% and 89.9%, respectively, while the wood-hemp hybrid construction method is 78%. These are due to the recyclability of the components in new buildings or the return of biological materials to the environment.

Life Cycle Assessment (GWP)

With regard to the greenhouse gas equivalent (GWP), the different construction methods naturally show divergent values. The steel construction method has a GWP of 4.03 ktCO_2e, while the wood-steel hybrid construction method has a higher value of 8.85 ktCO_2e. The wood-hemp hybrid construction method generates a GWP of 0.385 ktCO_2e, while the wood-straw hybrid construction method has a negative GWP of -0.46kt CO_2e.

In conclusion, it can be said that the exclusively wooden structures with organic insulation have a better GWP and lower mass than the structures with steel and non-organic insulation. The construction methods with proportional steel components offer a higher circularity indicator, as well as recycling. Depending on the availability of primary building materials, a construction method with wood-straw or wood-hemp construction is advantageous. If this availability does not exist, steel construction and wood-steel hybrid construction offer an alternative by using more secondary building materials.

Building Services

Looking at the entire life cycle of a building, preparing the site and erecting the building structure represent only low CO_2 (equivalent) emitters. The energy required to heat and cool a building during operation exceeds that required for construction many times over. [26]

In addition to the generic factors of the building structure that also apply here – modular design, recyclable materials and adaptability – the following factors can lead to a reduction in emissions:

- Use of passive energies: solar resources, wind, geothermal energy, biomass
- Energy-efficient systems: The integration of energy-efficient heating, ventilation and air conditioning systems reduces energy consumption and the associated CO_2 emissions.
- Building automation: The implementation of intelligent control systems optimizes energy consumption and contributes to resource savings.

No variant considerations were carried out for the building services systems as part of the study project. On the one hand, this is due to the subject-specific, architectural orientation of the students, and on the other hand, an evaluation in madaster is currently only possible on the basis of reference values per m² GFA. An evaluation based on the BIM model is therefore only of limited use.

Production

Due to the long lifespans of factories and industrial buildings, production and logistics have the greatest impact on the sustainability and circularity of the overall system. As a result, the energy and material flows in factories during the operating phase have a significant impact on the CO_2 footprint over the life cycle. Figure 11: Product life cycle in a circular economy based on shows the product life cycle in the context of a circular economy.

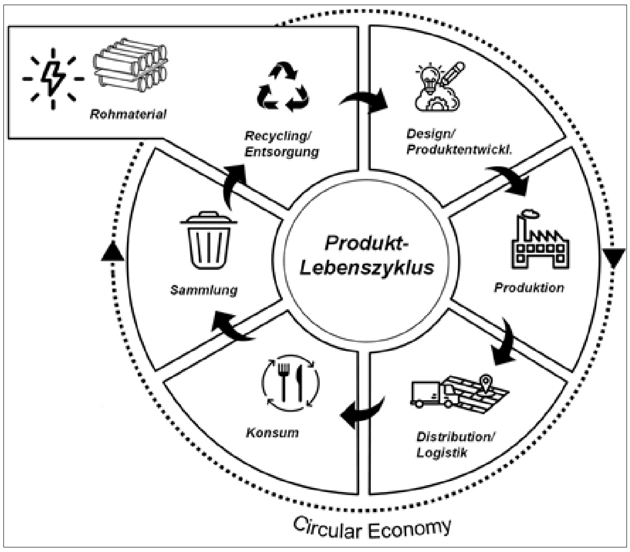

Figure 11: Product life cycle in a circular economy based on [27,28]

In order to balance the CO_2 footprint, the concept of the Greenhouse Gas Protocol (GHG) was developed. Three scopes are distinguished for balancing. Scope 1 takes into account emissions from sources that are directly caused by the respective company (e.g. fuels as energy sources, own vehicle fleet). Scope 2 includes indirect emissions from the generation of purchased energy. Scope 3 covers all other emissions along the entire value chain (upstream and downstream emissions). Lack of information, a complex conversion to CO [29] [29]2equivalents by means of databases (e.g.) and a difficult problem of delimitation and attribution of emissions makes CO_2 [30] [31]-Accounting. [2]

In order to enable resource-efficient production, the path from a linear production economy to a circular economy must be accelerated. According to the cradle-to-grave approach, the entire process along the value chain, i.e. from the product idea or development to recycling, should be taken into account. With regard to circularity in production, it is possible to [32,33] ROESCH [34] identify three fields of design that show potential for action for resource-efficient and sustainable production:

1. Sustainable and production-oriented product design
2. Process technology and process optimization
3. Recycling, use and product return

Sustainable and production-oriented product design aims to design products in such a way that both their production and use are resource-efficient. The foundation for circular production is already laid in the selection of recycled or rapidly renewable raw materials. Furthermore, they should have regional availability and be modular in design to enable easy dismantling for recycling. [33]

Due to the direct coupling of the design fields of product design and process technology, attention should also be paid to sustainable process-side implementation in the design of the products. The choice of process technology is shaped on the one hand by the product design and on the other hand by the functionality and cost-effectiveness of the process. Extensive resource and energy efficiency is currently often still of secondary importance. However, the optimization of existing manufacturing processes has great potential for savings. For example, lowering temperatures and heating up machines and systems can lead to reduced energy requirements. Further strategies for increasing resource efficiency, especially for small and medium-sized enterprises, have been summarised in VDI 4801. Furthermore, the use of process-related waste heat to heat the factory is a good option. By introducing lean methods such as the pull principle or Kanban, overproduction, scrap and inventories can be reduced, which translates into a reduction in the use of materials. Material flow analyses can provide essential potential for improving the use of materials. Furthermore, energy analyses and measures based on them can make a significant contribution to increasing energy efficiency in companies. There is also great potential in the optimization of cross-sectional technologies. Process-related heating and cooling generation, drives and motors, lighting or compressed air are used by almost every industrial company. Avoiding compressed air leaks can be avoided, for example. have a savings potential of 30% and leads to a direct CO_2 [35] [36] [37] [38] [39] [2] Decrease. The third field of design can be located at the end of the cradle-to-grave process. In addition to the recycling of raw materials, it also includes the reuse of individual elements or product components. By upcycling products and intelligent reuse systems in the production chain, the life cycle of products can be significantly extended. The reuse or recycling of individual components of the products thus directly increases the material efficiency of the value chain. This also leads to potential on the cost side, as the material cost share is over 40% of the total costs in the manufacturing industry. These examples underline the complex interactions between product design and recycling. Products should be designed and produced in such a way that all resources used are again raw materials for new products and in this way the natural resources are in a cycle. [40] [41][42].

Logistics

In addition to production, the logistics sector also offers potential for optimisation in terms of sustainability and resource efficiency. In addition to environmental aspects, this can also reduce costs and increase competitiveness. In general, transport in industry and commerce is responsible for a large part of the emissions emitted. A distinction can be made between internal and external logistics. For internal logistics, factory planning in cooperation with building planning lays the foundation. An optimized design of material flows and transport routes within a factory not only has an efficient effect on transport time, but also on resource consumption. The choice of energy-efficient means of transport strengthens this effect. Avoiding empty runs can also reduce CO_2 emissions. Innovative sharing models enable the joint and thus more efficient use of resources such as storage facilities and vehicles. [43] [44]

External logistics usually includes the entire supply chain. The high complexity and lack of transparency leads to a more difficult identification of optimization potential. First of all, the selection of the location of the factory already narrows down a regional selection of possible suppliers but also customers, which already has a considerable influence on transport costs (see Section 2.1). The choice of means of transport also has a significant influence on emissions. If rail is preferred to road, the decision has a significant factor that has a positive effect on the emissions emitted. In addition to the company's own transport, the sustainability of logistics can be increased by optimising packaging. The use of reusable or recyclable load carriers, for example, reduces the production of waste. [45] [46]

Summary and Outlook

The integration of circular principles into factory and industrial construction opens up the possibility of not only increasing resource efficiency, but also significantly reducing CO_2 emissions. Through targeted measures in the areas of location, building construction, building services, production and logistics, companies can achieve a sustainable transformation of their value chain and thus contribute to an environmentally friendly future. In this article, the different active systems were described and partly evaluated within a study with the help of madaster.

The user interface as well as the tabular and graphical representation of components and environmental product declarations (EPD) in madaster offer a comprehensive overview of the current status of the project and the specific features. The layout design developed by madaster and the detailed breakdown of different categories such as the mass of materials used, the circularity indicator with origin information and the recyclability of the materials as well as the greenhouse gas potential (GWP) in the material passport have made it possible to effectively compare the results of the individual construction methods. The integration of the components with the databases required the majority of the time required for the entire analysis. A potential solution to save time could lie in a link directly in the modeling software. The use of the components across projects and the easier mapping of variants would thus be possible. Since all construction methods in this study were analysed with the same IFC file, an increased computational effort was required for the creation of alternative construction methods, which in practice is rather an exception. Using the Variants feature in the project provided an efficient way to test the effects of different materials on the values under investigation without having to create a new project and incur the associated linking effort. Finally, it was possible to integrate the described construction methods into madaster without prior knowledge. Due to the uniform basis of each construction method, it was possible to compare the different results and identify the respective advantages and disadvantages.

However, the results also underline the need for further research. While an assessment of circularity and a reduction of CO_2 emissions based on variants is already possible to some extent from the building point of view, this has so far been largely unexplored with regard to production and logistics processes from a process perspective. The basics and approaches set out in the sections now need to be tested in practice. The aim must be to make all active systems assessable and to consider them in the overall context of synergetic circularity planning and evaluation.

It is not only important to look at the systems individually, but also to uncover and evaluate dependencies between the active systems. For example, Process heat can be used as waste heat from production processes to heat parts of buildings. Another example is air filtration and ventilation systems to be installed from the point of view of building and building services planning, which can reduce pollutant emissions from the processes in the best possible way. These examples show that no isolated solutions, but only a holistic view of buildings, building services and production and logistics processes can improve the circularity of the overall system.

Acknowledgements
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Biography
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Christian Blanke (*1987) After studying wood industry at the University of Hamburg in the field of material flow analysis and value added accounting, he worked at INFRO on research projects on resource availability and cascade use in value chains as well as on the topic of wood resource use in the construction industry. He then worked at Heinze GmbH in the field of market data analysis for the construction industry. At madaster, Christian Blanke is responsible for manufacturer matters on the platform and is responsible for research projects and cooperation partnerships.

Leonard Rieke, (*1995) studied industrial engineering at Leibniz Universität Hannover, Universidad de Alcalá (UAH) Madrid and the University of Antwerp. Since 2021, he has been working at the Institute of Factory Systems and Logistics (IFA) at Leibniz University Hannover as a research assistant in the Factory Planning Department. In research and industrial projects, Mr. Rieke is mainly concerned with cost calculation in the early phase of factory planning.

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