

2 Monitoring environmental impact

An important first step in sustainable material use is to monitor the environmental impact of the construction materials used. This makes the use of materials and the associated environmental impact clear and measurable. Monitoring can be done at both element level and building level. The ultimate goal of making it transparent and measurable is to gradually achieve less carbon in constructions by raising the bar each time.

3 Monitoring environmental impact at element level

Comparison of environmental impact at element level In order to gain insight into the influence of design choices on the environmental impact of construction elements, a study was conducted into the environmental impact of a pendulum column in various construction materials concrete, steel and wood with different qualities. The starting point for this study is a pendulum column with a length of 6.0 m with a fire resistance requirement of 60 minutes and a column load of 500 tons. For this range of variants, the shadow price and carbon footprint were determined for each column variant on the basis of the available data from the national environmental database and MRPI sheets of the relevant suppliers. The results show a large variation in the environmental impact. The shadow prices vary from € 28.8 for the variant with the least environmental impact to € 80.7 for the variant with the greatest environmental impact. It can be concluded that environmental gains can really be achieved through conscious design choices and monitoring. This comparison method also provides insight into how the most sustainable construction can be achieved at material level.

Below is an overview of the 3 column variants with the least environmental impact:

1. Douglas fir tree trunk shadow price: € 28.8
2. economically reinforced prefab (C53/65) concrete column: shadow price: € 31.7
3. high-strength steel column (S460) with fire-resistant cladding: shadow price: € 34.0

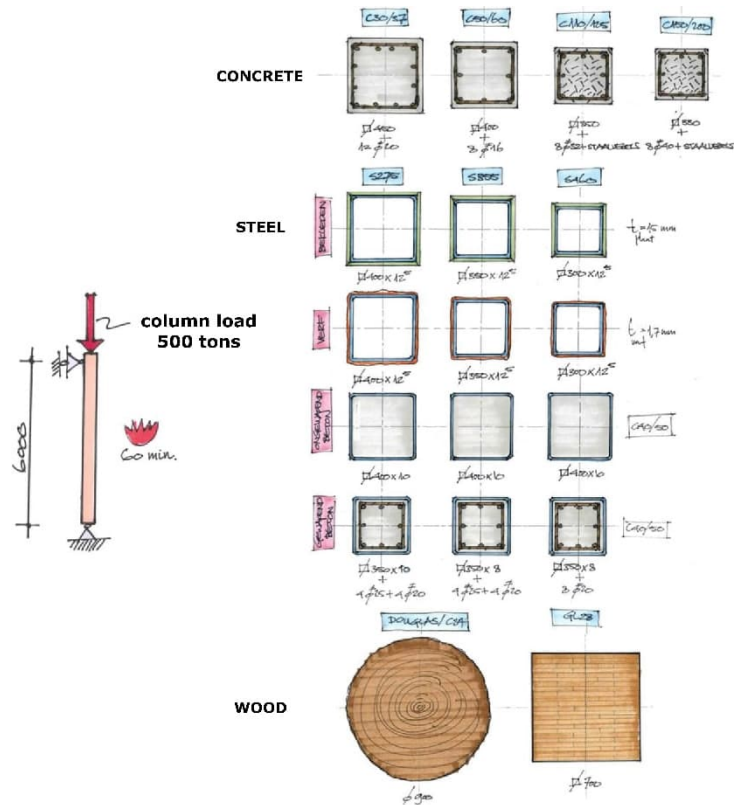


Figure 2: study environmental impact column variants in concrete, steel and wood of a pendulum column (l=6.0m)

4 Monitoring environmental impact complete building structures

In order to move from the environmental impact of standalone construction elements to complete building support structures, ABT has developed a Environmental-Impact-Monitoring (MIM) tool with a link to 3D construction models in REVIT.

4.1 MIM-tool 3D construction models

With this tool, the carbon footprint and shadow price of the modelled support structure are monitored in REVIT in real time. For this purpose, the shadow price and carbon footprint of all construction materials and construction elements have been determined and included in a database. This is linked to the environmental database and to self-developed tools such as the ABT concrete tool, which calculates the environmental impact of a reinforced concrete structure.

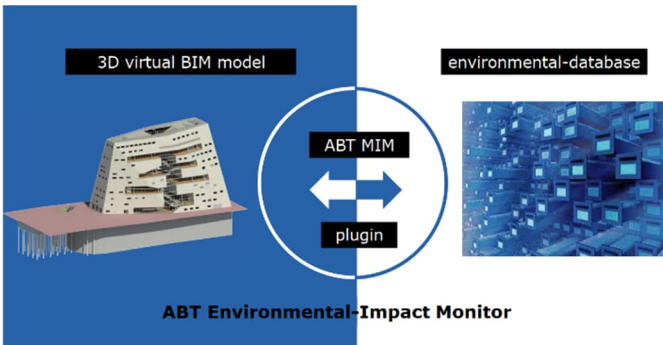


Figure 3: the ABT MIM tool is a REVIT Plugin and connects the environmental database with the BIM-model

During the design of the main support structure, the use of materials and the associated carbon emissions and shadow price of various design options can be continuously monitored. By

subcategorising the construction elements, it is also clear which components contribute most to the environmental impact. There is a distinction made between the substructure and superstructure. The substructure consists of foundation beams and footings, and if present, the foundation piles. The superstructure, it is categorized into floors, beams, walls, and columns.

This makes it possible to steer towards a minimum environmental impact of the support structure. 3D models that have been put together using REVIT are both an aid and a control tool in this respect. The material savings and environmental benefits that are achieved during the design process are measurable by this method and are expressed in the carbon footprint and shadow price for the building.

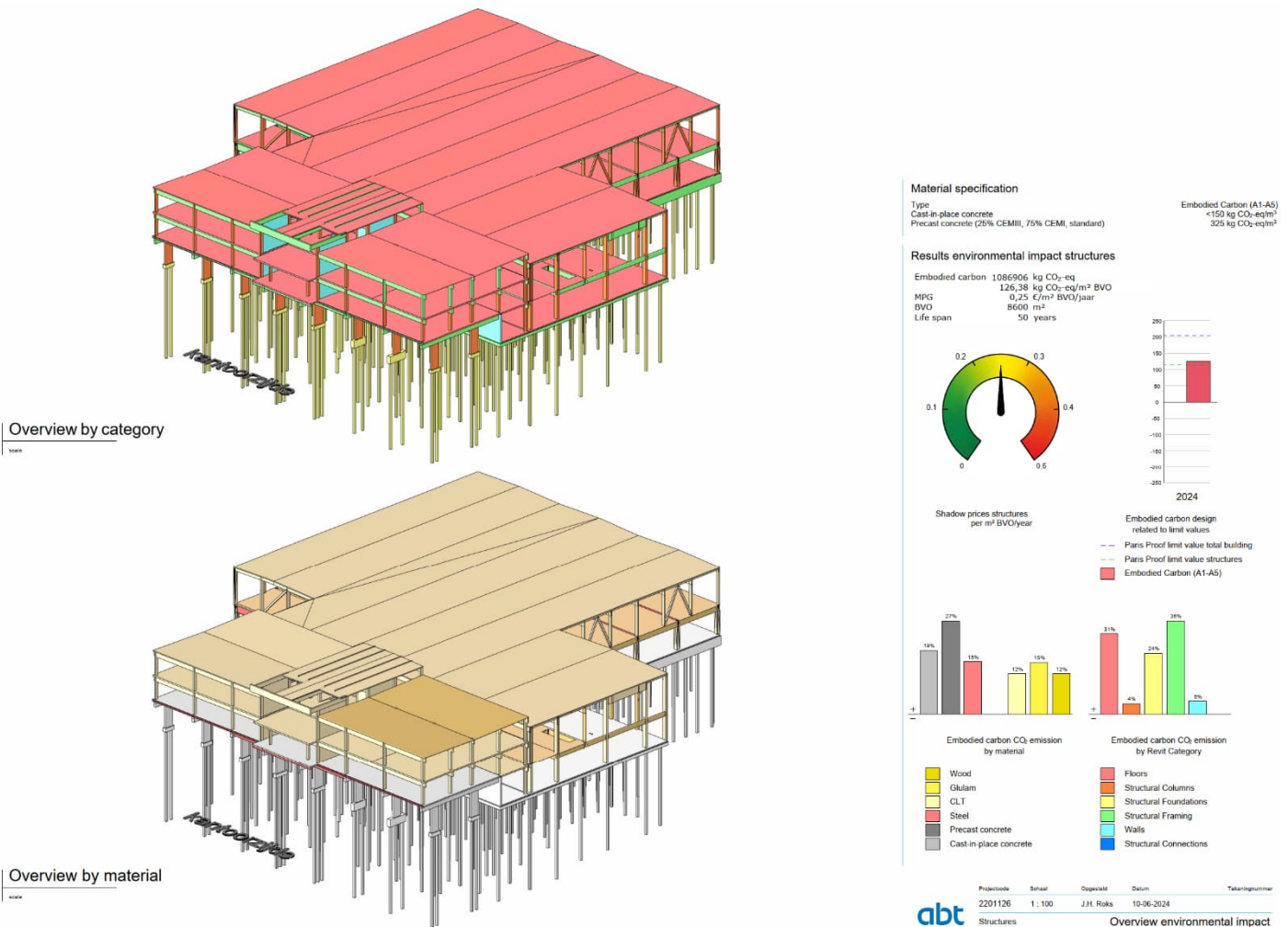


Figure 4: the ABT MIM tool is monitoring by construction materials and by building components

5 Case study Saxion Apeldoorn

Case study new construction educational building Saxion Apeldoorn At an early stage in the design process of the new construction of the educational building of Saxion in Apeldoorn, which opened its doors last school year, the environmental impact of two construction variants was compared.



Figure 5: new construction Saxion School Apeldoorn

The construction variants were designed on the basis of 2 possible building shapes for the new construction, namely a 4-storey L-shaped variant and a 3-storey variant with a canopy over an existing building.

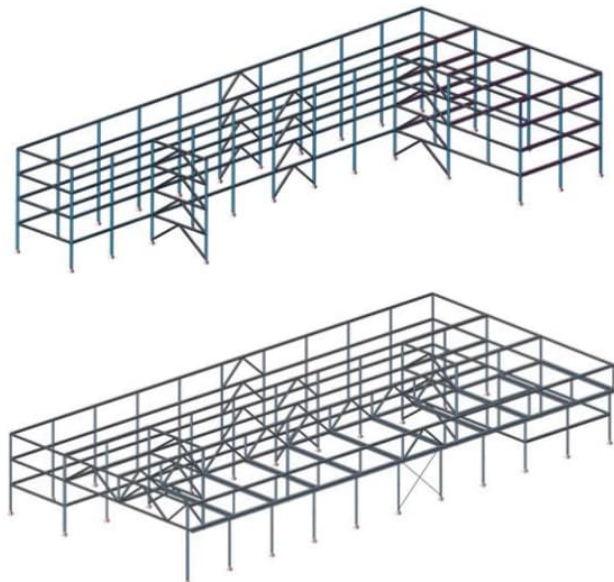


Figure 6: 4-layer L-shaped construction variant (A above) versus 3-layer construction variant with canopy (B below)

5.1 Comparison of 2 alternate set up of Steel skeleton

For both variants, a construction was designed that consists of a steel skeleton of steel columns and beams with channel plate floors. With the environmental impact monitor, the material kilos of the concrete and steel, the carbon footprint and the shadow price were determined for both construction variants. By comparing these with each other, a good picture is created of the material consumption and the environmental impact of both construction variants. On all fronts, the 4-layer design scores approx. 20% better than the 3-layer variant, which can be explained by the more compact design of this variant (see figure below). The total environmental gain achieved by realizing the 4-layer new construction variant amounts to $42 \text{ kg CO}_2/\text{m}^2 * 2,500 \text{ m}^2 = 105,000 \text{ kg CO}_2$. This corresponds to 700,000 travel kilometers by car or 210,000 plastic bottles. A great result!

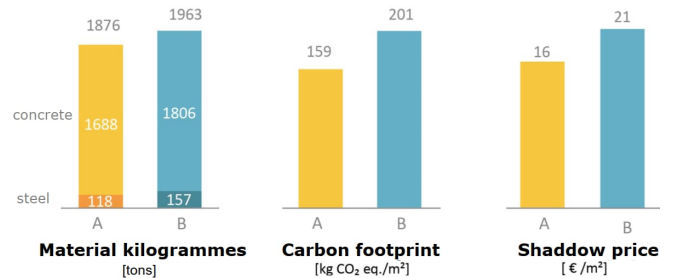


Figure 7: case study construction Saxion Apeldoorn

5.2 Flexibility in lay-out

In addition to the environmental gain achieved in material consumption, the design focuses on flexibility in order to be able to easily adapt the building to changing educational visions and thus extend the lifespan of the building. The construction has also been given a remountable design, so that in the event of demolition the components can be easily dismantled and reused. In this way, a future-proof, flexible and sustainable educational building has been created with a low carbon footprint. * *due to lack of space, this part has been omitted figure: study environmental impact column variants in concrete, steel and wood of a pendulum column (l=6.0m)

6 Building Paris proof

A Paris Proof built environment means that buildings are designed and renovated to meet the climate goals of the Paris Agreement. This task requires a Whole Life Carbon approach. To take the first step towards Whole Life Carbon, the Dutch Green Building Council (DGBC) publishes the calculation protocol for material-related CO₂: Paris Proof Material-Related Emissions. [1] Just like with operational energy use, the protocol indicates a threshold value for the Paris Proof level.

6.1 Carbon Budget Approach

In the protocol, a budget approach has been chosen: the amount of CO₂ that the construction sector is still allowed to emit. Material-related emissions are responsible for 11% of CO₂ emissions in the Netherlands. Within the scenario for 1.5°C warming, we globally have an emission budget of 400 Gt CO₂ equivalent left. If we allocate the budget based on population, this results in 909 Mt CO₂ for the Netherlands. Based on the share of material-related emissions, this leaves room for 100 Mt embodied CO₂ budget for the Dutch construction task (including civil engineering). Without reduction, the budget will be exhausted within 5 to 8 years, so before 2030.

Table 1: the target values for embodied carbon for new construction for the respective year

Paris Proof target values	Embodied carbon kg CO ₂ -eq per m ²			
	2021	2030	2040	2050
living	200	126	75	45
residential	220	139	83	50
office	250	158	94	56
retail	260	164	98	59
industry	240	151	91	54

6.2 Target values embodied carbon

The calculation protocol Paris Proof Material-

Related Emissions enables parties in the chain to calculate the CO₂ impact of their new construction and renovation projects based on their MPG calculations. To meet Paris Proof material-related CO₂-eq., the building must have an embodied CO₂-eq. value per m² GFA that is lower than or equal to the target values for new construction or renovation as indicated in the protocol for the respective year (table 1). The target values are set stricter each year. The premise for this is that the industry, through sustainable innovations, continuously makes their products more sustainable in order to meet the stricter target values. Since approximately 60% of the total amount of building materials is formed by the supporting structure in the budget approach an equal part could be assigned for the embodied carbon in the the structural design.

6.3 Monitoring embodied carbon

By monitoring our designed structures during the design process, the carbon emissions of the structures we design have been made transparent. By consistently doing this for all projects within our consortium, a well-filled database with data on the carbon emissions of building structures is created. This provides good insight into the different structural setups in constructions for concrete, steel, and wood for various building typologies. In the overview of figure 9 the carbon emissions (GWPa) for several building structures for Oosterhoff Group projects are shown. Wherein the green dots represents the wooden structures and the red dots the concrete and steel structure.

6.4 Benchmarking against target values

When benchmarking the embodied carbon against the target values, it becomes clear that most of the projects exceed the increasingly strict limit value for Paris Proof Constructions. It is clear that buildings with wooden structures are scoring better than those made of steel or concrete. However half of the wooden structures are above the critical line. The overview makes it clear that cutting carbon emissions in structural design is urgent to meet the target values of Paris Proof constructions and there is a crucial need for extensive progress!

CO₂ emissions production and construction phase (GWPa) completed projects Oosterhoff group

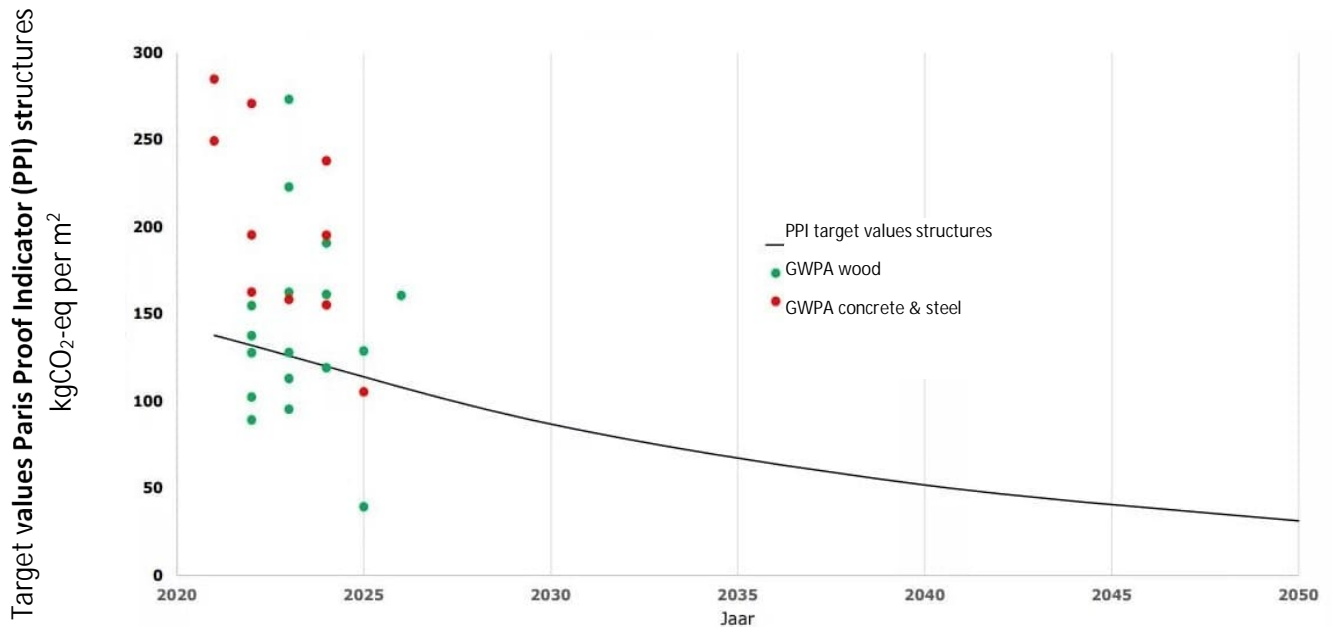


Figure 9 Overview of the CO₂ emissions in the production and construction phase (GWPa) of the Oosterhoff Group (green dots: wooden structures; red dots: concrete and steel structures) and the increasingly strict limit value for Paris Proof Constructions.

7 Comparison Paris Proof Indicator (PPI) residential separating floors

In order to comply with the Paris Climate Agreement and European legislation, CO₂ emissions from construction must be reduced every year. Floors have a major share in the environmental impact of buildings. In order to be able to build Paris Proof, we therefore look for the optimal floor structure for the project within our projects. Since there are many functional aspects to floors, such as fire, acoustics, load-bearing capacity, integration of pipes, it is important to approach the floor structure integrally.

7.1 Variants study

In a variant study, we made an integral comparison between different home-separating floor structures. The key question here: which floors are suitable for building Paris Proof with the associated cost level. What did we compare? The starting

point of the study is a home-separating floor that can span approximately 5 meters. In the floor structure, a distinction is made between variants in traditional concrete, more sustainable concrete and timber construction with associated finishing packages, all suitable for underfloor heating. The material-related CO₂ emissions (PPI) of the floor variants are made clear. The total floor thickness, weight and direct construction costs have also been determined.

7.2 Conclusions comparisons

What does the study reveal? Based on this variant study, we conclude that:

1. an integral consideration of floor variants is necessary for a good assessment rather than a comparison of individual construction layers;
2. certainly when biogenic storage is included, wooden floors score best and can even be made CO₂ neutral;

3. a significant environmental gain can be achieved by making concrete more sustainable, without a major increase in direct construction costs;
4. the difference between the more sustainable concrete and wooden floors is limited when biogenic storage is not included;
5. the structural finishing of wooden floors in particular determines up to approximately 55% of the material-related CO₂;
6. dry screed floors for wood are relatively expensive, but are a good choice for circularity and also for reducing carbon emissions;
7. to limit the environmental impact, the finishing floor can be better made of anhydrite than of sand-cement screed;

8. to limit the environmental impact, the mass layer on floors can be better made of sand/gravel than of foam concrete or by increasing the thickness of the sand-cement screed;
9. the wooden and sustainable concrete variants meet the current requirements of Paris Proof construction. The traditional variants do not meet this by far and are far beyond the target values. Since the target values will be stricter for all variants a continuous improvement is necessary;
10. to meet future requirements for Paris Proof construction, the floor structure will have to be increasingly sustainable by using sustainable materials and by a smarter design of lightweight innovative floor constructions that meet sound and fire resistance requirements;

abt Comparison of Paris Proof Indicator (PPI) for residential floor constructions

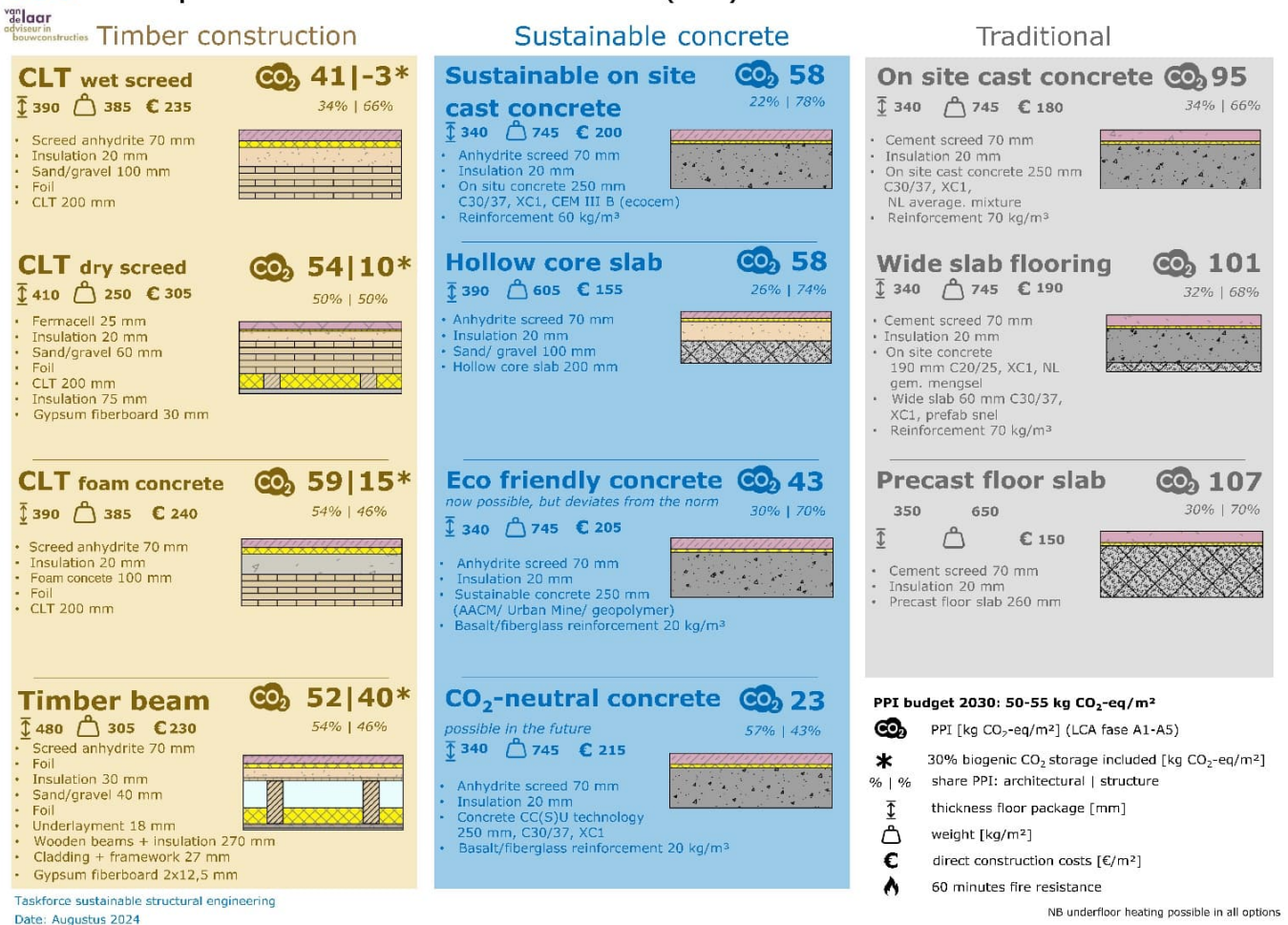


Figure 10 Overview of Comparison variants study Paris Proof Indicator (PPI) residential separating floors

8 Key approaches Paris Proof design

Achieving the target values for Paris Proof constructions involves several strategies to reduce carbon emissions in structural design. Here are some key approaches:

1. Material Selection:
 - Use low carbon materials: opt for materials with lower embodied carbon, such as sustainably sourced timber, recycled steel, and low-carbon concrete;
 - Innovative materials: explore the use of new materials like carbon neutral concrete, X-carb steel or biobased materials;
2. Efficient Design:
 - Optimize structural design: design structures to use materials more efficiently, reducing the overall amount of material needed;
 - Modular construction: use modular and prefabricated components to minimize waste and improve construction efficiency;
3. Reuse and Recycling:
 - Repurpose existing structures: whenever possible, renovate and repurpose existing buildings instead of demolishing and building new ones;
 - Recycled materials: incorporate recycled materials into new constructions to reduce the demand for virgin materials;
4. Lifecycle Assessment:
 - Conduct Lifecycle Assessments (LCA): regularly perform LCAs to understand the environmental impact of materials and construction methods over the building's entire lifecycle;
 - Benchmarking: continuously benchmark against target values to ensure progress towards reducing embodied carbon;
5. Collaboration and Innovation:
 - Collaborate across disciplines: work closely with architects, engineers, and sustainability experts to integrate carbon reduction strategies from the early design stages;
 - Adopt new technologies: utilize digital tools and software for carbon footprint analysis and optimization;

By implementing these strategies, it is possible to make significant progress towards meeting the target values for Paris Proof constructions and contributing to a more sustainable built environment.

9 Conclusion

The transition from energy-neutral to carbon-neutral buildings is essential to meet the Paris Proof standards. Structural engineers play a crucial role in this transition by designing buildings with sustainable materials and minimizing environmental impact. This paper highlights several key strategies to achieve these goals. Using low-carbon and innovative materials such as sustainably sourced timber, recycled steel, and low-carbon concrete can significantly reduce the carbon footprint of buildings. Optimizing structural design to use fewer materials, incorporating modular construction, and reusing existing structures and materials are effective ways to minimize environmental impact.

Implementing tools like the Environmental-Impact-Monitoring (MIM) tool allows for real-time tracking of carbon emissions and shadow prices during the design process. This transparency helps in making informed decisions to reduce carbon emissions. Conducting lifecycle assessments (LCA) and benchmarking against target values ensures continuous progress towards reducing embodied carbon. The Saxion Apeldoorn case study demonstrates the benefits of early environmental impact assessment and flexible design, resulting in significant carbon savings and a future-proof building.

Achieving Paris Proof standards requires a Whole Life Carbon approach, with strict target values for embodied carbon. Continuous monitoring and innovative design solutions are necessary to meet these evolving standards. The paper concludes that cutting carbon emissions in structural design is urgent and requires extensive progress. By implementing the outlined strategies, the construction industry can make significant strides

towards a sustainable built environment that aligns with the Paris Agreement goals.

10 References

- [1] DGBC Dutch Green Building Council and NIBE M.Spitsbaard and M. van Leeuwen. *Paris Proof Embodied Carbon Background Report* 23 November 2021.