Slutrapport för projekt

RECINA Återanvändning av Kompositdelar i Infrastruktur

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RECINA Återanvändning av Kompositdelar i Infrastruktur

RECINA - Reuse of composite parts for infrastructure applications

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Titel på projektet – engelska RECINA - Reuse of composite parts for infrastructure applications
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Förord

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Innehållsförteckning

Sammanfattning

RECINA-projektet fokuserar på utvecklingen av en "cirkulär ekonomisk baserad FRP-brodesign", där uttjänta glasiberkomposit-delar (GFRP) återanvänds som basproduktionsmaterial till broar. Denna projektidé har potential att ta itu med både frågan om hållbarhet inom avfallshantering av glasiberkomposit (GFRP), och minskning av investeringskostnaderna för komposit broar.

Syftet var att återanvända GFRP-isolator, som annars deponeras, i nya produkter/tillämpningar. Under RECINA-projektet har dessa GFRP-isolatorer använts som konstruktionselement i en FRP-brodäck konceptdesignen. Två sandwichpaneler (Fig. 1) har tillverkats och testats för att validera konstruktionens genomförbarhet. Bärförmågan och brottmoden fastställdes och jämfördes med tidigare utförd numeriska analys. Baserat på dessa resultat designades och tillverkades en 7 m lång gånggolfbro. En livscykelanalys genomfördes för att fastställa miljöfördelarna med att återanvända EoL GFRP i den golf bro. I ett större perspektiv har projektet också reflekterat över vilka förutsättningar är nödvändiga för att möjliggöra den ekonomiska lönsamheten av att återanvända uttjänta GFRP-kompositer.

De involverade disciplinerna i projektet inkluderar marin (Marstrom Composite), fordonsindustri (Composite Design), infrastruktur (Eventhotell) och energi (Hitachi Energy Sweden AB). RISE SICOMP och Chalmers deltog med komposit och forskningsexpertis inom broanläggning. Under projektets gång anslutade sig två andra projektpartners, Podcomp och GreenPlank och försåg projektet med GFRP-tillverkningsavfall (PodComp) och återvunnen kompositrall (GreenPlank).

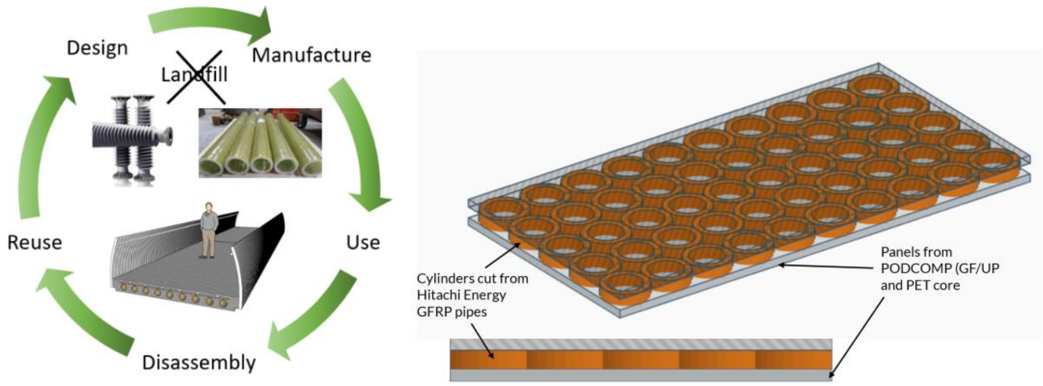


Fig. 1: The RECINA Project concept to re-use end-of-life GFRP insulators in bridges deck applications

Summary

The RECINA project focuses on the development of "circular economy-based FRP bridges design", where decommissioned FRP parts are reused as the base production material. This idea has the potential to address both the issue of sustainability in dealing with Glass FRP (GFRP) waste handling, and also that of decreasing investment cost for FRP bridges.

Specifically, the aim is to re-use GFRP electrical insulator pipes otherwise aiming for landfill for bridge construction. During the RECINA project these GFRP parts have been used as construction elements in the conceptual design of FRP bridge decks. Two demonstrator sandwich panel (Fig.1) have been manufactured and tested to validate the design feasibility. The load bearing capacity and failure modes were determined and compared to numerical analysis previously carried out. Based on these results, a 7 m long pedestrian golf bridge was design and manufactured. A Life Cycle Analysis was conducted to determine the environmental benefits of re-using EoL GFRP in pedestrian bridge deck panels. At a larger scale, the project has also reflected on what conditions are necessary to make possible the economic profitability of repurposing end-of-life GFRP composites.

The involved disciplines in the project include marine (Marstrom Composite), automotive (Composite Design), infrastructure (Eventhotell) and energy (Hitachi Energy Sweden AB). RISE SICOMP and Chalmers participated with FRP and civil engineering research expertise. Also, during the project, two other project partners, Podcomp and GreenPlank, joined and supplied the project with GFRP manufacturing waste (PodComp) and recycled composite decking board (GreenPlank).

Inledning och bakgrund

In 2017, 1118 kilotons of glass fibre-reinforced polymers (GFRPs) were produced in Europe, of which 40 kilotons in the Nordic region, which showed an increase of 10% since 2012. GFRPs represent today 98% of the composite market in the boat and wind turbine sectors. In these two sectors, it is estimated that the amount of GFRP products reaching their end-of-life in the coming years will be considerable (Naqvi et al. 2018). This is a major concern in terms of sustainability, because reuse or recycling of GFRP is rarely considered in the industry today (Halliwell, 2006).

The recent EU directive from 2015 (2000/53 / EC) suggests that 95% of the end-of-life/waste should be reused or recycled. Therefore, new technical solutions for reusing and/or recycling of GFRP composites – at large scales – must be developed.

Additionally, an increasing demand on FRP lightweight structures has been observed in transport and infrastructure applications in the last decade (Oliveux et al., 2015). In addition, the market for pedestrian and bicycle bridges is rapidly growing in Europe as policies promoting shift to healthy and sustainable mobility are introduced. In remote locations FRP bridges are the perfect solution due to little needed maintenance, and in highly populated areas due to prefabrication and their fast installation where the lightweight FRP structures help to significantly reduce the traffic disturbances. However, the initial investment cost is often a barrier for selection of this solution (FALCON project, 2018).

Economic challenges in GFRP waste management are mostly related to the current cost for landfill or incineration, which often make it difficult to justify other more costly alternatives. Even though many industries want to find better alternatives for their composite waste management today (e.g.: Vattenfall recently committed to ban landfilling for their future FRP wind turbine blades to be decommissioned – Vattenfall, 2021).

The main technical challenges in re-using EoL GFRP parts in new applications are: (i) to understand the structure of the decommissioned part, and what is it made of, (ii) gather enough parts of the same type to build the necessary critical mass to develop a profitable value chain, (iii) develop a robust quality control process to validate and certify the parts to be re-used. Also, the design of the product that will be made of re-used GFRP parts should be robust enough so that small variation in dimension and quality of the base EoL material should not alter the quality and functionality of the new product.

Many industries manufacturing GFRP products want to find more sustainable solutions to replace incineration or landfill alternatives that are unfortunately mostly chosen today. However, few research projects have been looking into the subject of re-using EoL (or manufacturing waste) GFRP composite. Most of these projects have been carried out in Europe or in the US. A thorough state-of-the-art review can be read in André et al. (2020 and 2021). We can observe that the interest in repurposing EoL GFRP has grown significantly during the last 2 years.

A recent example of successful re-use of EoL GFRP in new structural application is the construction of a pedestrian bridge in Poland by the polish company Anmet (Composite World, 2021), see Fig. 2.

This bridge is the first of its kind in the world. It is a great achievement as it gives a concrete example of how to re-use blades in new structural applications such as bridges.

Fig. 2: World first pedestrian bridge made with decommissioned wind turbine blades, Anmet, Poland, 2021

The RECINA project aims to contribute to the development of a "circular economy-based design of FRP bridges", where decommissioned GFRP parts are used as the base production material. This approach addresses both the issue of sustainability in dealing with GFRP waste handling, and also that of decreasing investment cost for FRP bridges. The possibility of extending the service life of GFRPs while at the same time minimising their impact on the environment are considered highly favourable and industrially relevant.

In the long term the project has the potential to benefit industries with large stream of composite structures (e.g. wind power, boats, construction, vehicles) and the recycling industry by encouraging a more circular use of materials. It will also create opportunities for new entrepreneurs, and provide a more resource-efficient society, which in turn reduces the environmental impact of these materials. Finding new climate-smart applications in transport infrastructure for these recycled streams would provide an opportunity for increased utilization of today's end-of-life GFRP composite materials. That will also increase competitiveness of the Swedish transport infrastructure sector by featuring innovative and sustainable solutions.

To this end, RISE SICOMP and Chalmers University of Technology are teaming up in this project with Hitachi Energy, Marstrom Composite, Composite Design Sweden and Eventhotell to work on innovative pedestrian and bicycle bridge deck concepts where the base material is decommissioned GFRP electric insulators from Hitachi Energy composite manufacturing plant.

The expected results from the project are (i) the conceptual design of FRP pedestrian bridge using decommissioned GFRP pipe, (ii) a greener production line by reaching near zero production waste at Hitachi GFRP pipes plant and (iii) trigger circular economy design mind set for large GFRP parts in the infrastructure sector.

A demonstrator has been manufactured to validate the feasibility of our solution for "circular economy based FRP bridges deck design". Four of the project partners (Composite Design, Marström, RISE SICOMP and Chalmers) were also involved in the construction of Sweden first FRP pedestrian bridge in 2017. It was a strong source of knowledge in the RECINA project.

Genomförande

Project partners:

The project was initially composed of RISE SICOMP AB, Chalmers, Hitachi Energy Sweden AB (ABB AB at the start of the project), Composite Design AB, EventHotell AB and Marström Composite AB. During the project, two other companies joined the project, PodComp AB and GreenPlank AB (see Fig. 3).

Fig. 3: The RECINA Project: project partners

Work packages and method used:

The RECINA project is divided in 4 work packages (WP) covering Project Management and Dissemination (WP1), Classification of available GFRP pipes to be re-used at ABB (today Hitachi) (WP2), Conceptual Designs of FRP pedestrian bridge parts (WP3), and Proof of concept and experimental testing (WP4). (Fig. 4).

The technical work packages were formed to have a chronological development in the project, with a systematic approach built on:

1. the mapping of the available material
2. the technical client demands and requirements
3. a brainstorming for generating conceptual designs
4. the conceptual design selection, detailing and structural analysis
5. the prototype manufacturing and testing
6. reflections on how to improve the material flow and qualitatively determine the environmental benefit of re-using GFRP pipes.

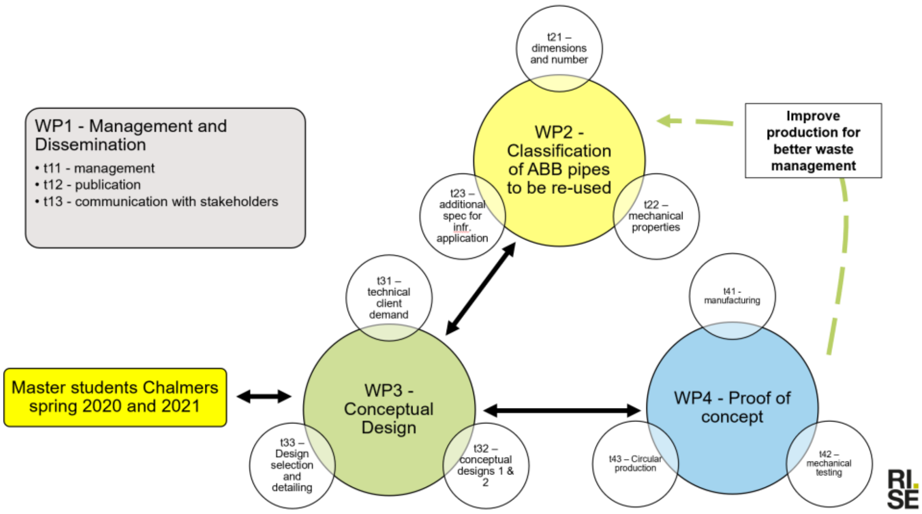


Fig. 4: Work packages and associated tasks

- *WP1: Project management and dissemination*

The project was carried out during 2020-2021, i.e. during the outbreak of the Corona pandemic. All project meetings were carried out digitally, which was of course limiting the possibility for visiting the manufacturing lines and equipment at the project partners' facilities (Fig.5). The RECINA project team, however, overcame this issue by showing a lot of flexibility and adaptation to the situation.

Meeting	Place	date	Activity in Focus
Project granted!	Teams 1	March 2020	Kick off, admin, budget, …
Spring 2020	~~F2F~~[1] - ABB – RISE (Piteå)	~~April~~ May	Understanding the "raw" material
Mid 2020	Teams 2	September	Client demand and Conceptual design
End 2020	~~F2F~~[2]-Composite Design	December	Seminar 1 on conceptual design
Spring 2021	Teams 3	March 2021	Detailed design and manufacturing
Spring 2021	Teams 3b	June 2021	Tests, large demo, circular design
Fall 2021	~~F2F~~[3]-Marström	September	Seminar 2 on demonstrator, test results
Final meeting	Teams 4	December	Final report, achievement, budget

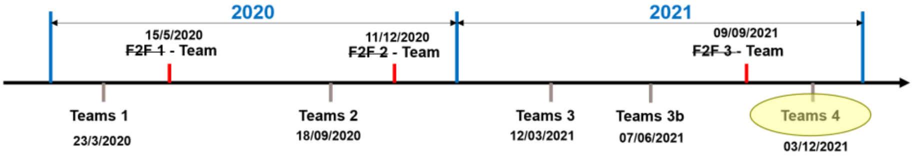


Fig. 5: RECINA: project meetings progress 2020-2021

The project progress and results were disseminated in several workshops, meetings and conferences (see the list further down in this report).

Additionally, communication with other project groups in Sweden and in Europe, working with similar topics of managing EoL composite structures have been taking place.

- *WP2: Classification of ABB pipes to be re-used (ABB became Hitachi Energy during the project)*

The first technical WP has been focusing on mapping the GFRP pipes manufactured at Hitachi and that are scrapped when failing to pass the quality process.

The GFRP pipes are the core structure of electrical insulator that Hitachi manufactures in Piteå, Sweden. They are made using the wet filament winding manufacturing process with glass fibers and epoxy matrix. The entire insulator is made of three main parts: the GFRP pipe, a silicone rubber housing with sheds and two aluminum end fitting flanges. Depending on the market demand, these insulators vary in length and diameter, and the section of the same insulator can also be circular or conical. The length can be up to 15m and outer diameter up to 1m (see Fig. 6).

Fig. 6: Composite insulator manufactured at Hitachi, Piteå.

During the manufacturing process, the insulators are going through numerous quality control to ensure that the quality requirements of the product are met, and to be able to detect any defect as early as possible in the manufacturing process.

The main functions of these insulators in service are to electrically insulate (not allowing current to pass through the material), mechanically support and separate electrical conductors in vital equipment (transformers, bushings, beakers) in power grids for transition of electrical energy e.g., from a hydro power plant or wind park to a densely populated area.

If the electrical insulation is compromised by defects in the material the insulator needs to be scrapped to not cause electrical flash overs and power outage in the electrical power grid. These defects are usually very small and are not influencing the mechanical capability of the insulator.

Another partner joined the project to supplying composite manufacturing waste

In the project proposal for the RECINA project, the focus was only on re-purposing manufacturing scrap from Hitachi (GFRP pipes). However, during the course of the project, in particular after the brainstorming session and the generation of conceptual designs, it became obvious that a manufacturing scrap from another Piteå composite company, Podcomp, could be used in combination with the GFRP pipes from Hitachi.

Podcomp is a company that is mainly manufacturing composite bathroom modules for the construction sector. The modules are made of glass fibre / unsaturated polyester and PET core sandwich panels. These are used for the floor, walls and ceiling parts of the modules.

Fig. 7: Composite bathroom module during production at Podcomp, Sweden

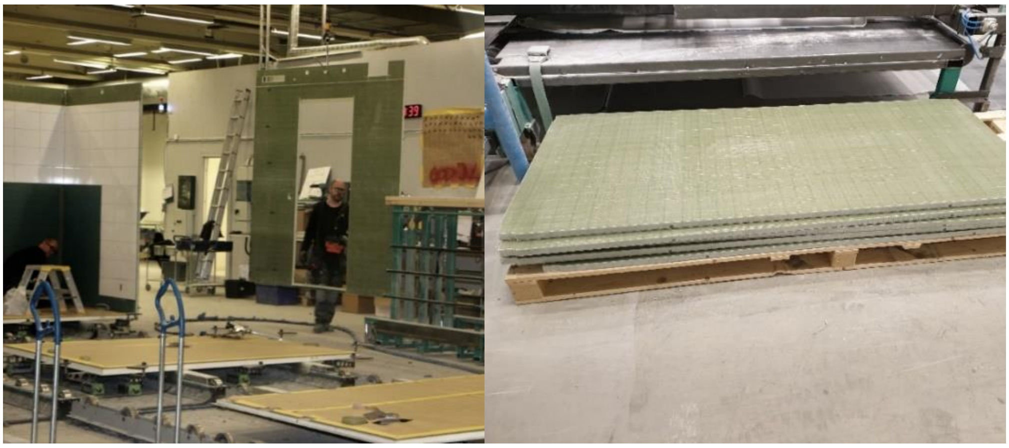


Fig. 8: Cut-outs for door opening and resulting composite panels

During production, cut-outs are made in the walls to provide openings for windows and doors. These cut-outs can be up to 2 x 1m for the door opening. Such composite panels are great structures to be re-used in other applications: they are brand new and have high quality. In addition, their dimensions allow both for a large range of new applications and for easy transportation if to be processed somewhere else.

Today, Podcomp produces approximately 10 composite bathroom modules per day.

- *WP3: Conceptual Design*

Based on the mapping of the material available from WP2 and on the client demands and requirements, a brainstorming process was carried out to generate concept design ideas. Preliminary ideas were thereafter evaluated based on the manufacturability of the design, but also on the robustness of the concept to absorb the variation of the GFRP pipes flow in terms of dimensions and properties. All project partners participated in this process.

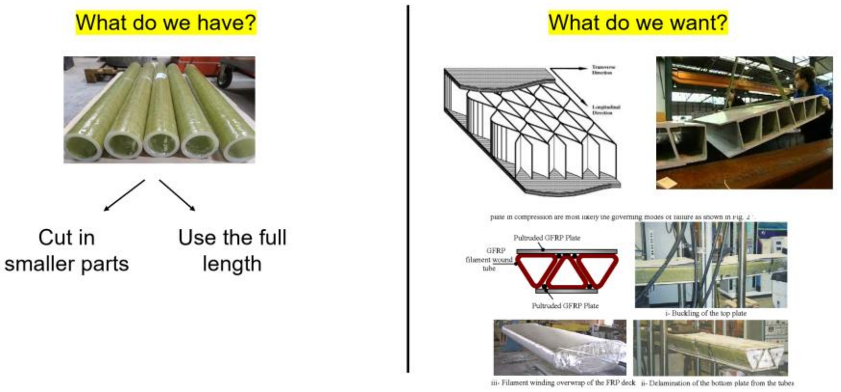


Fig. 9: First step during the concept design generation: What do we have? What do we want?

The most promising design was thereafter further investigated using numerical analysis at RISE and Chalmers. A detailed study of the manufacturing process was also carried out together with Composite Design and Marström Composite. During the entire process, the principles of circular design were in focus: the final design should be able to ease the future disassembly or recycling process.

Some other concept designs were also further investigated using numerical analysis in order to obtain preliminary quantitative results and widen the range of potential applications. These other concepts were mainly for wall and balcony application (Chalmers and Eventhotell).

- *WP4: Proof of concept*

Two prototypes of the deck panel were manufactured based on the concept developed in WP3 (Fig.10). Mechanical tests were carried out and compared to the estimations obtained from the numerical analysis conducted in WP3. Very good results, in agreement with the estimated failure load, were obtained.

Fig. 10: Manufacturing of deck panel prototype

We also approached a possible end-user for a bridge made with the decking panels developed in the project. Mölndal Golfklubb (Mölndal GK) needed to replace an old and degraded 5 m long wooden bridge. The RECINA project team decided to work on the design of a simple small bridge made with re-purposed GFRP structure. Both the decking system and the girders were recovered from manufacturing scrap, i.e. the final bridge was approximatly 90% made of recycled or re-purposed material.

To quantitatively estimate the environmental benefit of re-purposing GRFP to manufacture this bridge, the energy utilization during the different production steps was reported and analysed using LCA approach.

Given the fact that the bridge was the first of its kind, discussions on how to optimize material transport and manufacturing processes were made during this part of the project. These discussions paved the way for a potential following research project where circular business models could be developed for such product.

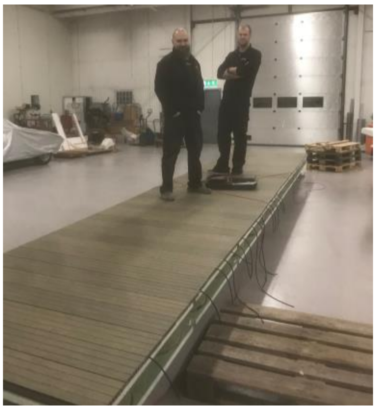


Fig. 11: Bridge prototype during assembly at Composite Design

Resultat och diskussion

- *WP2: Classification of the pipes to be re-used*

During manufacturing, approximately 75 % of the scraped insulators are GFRP pipes without flanges and silicone. The most common defect in rejected pipes are:

- Small contamination that can be conductive
- Scratches on the inner surface (liner)
- Voids/air inclusions
- Machining failures
- Dry inner surface (liner)
- Impregnations defects

However, these are brand new, stiff and strong GFRP pipes. The defects are very small compared to defects allowed in wind turbine blades and boats and are neglectable from a mechanical point of view. Fig. 12 shows an example of GFRP pipes that sometimes need to be scraped and sent to landfill.

Fig. 12: Example of GFRP pipes

Hitachi Energy is constantly working to reduce the waste and reducing the footprint by,

- Work with continuous improvements to reduce the number of GFRP pipes that needs to be scrapped due to defects.
- Optimize utilization rate of the GFRP pipes to reduce production waste
- Participate in research projects to find future alternatives to landfill e.g.,
    - Shredding scraped pipes to granulate for cement- based products. (RECYTAL project, 2017)
    - Recycling chemicals and fibers by thermochemical conversion methods e.g., pyrolysis.
    - And in in this project re-use GFRP pipes in other structural applications.

The factory loading and production mix in the Hitachi insulator factory in Piteå vary from year to year. Obviously, this means that the flow of scraped pipes is not constant in terms of dimensions and volumes when it is heavily dependent on the market demand for isolators.

Table 1 shows the top five scraped tubes during 2020. Their high quality makes them a very good candidate for re-use in other structural applications. However, the big challenge is the fluctuating flow of scraped pipes which makes it hard for a supply chain to handle and predict availability of incoming materials to another structural application than the insulator was initially intended for.

Table 1: The five most common scraped pipes during 2020.

Position	Shape	Inner/outer diam [mm]	Length [mm]	Fiber angle [°]
1	Cylindrical	310/334	2000	±38
2	Conical	120/162	150 2000 800	±25 ±25/87/±25
3	Cylindrical	321/348	3200	±28
4	Cylindrical	130/148	3200	±36
5	Conical	210 / 228	700 1500 600	±42 ±51

- *WP3: Conceptual Design*

The end-user demands and requirements were first analysed to better understand what type of design was needed.

Essential requirements for building components are different than the requirements for bridge deck applications.

The most relevant requirements for building components are:
1. Mechanical resistance and stability
2. Safety in case of fire
3. Hygiene, health and the environment

Additionally, it is very important not to make the recycling of the new products more complicated that the original material/product, and the cost should not be more than existing traditional solutions.

The selection of a bridge deck system depends on multiple important factors such as structural demands, weight, initial cost, maintenance requirement and end-of-life management. Most of the time the cost is the governing factor, especially the initial cost. The deck is the most vulnerable component in a bridge as it is the most exposed element to weather and imposed loads. The bridge deck needs to be connected to the girders for both gravity and uplift loads. FRP decks are lightweight and at the same time have high mechanical properties such as specific strength and stiffness, FRP decks have also low maintenance cost and are easy to manufacture in prefabricated production process. Regarding the whole bridge, with main load bearing elements made of GFRP (e.g. wind blades as shown in André et al. (2020)), the waste management is simplified by using similar materials through the entire bridge as the pipes to be used in the decking are epoxy based GFRP.

Two brainstorming sessions were conducted to understand the base product (GFRP pipes) and allow ideas to grow and mature between the two sessions. At the beginning of the session, we saw the following possible applications:

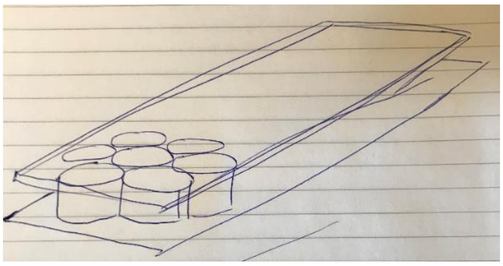
- Decking systems for pedestrian bridges
- Concrete filled tubes as durable column and pile components
- Buss stations, small parkings, bike stations
- Catwalks and Balconies
- Handrailings

In a primary stage of ideation around the re-use potential of these GFRP pipes, the main focus was on finding a robust deck design independent of their variation both in terms of (i) length, (ii) diameter, and (iii) availability (production depends on the demand on the insulator market

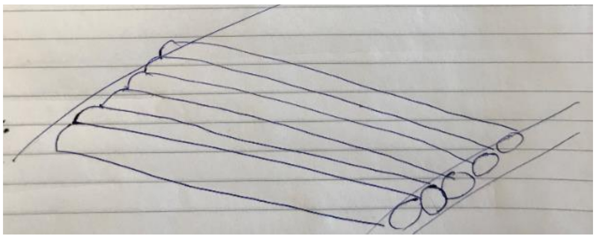
As shown in Fig.9, we could see two alternatives in how to re-use the GFRP pipes:

1. Cut the pipe in smaller unit pieces that can be reassembled in a specific manner to build up a new product.
2. Use the pipe in their full available length, taking advantage of the length, as well as bending strength and stiffness.

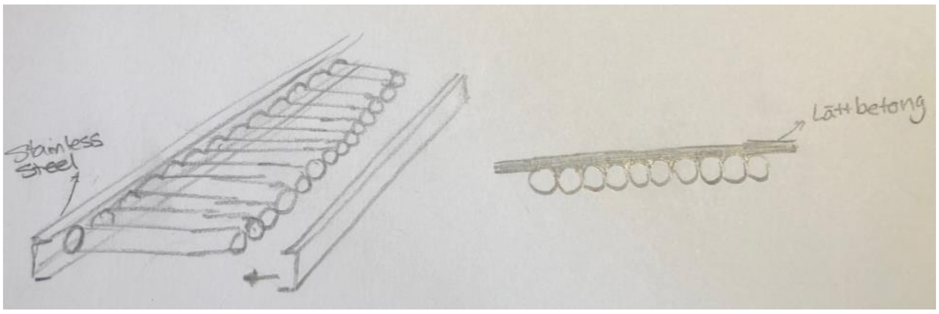
The ideas generated at the beginning of the RECINA project are shown in the drawings in Fig.13.

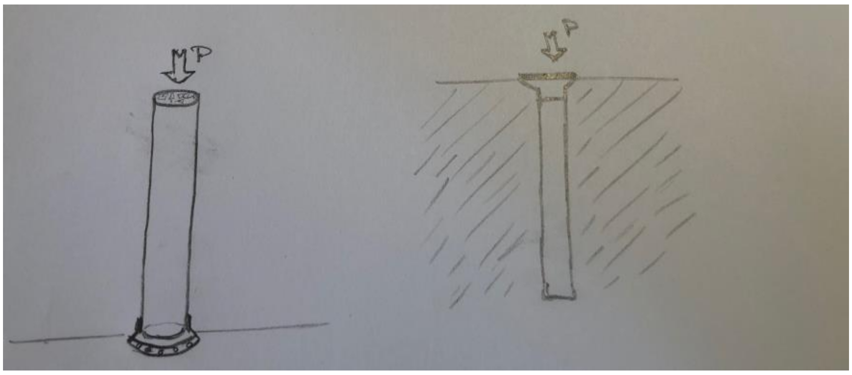


a) Pipe cut in short cylinders and used as the core of a sandwich panel.

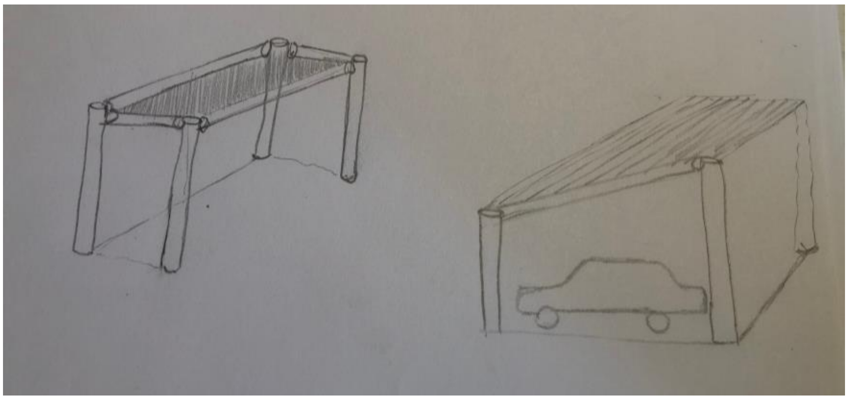


b) Pipe assembled with each other and forming the bearing part – full length used





c) Pipe used as is as cast in place concrete form. The concrete will also be protected from the outside environment by the FRP pipe.



d) Pipe used as columns in smaller constructions such as carport or bike shelter.

Fig. 13: Concept generation - brainstorming session

From the results obtained in WP2, we however rapidly understood that developing a concept based on reusing the pipes in their full length will not be successful as the variation in dimension of the manufacturing scrap cannot be predicted.

One way to try to solve that challenge is to cut the pipes to shorter rings (Fig. 14) with a predetermined length which would result in a much more predictable incoming material flow. This second alternative also allows the potential re-use of almost 100% of the pipe production waste.

However, the next challenge is then to find a structural application that can cope with rings with predetermined length but variation in diameters and mechanical properties, see example in Table 2 of rings harvested for this project.

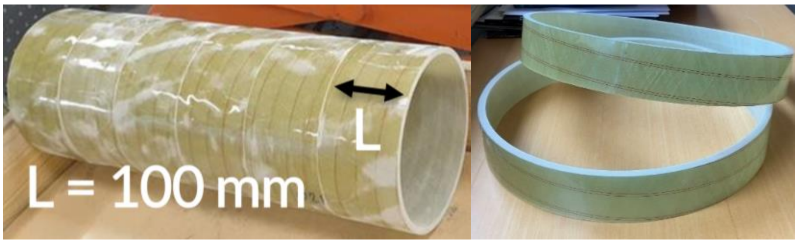


Fig. 14: Rings cut from two different GFRP pipes.

Table 2: Estimated mechanical properties of rigs from scraped GFRP pipes.

Properties	**Ring 1**	**Ring 2**	**Ring 3**	**Ring 4**
Inner/outer diam [mm]	ϕ160/ϕ187	ϕ210/ϕ225	ϕ311/ϕ332	ϕ311/ϕ324
Fiber angle	**[±25°/±87°/±60°]$_s$**	**[±36°]**	**[±40°]**	**[±25°]**
E1 [GPa]	18.7	17.8	15.1	28.2
E2 [GPa]	25.2	11.0	11.5	11.0
G12 [GPa]	8.0	11.6	12.2	9.0
α1 [1E-06/°C]	18	7	10	5
α2 [1E-06/°C]	11	25	20	33
S11 [MPa]	+49 / -185	+123 / -123	+99 / -103	+245 / -215
S22 [MPa]	+80 / -245	+44 / -88	+54 / -85	+33 / -113
S12 [MPa]	±60	±79	±81	±69

The concept that was kept for further investigation was the sandwich panel concept were the core is made of cylinder sections cut from the GFRP pipes.

The sandwich panels in this concept are composed of rings bonded to two face sheets with help of an epoxy adhesive, in a similar way that was reported by Hartoni et al. (2017), see figure 15. The pipe rings can be cut in different lengths to give the required bending stiffness and strength to the panel. The face sheet material used was the door blade resulting from door cut-outs from Podcomps bathroom modules (also GFRP manufacturing waste).

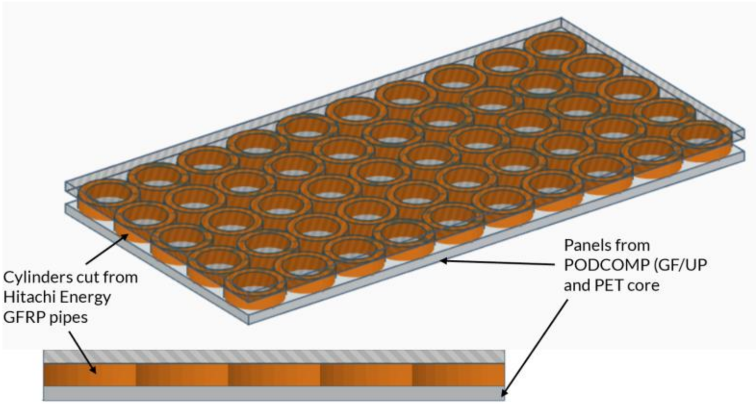


Figure 15. 3D impression of the RECINA sandwich panel

At this stage of the concept design development, it was important to investigate how the diameter and arrangement of the rings influence the structural behavior of the sandwich panels.

The pipe sections can be put together in two arrangements, referred to as square (□) and cross (x) formats as illustrated in Figure 16. The cut pipes act as web elements and produce a structure similar to honeycomb sandwich panels which display very good stiffness properties and patch load resistance.

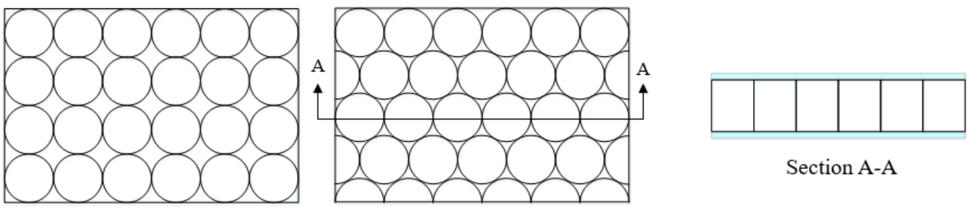


Figure 16. Arrangement of the cut pipes as webs in the conceptual sandwich panel in (a) square and (b) cross formats.

To evaluate the mechanical performance of the conceptual sandwich panel, numerical models of the concept were developed using finite element software package ABAQUS (ver. 6.13). A Parametric study was carried out to investigate the effects of pipe diameter and arrangement of the pipes. 3D models of a panel with size of 4x4m^2

using linear 4-node shell elements were constructed and subjected to a uniformly distributed load of 5kN/m^2. The webs had a height of 300 mm and panels were simply supported on two line supports as shown in Figure 17. The face sheets had a thickness of 12 mm. Full bonding between the pipes and face sheets was assumed and a gap of 3mm was considered between the pipe walls. The latter assumption was made to avoid the contribution from possible out-of-plane shear stiffness from the interaction of the pipes with each other, an effect which cannot be guaranteed due to manufacturing tolerances. Six different diameters for pipes were considered to investigate the effect of pipe diameters on the stiffness of the sandwich panels as illustrated in Figure 18.

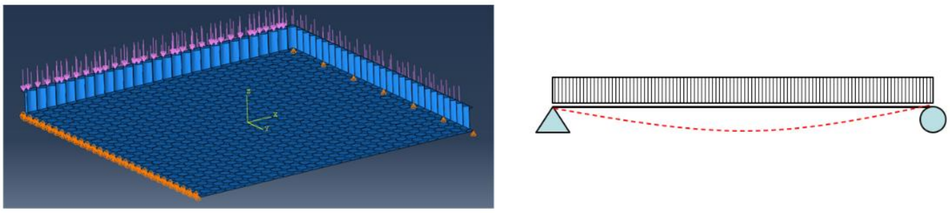


Figure 17. FE model – mesh and applied boundary conditions.

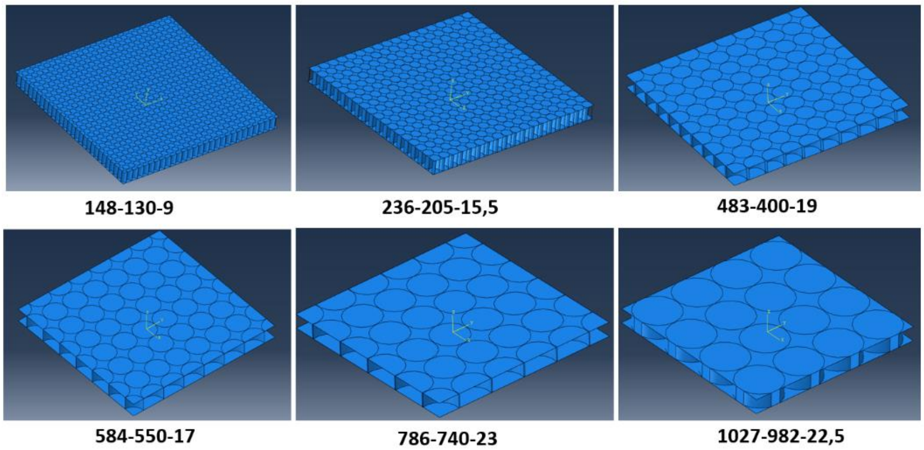


Figure 18. FE Parametric study - sandwich panels with different pipe diameters. The numbers represent the outer diameter, inner diameter and the wall thickness of the GFRP pipes.

Two types of deformations can be identified in the panels: a global deformation due to global bending action and a local deformation due to bending of the top face sheet as shown in Figure 19. Therefore, the deformation experienced on the top face sheet, would be somewhat larger than that of the bottom sheet (i.e. total deformation= global deformation + local deformation). This local deformation is a function of the diameter of the pipe used as web elements and the larger the pipe diameter, the larger the local deformation. The global (D) and total deformations (d) of the panel are plotted against the pipe diameter in Figure 20. It can be observed from this figure that smaller pipe diameters would result in higher stiffness. This is expected because the larger number of webs in this case would result in higher degree of composite action between the top and bottom face sheets and less shear lag effect and thus larger stiffness. Nevertheless, there will be a certain diameter below which the stiffness would become constant. This can be introduced as the optimum diameter. In the specific case studies in Figure 20, this diameter can be identified as ca. 450 mm.

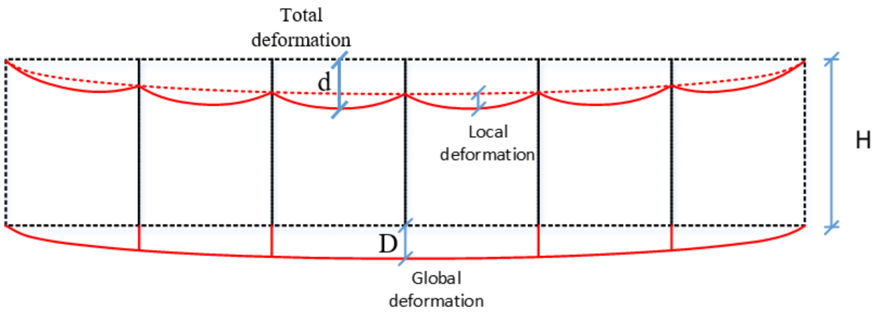
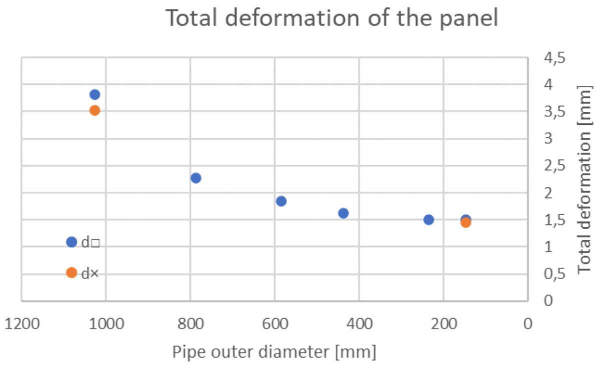
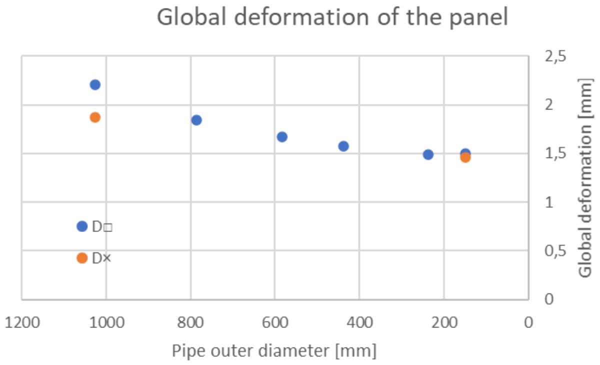


Figure 19. Different types of deformations in the considered sandwich panel

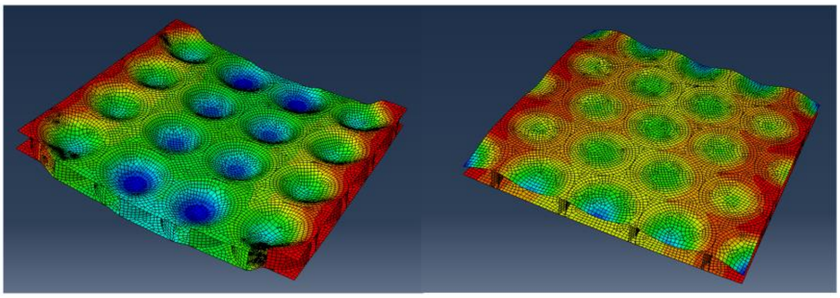


a)



b)

Figure 20. Maximum deformation of the sandwich panels (a) total deformation on the top face sheet and (b) global deformation on the bottom face sheet.



□ format X format

Figure 21. Deformation of the panels in relation to the square (□) or cross (x) position of the pipes rings in the core

As mentioned earlier in the report, other concept design for balcony, wall elements and sound barriers were further investigated using numerical analysis. The main results for balcony and wall elements are presented here:

Balcony

The concept of using the RECINA sandwich panels for balcony was studied based on 2 different methods to support a balcony with a size of 3 x 1.8 m. These 2 boundary conditions are shown in Fig.22 and are (i) the fully supported case where all sides are restrained, and (ii) the case where only the longer sides are restrained. These 2 alternatives have different requirements on the structure of the balcony and behave also differently upon loading.

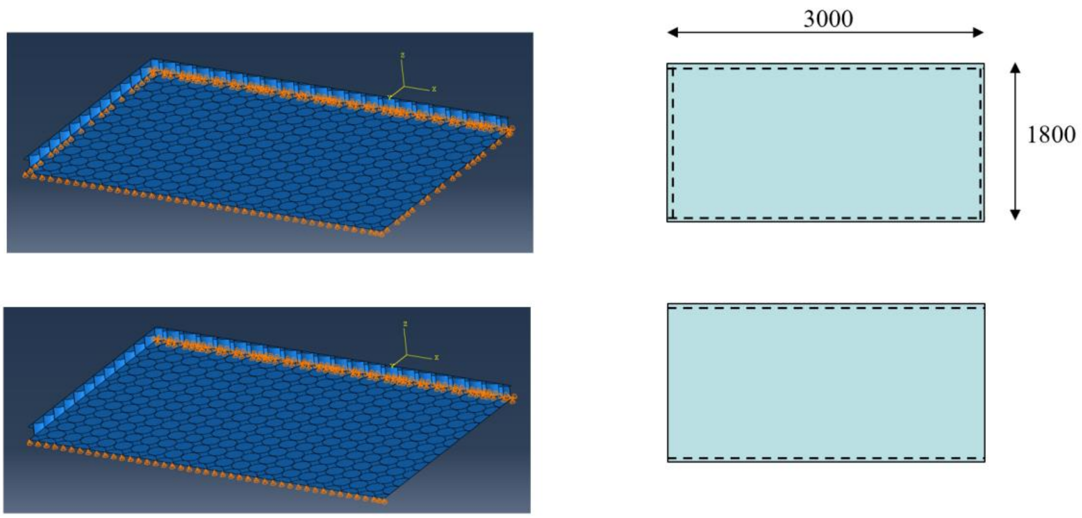


Figure 22. Boundary Conditions applied for balcony FE model

The sandwich panel used in the model has a top/bottom sheet with a thickness of 10 mm, and the total thickness is 100 mm.

The material properties used were E = 18 GPa for the GFRP pipe material and E = 12 GPa for the face sheet.

The maximum deflection observed were 0.7 mm and 0.5 mm for the semi-supported and fully supported BC alternative respectively.

The allowable deformation being L/400= 4.5 mm (L = 1800 mm), the panel with a thickness of 100 mm does fulfil the deformation requirement. As the allowable is much larger than the estimated deformation, it is reasonable to conclude that the height of the panel could be smaller than 100 mm.

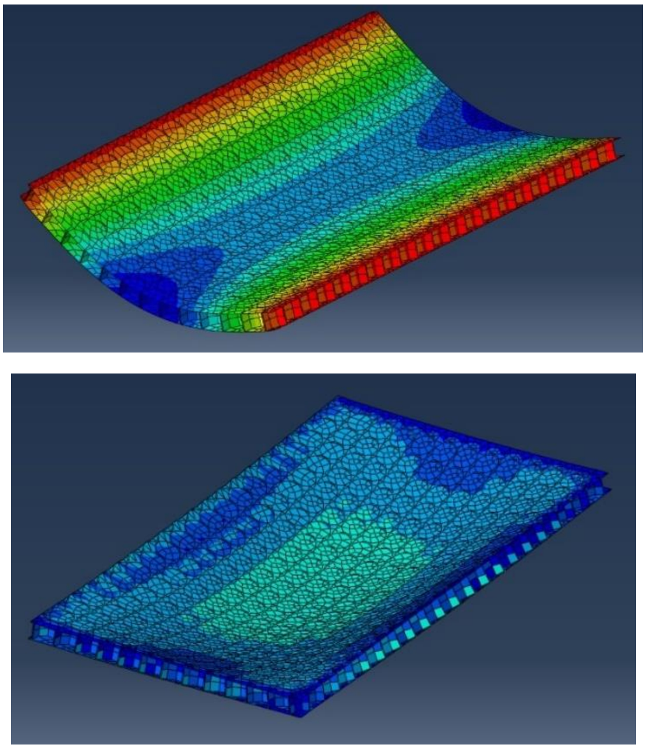


Figure 23. Deflection of the balcony during loading

Wall element

The structural analysis of a representative wall element with an opening was carried out. The loads applied were (see Fig. 24):

- Wind load of 2 kN/m2
- Line load of 11 kN/m on the wall.

The results of the FE models show that the design load levels have a minor impact on the deformation of the wall. The maximum deformation was 0.3 mm. Similarly, the maximum stress recorded on the contour plot in Fig.25 was 1.5 MPa.

This preliminary numerical analysis of a wall structure made of the sandwich panel developed in the RECINA project show that the panels could be used for such application. However, as it was reported earlier, aspects related to fire and other regulations on material in living environment would have to be considered if the concept idea is to be further investigated.

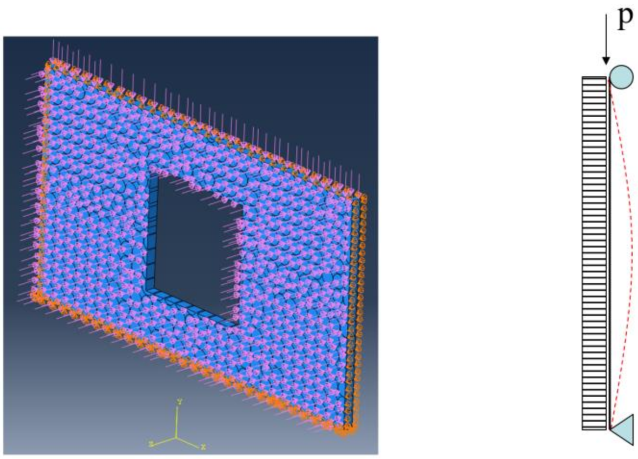


Figure 24. Boundary Conditions applied for wall element FE model

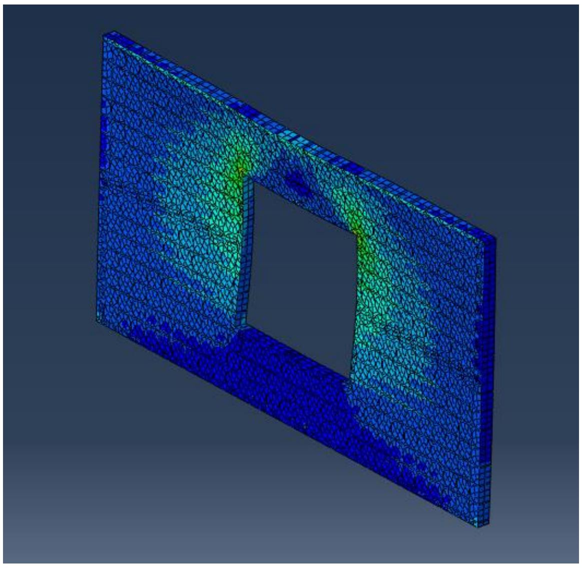


Figure 25. Stress contour plot for the wall element during loading

- *WP4: Proof of concept*

Manufacturing the 2 first sandwich panels prototypes

The manufacturing and testing of the two prototypes was carried out to show that the concept design developed in the project was yielding the same behavior as observed during the FE model campaign and therefore validate the concept.

Figure 26. Manufacturing the prototype sandwich panels

The manufacturing of the sandwich deck panels included the following steps: (1) cutting the pipes in required length, (2) cleaning and surface preparation of the face sheets, (3) bonding the pipes to the first face sheet and curing, and (4) bonding the second face sheet to the pipes and complete the manufacturing, see Fig. 26.

Experimental testing

The two prototype panels were thereafter tested at RISE. The dimensions of the panels were 1940 mm in length and 900 mm in width. The thickness was 105 mm.

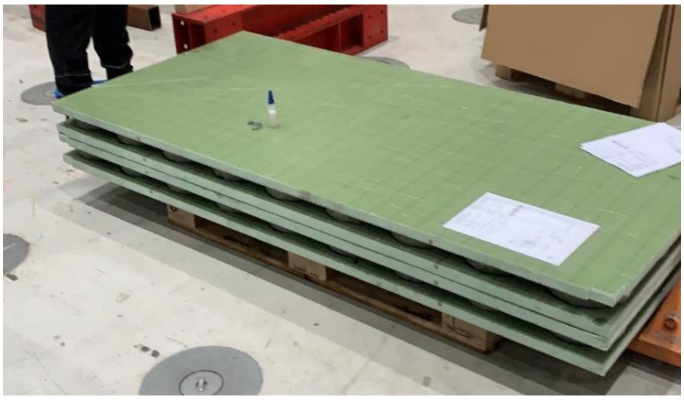


Figure 27. RECINA sandwich panels before experimental testing

Only one panel was tested to failure (Ultimate Limite State, ULS); the other panel was tested to determine the bending stiffness variation through cyclic loading at different load levels: (1) 2 cycles 0- 2 kN, (2) 2 cycles 0-4 kN, (3) 2 cycles 0-6 kN and (4) 2 cycles 0-10 kN.

For the loading set-up, the idea was to resemble a golf cart. The weight of such carts varies between 700-1000 kg depending on the size. The heaviest option of 1000 kg was taken in the tests, and the distance between the support was chosen as the axel width of the golf cart shown in Fig. 28, i.e. 850 mm.

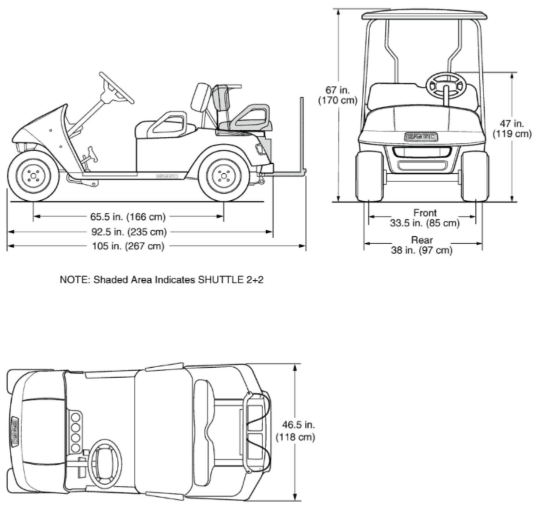


Figure 28. Typical golf cart dimensions used to determine the position of the support for force introduction

The test set-up data (dimension, loading rate, measurement method, etc.) are shown below and in Fig. 29-31:

- ***Dimensions:***
- Distance between loading points: 850 mm
- Loading area: 200x200 mm
- Rubber thickness 25 mm
- Free span: 1720 mm
- Steel support plate, 100 mm width and 10 mm thickness
- ***Load and deformation measurement:***
- The load was measure with a load cell positioned over the beam used to introduce the load.
- Displacement measurement in span mid and under the two load points.
- Digital Image Correlation (DIC) measurement was also used on the top of the panel, but no failure was observed at that location (failure happened outside the DIC measurement area)
- ***Loading rate:***
- Displacement control in ULS test: rate 3 mm/min
- Load control rate in SLS test: 2 kN/min

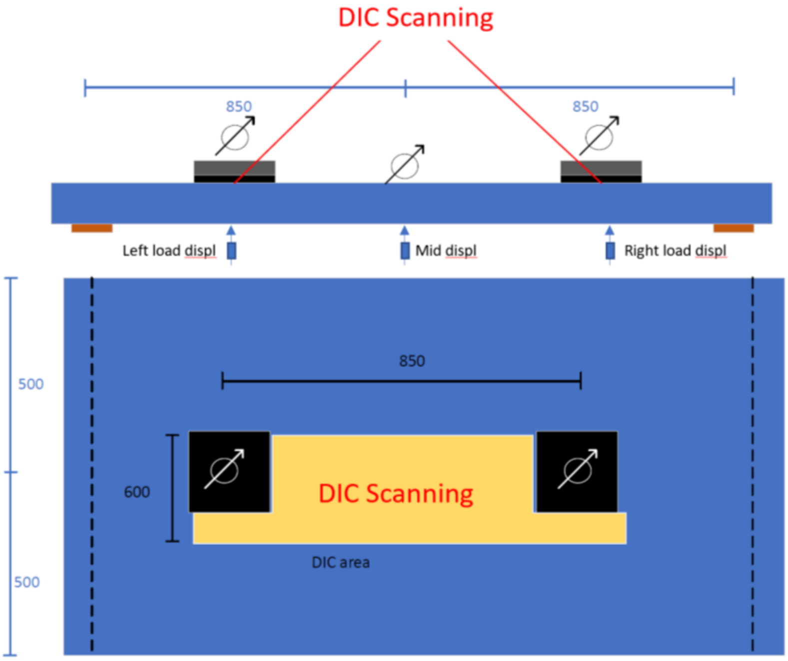


Figure 29. Dimensions and test set-up

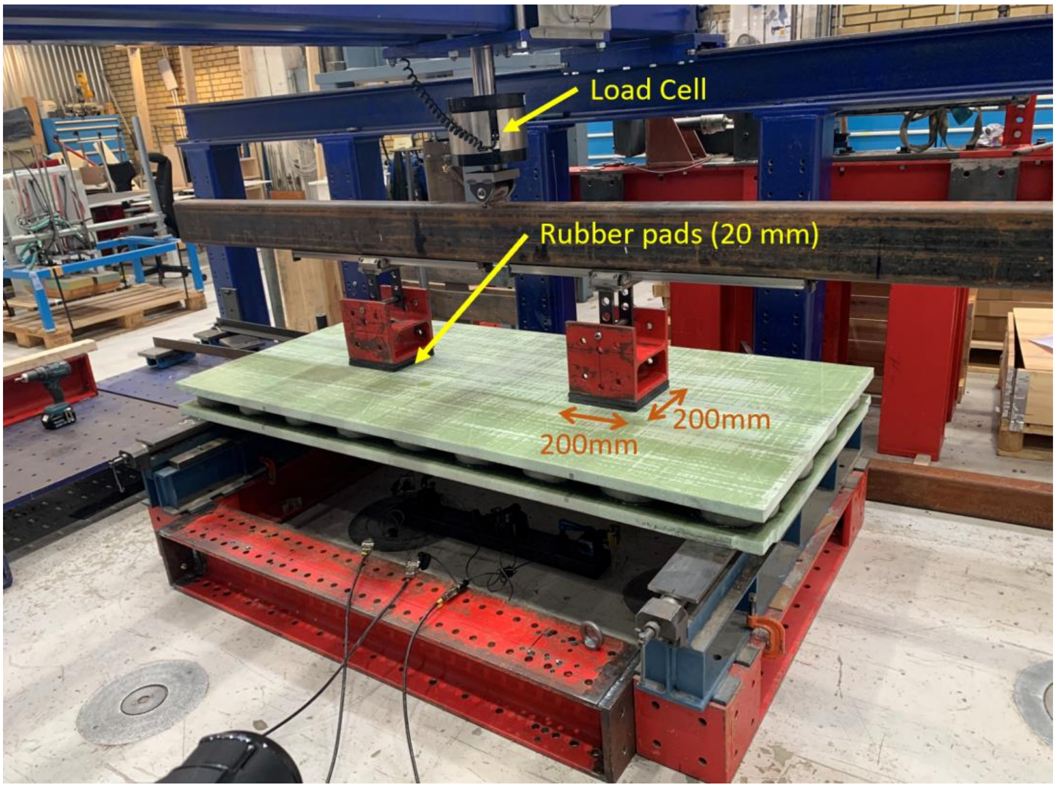


Figure 30. RECINA sandwich panels – test set-up

Figure 31. RECINA sandwich panels during mechanical test

The load-deflection curves for the SLS and ULS loading case are shown in Fig. 32-33. We observe a similar bending stiffness for the two panels of 3300 N/mm.

For the cyclic loading case, we can conclude that no damage occurs in the panel at these load levels (up to 10kN) as the bending stiffness is unchanged and no permanent deformations are observed.

For the ULS loading, the failure load was registered at 48 kN, i.e. more than 3 times higher than the design load for a heavy golf cart. We can see that the failure occurs in different steps, represented in Fig. 33 as clear decrease of the bending stiffness due to permanent damage in the panel. At 32 kN (9 mm deflection), we observe the initiation of damage in the foam core of the face sheet (see also Fig. 34).

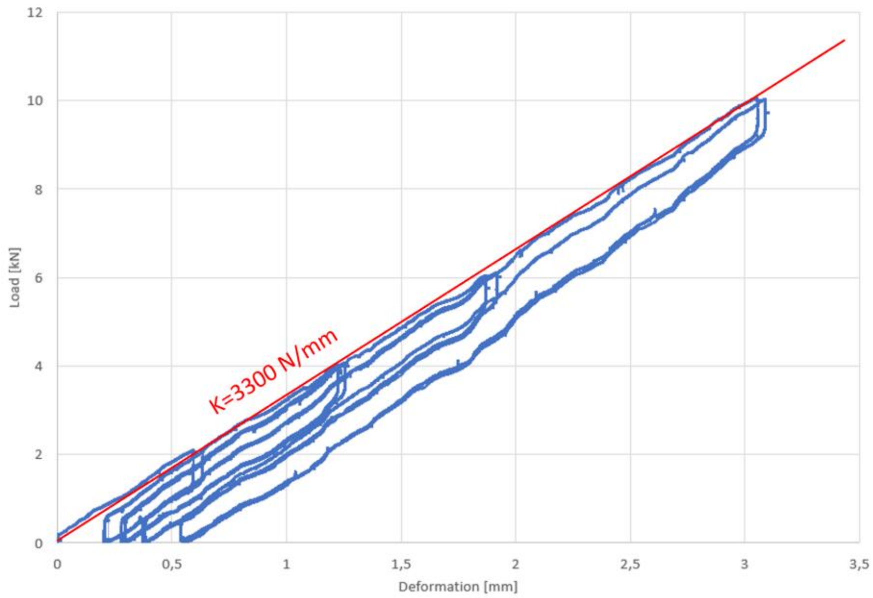


Figure 32. Load-displacement curve for the SLS cyclic loading mechanical testing

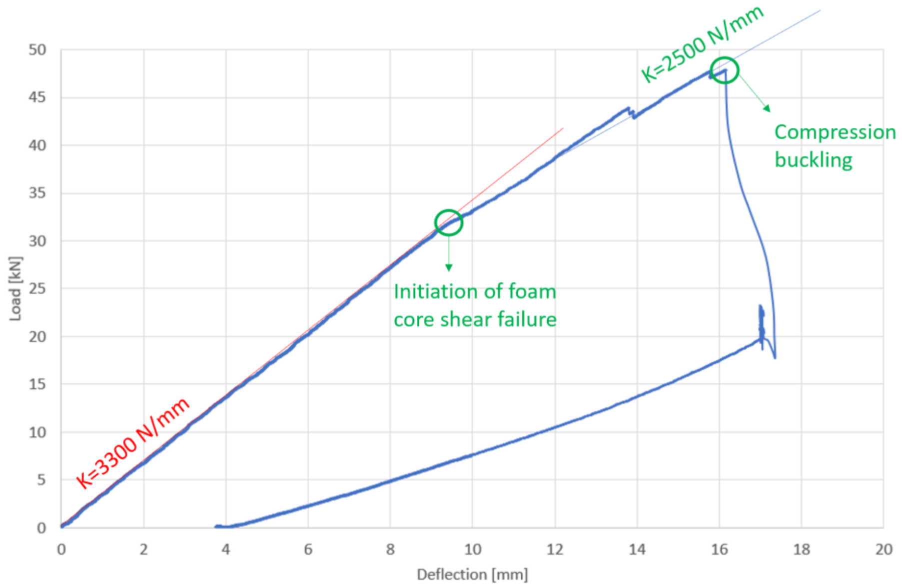


Figure 33. Load-displacement curve for the ULS mechanical testing

Failure mode was manifested by the shear failure in the foam core and most probably buckling of the compression face sheet glues to the webs, this probably initiating at load level close to 44 kN.

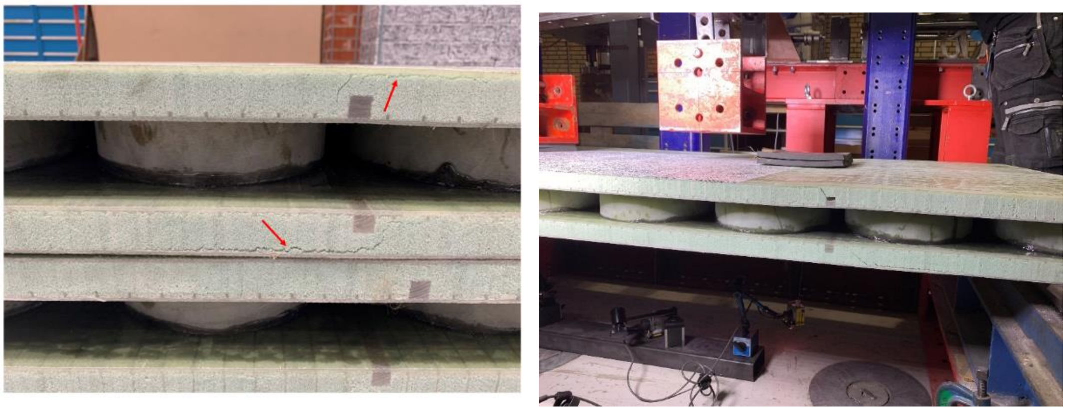


Figure 34. Shear failure observed in the panels after loading experiments

Pedestrian bridge prototype

The opportunity of realising a small pedestrian bridge made with the RECINA sandwich panels was made possible during the project. Contacts were taken with the end-user Mölndal GK as we believed that this was the ultimate verification that the concept developed in the project had a market value.

Furthermore, the bridge is strategically located close the hole 6 green and is used by approximately 250 persons daily during the nice spring and summer days. In other words, this is a perfect place to show an innovative composite bridge made of re-used GFRP, and potentially trigger interest and wider understanding of the concept of circular economy.

Figure 35. A smaller wooden bridge needs to be replaced at Mölndal GK

The current bridge is an old wooden bridge that has been partially closed during 2021 due to a risk of collapse. Mölndal GK was already planning to replace it when we approached them. The bridge makes the connection to the green over a small river. It can be seen in Fig.36 that the close water environment has been a large contributing parameter to the damages visible on the bridge. The advantage of using FRP material in this type of environment is that polymer composite materials are not sensitive to humidity and require much less maintenance than alternative material such as timber.

The new bridge will be slightly longer as it is planned to be positioned differently to allow a better access to the green, see Fig.37.

Figure 36. Deteriorated wooden bridge

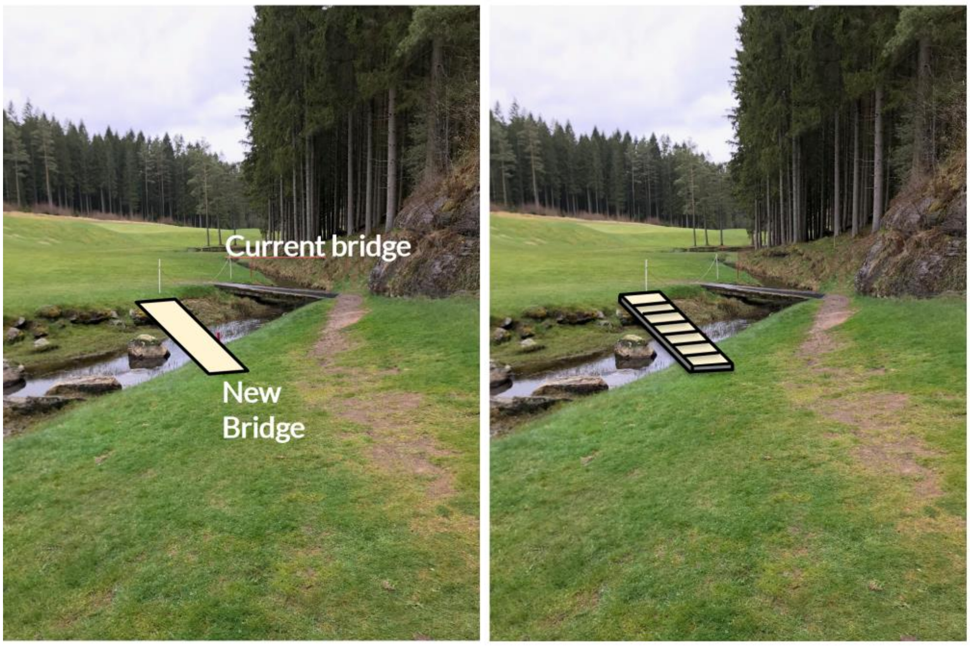


Figure 37. Position of the new RECINA bridge

The new bridge has a length of 7 m and a width of 1.3 m. The total length between the concrete beam support on the shores of the river is 8 m (Fig. 38). The dimensions of the concrete beam to be used as support are provided in Fig. 39. The bridge will be slightly inclined to avoid water stagnation.

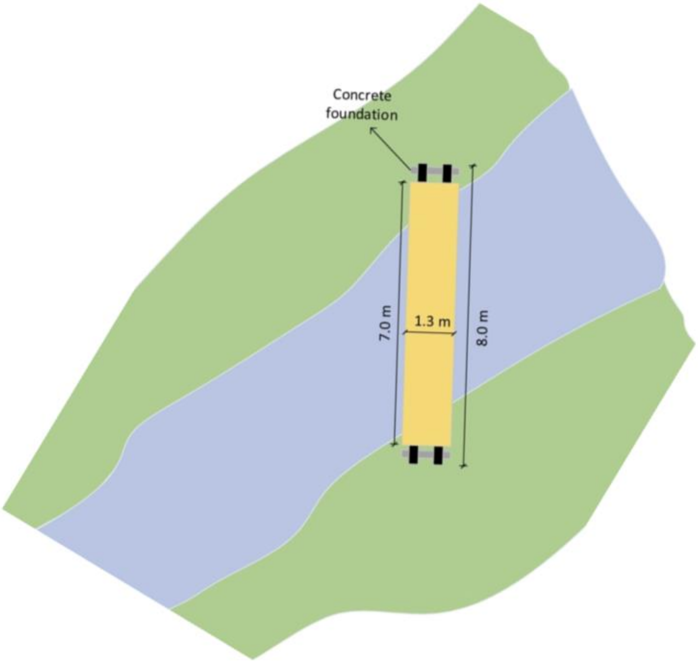


Figure 38. Top view and main dimensions

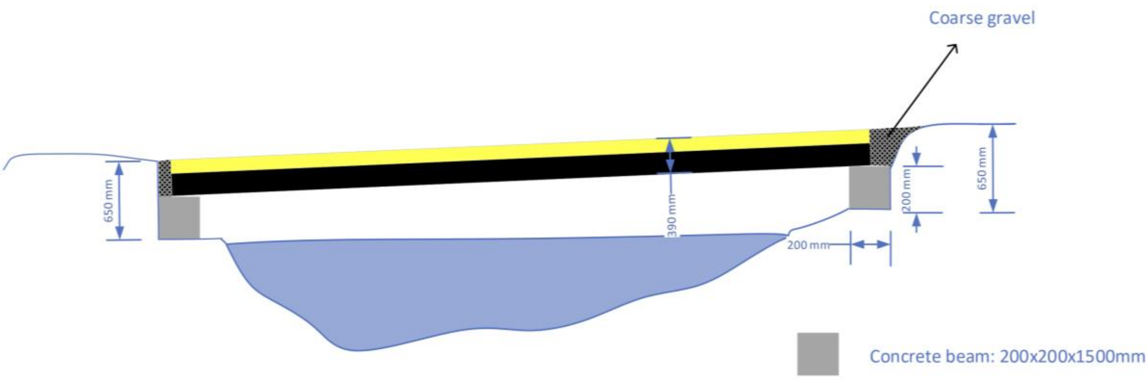


Figure 39. Side view (shore profile) and dimensions of the abutment

The bridge main concept is to use the decking system developed in the RECINA project together with two main girders to support the bridge deck over the river. The main girders could be steel I-beam or FRP pipes used in their full length (Fig. 40). The method used to attach the deck to the girder is explained further. Our approach was to choose a solution that will ease future disassembly and circular re-use when the bridge will reach the end of its service life (at least 80 years).

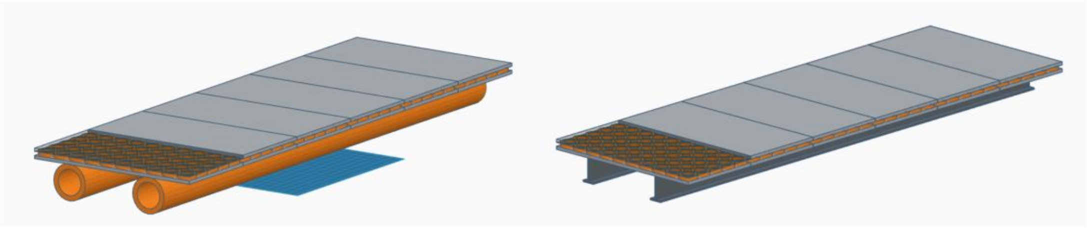


Figure 40. Bridge main concept - RECINA deck panel on two main girders.

Hitachi also manufactures utility poles made of composite material (fiberglass and epoxy) with an outer casing of thermoplastic, see Fig. 41. Their life expectancy is over 80 years. While reflecting on the type of girders that will be used for the bridge, it was suggested from Hitachi that they could provide the project with 2 poles that had been scrapped because of minor manufacturing defects. Like the GFRP pipe used for the decking, these poles were fulfilling all the mechanical requirements needed to be used as girder for the bridge application. The composite poles are, like the remaining part of the bridge, maintenance free. (Hitachi Energy, 2021).

Figure 41. GFRP utility poles from Hitachi

The design of the 8 sandwich panels needed for the bridge was slightly different than the protype panels experimentally tested and presented earlier in the report. Indeed, the dimension available for the GFRP pipes was different in terms of diameter. This was however not an issue as the concept design was developed in order to cope with the variation of the production waste stream. The dimensions of the panels used for the bridge are shown in Fig. 42. The GFRP pipes used were of 2 different types, both in terms of diameter and fibre orientation.

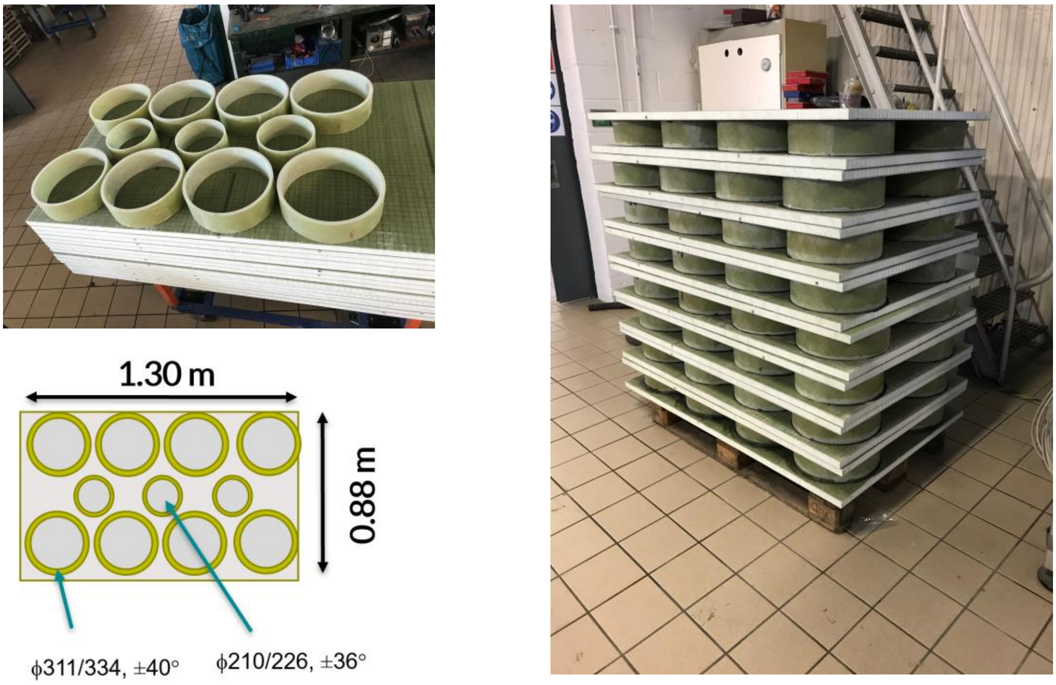


Figure 42. Dimensions of the sandwich deck panels and panels after manufacturing

To ensure a durable and long service life, a strong wearing surface was needed to be added on the top of the sandwich deck panel. A company manufacturing composite decking board was approached (Green Plank, Malmö). The project idea was presented, and Green Plank accepted to join the consortium and to provide the project with composite decking board.

These composite decking board are 90% made of recycled material and are very durable. The full composition is shown in Fig, 43.

Figure 43. Green plank composite decking board

The bridge deck panels were attached to the girder using steel U rods and steel plates specifically manufactured for that purpose. Schematic representations and pictures showing the deck/girder connections (a) as well as the panel/panel connections (b) are shown in Fig. 44.

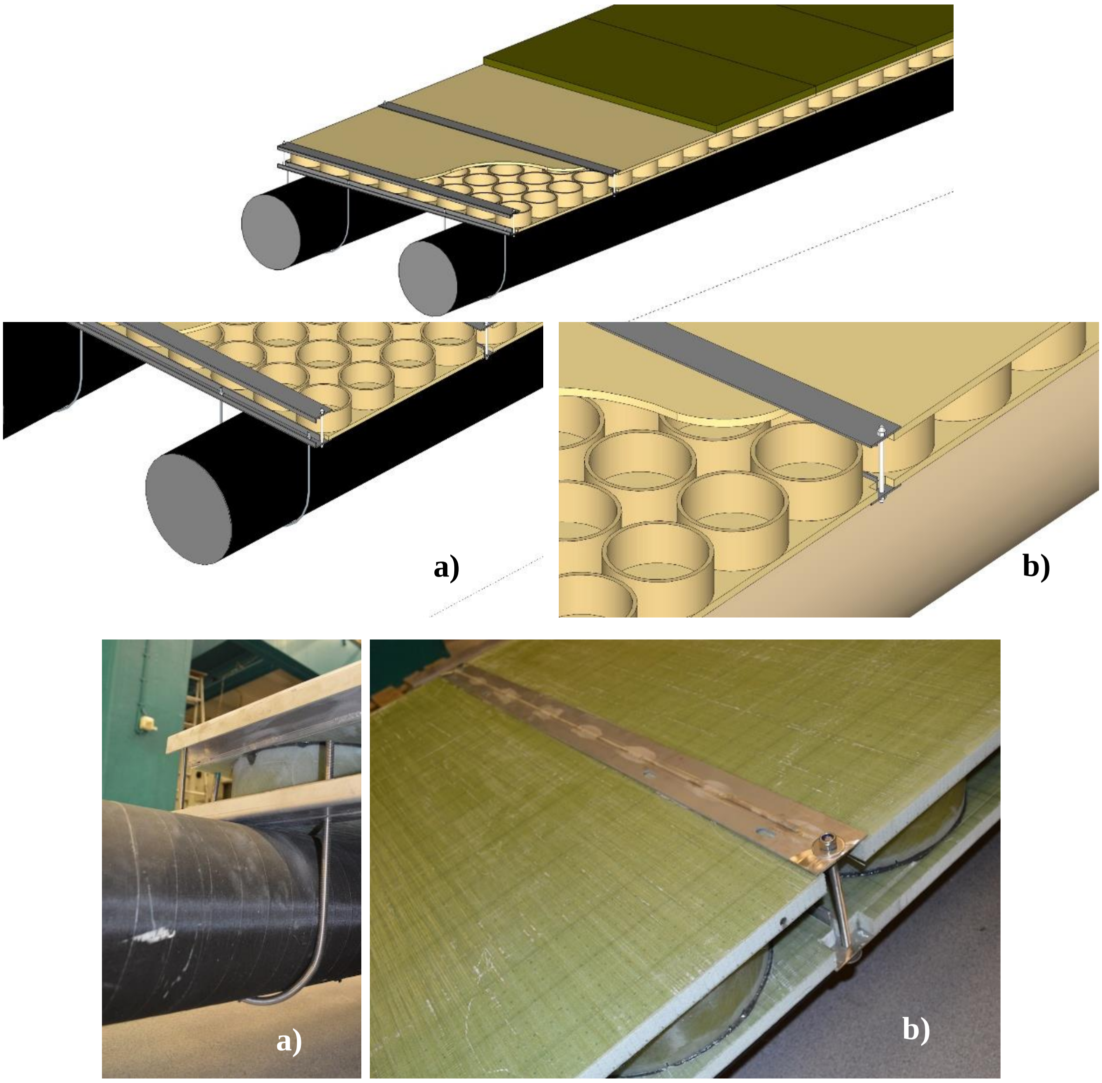


Figure 44. Connection: (a) bridge deck/girders; (b) Between panels

The bridge was thereafter assembled at Composite Design facilities and weighted (see Fig 45-47). The total weight was approximately 1250 kg.
The total height of the bridge, considering the girders, the deck and the wearing surface, was approximately 415 mm:

- Girder diameter: 230 mm
- Ring height: 100 mm
- Skin thickness: 2x30 mm
- Composite plank: 25 mm

Figure 45. Assembling the bridge different components

Figure 46. Bridge weighting and first pedestrian testing the bridge

Figure 47. Final bridge assembly

Environmental impact – Life Cycle Analysis Approach

The aim of carrying out a LCA was to determine the environmental impact of a pedestrian bridge manufactured with re-used GFRP parts. The bridge used for the study is the bridge built for Mölndal GK and presented earlier in the report.

The environmental impact has been quantified using CO2 equivalent measure (IPCC 2013 GWP 100), and the model was made in SimaPro (version 9.2) with data from Ecoinvent (version 3.7).

The boundary conditions (BCs) of the system studied were stretching from the design table to the positioning of the bridge at Mölndal GK, and are shown in Fig. 49. The system BCs includes the extraction of the raw material, the manufacturing of the bridge and transport.

Assembly, ground preparation on site, maintenance and waste management were not included in the study.

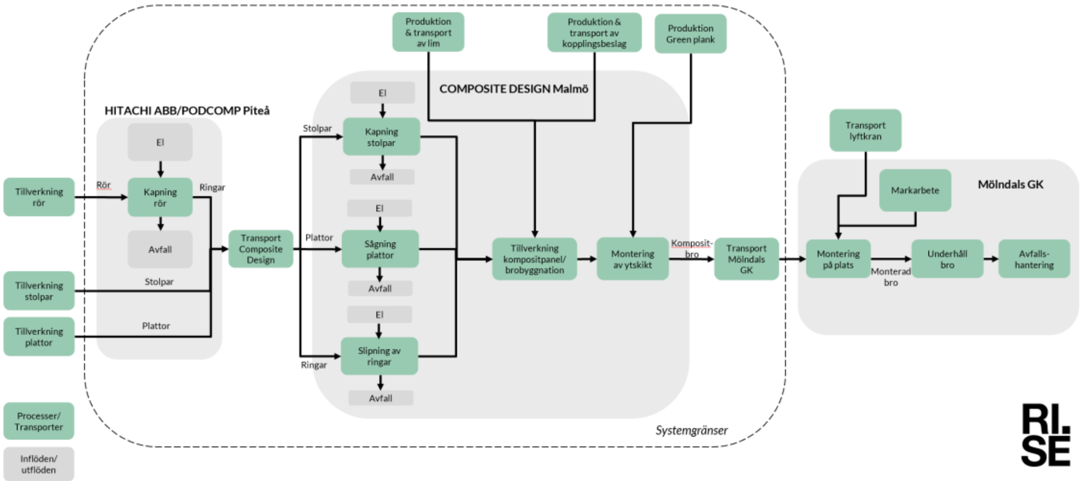


Figure 49. Boundaries of the environmental impact study

The material and resources used for the bridge manufacturing and transport are listed in Table 3, together with the dataset used in Ecoinvent for environmental impact calculation.

Table 3: Materials and resources used, and their EcoInvent Dataset.

Material or Resources	**Dataset Ecoinvent (RER = Europa, GLO = global, SE = Sweden)**
Adhesive	Epoxy resin, liquid {RER}| market for epoxy resin, liquid | Cut-off, S
Fittings & sheet metal	Steel, low-alloyed {GLO}| market for | Cut-off, S
Electricity	Electricity, medium voltage {SE}| market for | Cut-off, S

Transport	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S
HDPE	Polyethylene, high density, granulate, recycled {Europe without Switzerland}| market for polyethylene, high density, granulate, recycled | Cut-off, S
Wood fiber	Residual wood, dry {Europe without Switzerland}| shavings, softwood, measured as dry mass to generic market for residual wood, dry | Cut-off, S

The total environmental impact of the bridge is 370 kg CO_2-eq, with one third of the CO_2-eq coming from the steel fittings and sheet metals (kopplingsbeslag in Fig. 50). The re-used composite material are responsible for 22% of the total environmental impact, and for these specific materials, their transportation from the manufacturing plants in Piteå (Hitachi, Podcomp) to Malmö (Composite Design) was the largest contributor.

Based on the results obtained in this study, we can see that even though the environmental impact is already low for the bridge studied, there is potential for optimization, especially considering the transport and the assembly parts in steel.

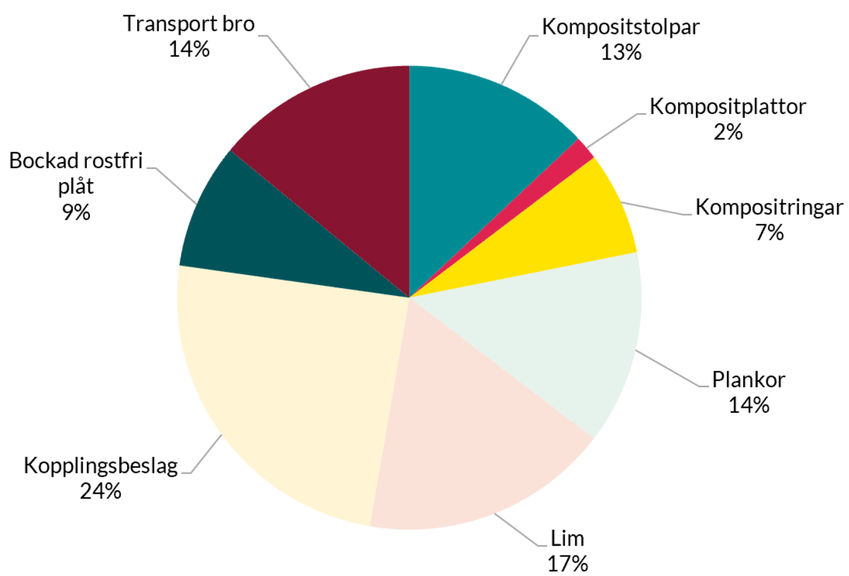


Figure 50. Environmental impact distributed between materials and resources used for the bridge

Slutsatser, nyttiggörande och nästa steg

The RECINA project has been focusing on the re-use of GFRP pipes and GFRP sandwich panels into new structural applications. The main objective was to develop a concept design, as well as manufacture and test in a lab environment a prototype of a bridge deck panel.

The RECINA project has successfully fulfilled the objectives that were planned at the beginning of the project. A robust concept design yields very promising results in terms of manufacturability, mechanical properties and ability to absorb the variable stream of GFRP waste.

A prototype bridge was also manufactured using the bridge deck concept developed in the project. The bridge will be positioned at the beginning of 2022 at Mölndal GK, close to Göteborg.

Other potential market application for the RECINA sandwich panel were also investigated, in particular wall elements and balconies. Some other examples where the RECINA panels can be used are shown in Fig.51.

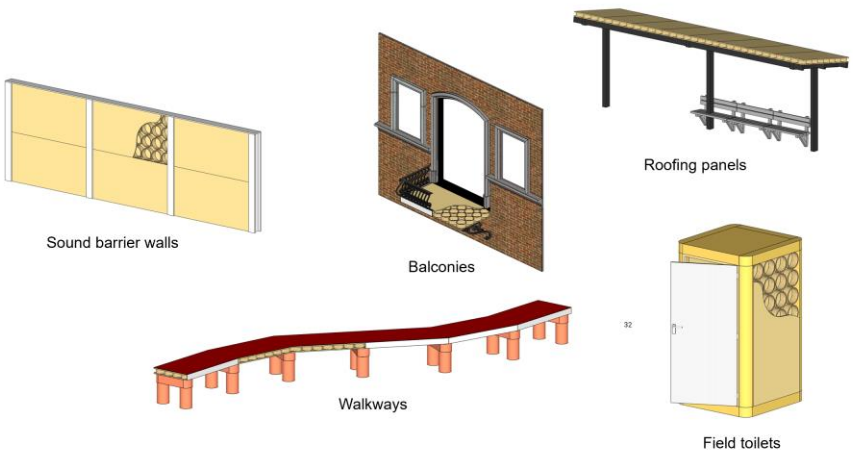


Figure 51. Potential other application where the sandwich panel developed in the REICNA project can be used

Additionally, the environmental impact study showed that CO2 equivalent could be decreased when the entire value chain will be gathered behind a circular business model.

Therefore, the next step to fully utilize the potential of re-using GFRP pipes in new structural composite panels will be the development of circular business models integrated in a value chain composed of EoL GFRP parts owners at one end, and companies manufacturing products based on re-used FRP at the other end. In between, many other links such as recycling companies, transporters and certifications institutes for quality check will have to be engaged to anchor the concept of re-using GFRP parts to the market.

Publikationslista

1-
The results of the RECINA project have been presented at the CICE 2021 conference in December 2021. The conference paper has been peer reviewed and published in a journal special edition in Springer.

The Re-use of End-of-Life Fiber Reinforced Polymer Composites in Construction | SpringerLink

André A., Juntikka M., Mattsson C., Nedev G., Haghani R. (2022) The Re-use of End-of-Life Fiber Reinforced Polymer Composites in Construction. In: Ilki A., Ispir M., Inci P. (eds) 10th International Conference on FRP Composites in Civil Engineering. CICE 2021. Lecture Notes in Civil Engineering, vol 198. Springer, Cham. https://doi.org/10.1007/978-3-030-88166-5_103.

2-
Also, an extended version of the conference paper will be submitted to a Special Issue of Turkish Journal of Civil Engineering during the spring of 2022. Results that were not included in the CICE 2021 conference paper will be added.

3-
Some of the results of the RECINA project were presented during the Circular material conference, April 2021, in Göteborg.

Microsoft PowerPoint - Cecilia Mattsson - Circular Materials Conference 2021__april21_14.45)

4-
The project was presented during the LIGHTer Summit in April 2021 as a keynote Lecture, i.e. an extended presentation of re-using EoL composite in new applications.

RECINA inspirerar oss om ”Cirkulär lättvikt” – Reza Haghani
lighter_summit_program_210420.pdf

5-
The project was also presented during the “Composite and Sustainability” Online Conference organized by Composite United, Switzerland, July 2021.

Creating circular streams from GFRP composite waste: Re-use and chemical recycling, by Cecilia Mattsson, Alann André, RISE Research Institutes of Sweden, Sweden

Online Forum "Composites and Sustainability", 2021 - Presentations (b2match.io)

Projektkommunikation

During 2020-2021, many activities have been contributing the dissemination of the RECINA progress and results:

- RISE web site - RECINA - Återanvändning av kompositdelar i infrastruktur | RISE
- Instagram (Podcomp) and LinkedIn
- Communication within IEA wind TCP task 45, Recycling of wind turbine blades, where Alann André is one of the two member representing Sweden.
- Communication with SuperUse studios, The Netherlands. Invitation of one of their architect Cesare Peeren during one of our meetings in December 2020.
- Communication through LIGHTer news (mars 2020) and LIGHTer summit (April 2021)
- Re:Source meetings (June and November 2020, Mars and June 2021)
- Re:Source evaluation day, June 2021 – The RECINA project was chosen as one of the projects to evaluate the Re:source program.
- Many meetings with owners of wind turbine blades which start to understand that the recycling or re-using of GFRP blades is a challenging question. Presenting the potential of re-using EoL GFRP through the achievement in the RECINA project was very helpful.
- Many meetings with Swedish communes during which was introduced the idea of building infrastructures with re-used GFRP structures.

Referenser

André A., Juntikka M., Mattsson C., Nedev G., Haghani R. (2022) The Re-use of End-of-Life Fiber Reinforced Polymer Composites in Construction. In: Ilki A., Ispir M., Inci P. (eds) 10th International Conference on FRP Composites in Civil Engineering. CICE 2021. Lecture Notes in Civil Engineering, vol 198. Springer, Cham. https://doi.org/10.1007/978-3-030-88166-5_103.

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Composite World, 2021 - Anmet installs first recycled wind turbine blade-based pedestrian bridge | CompositesWorld

European Commission (2015), Report from the Commission to the European Parliament and the Council on the implementation of regulation (EC) no 1013/2006 on shipments of waste

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Bilagor

Bilagor som skickas separat:

- *Administrativ bilaga*