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FiberEUse: Large-Scale Demonstration of New Circular Economy Value Chains Based on the Reuse of End-of-Life Fiber-Reinforced Composites—A Circular It Platform to Manage Innovative Design and Circular Entities †

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Abstract: The new Circular Economy System requires an innovative approach to the management of information. The FiberEUse IT platform is a solution that enables the exchange of information among stakeholders that works into and across the glass and carbon fibers value chains, from the design to the end of the circle of life. The IT solution supports companies in scouting new potential market applications and search information about companies, manufacturing processes, and objects. Those objects had been defined "circular entities" and can be products, materials, semi-manufactured objects, wastes, among others. The information available for each circular entity is the one which the company itself wants to share and can propose: description, informative details, technical details, processes adopted to create it, consultancy services used, etc. To obtain this necessary variety, the data model had been structured in a polymorphic way; being able to serve different product histories without the ambition to create a common and classic entity relationship schema but thinking by high level object-oriented design.

Keywords: circular IT platform; circular entity; information management; matchmake; enable value chains; polymorphic; search; open innovation; co-creation

1. Introduction

Glass fiber (GF)- and carbon fiber (CF)-reinforced polymer composites have revolutionized important manufacturing sectors, such as transport (automotive, aircraft, and boats) and construction (building and infrastructures, plants, and wind turbines), due to their lighter weight and intrinsically better corrosion resistance with respect to metals. The composite market by volume is dominated by glass fiber-reinforced plastics (GFRP), with an annual production volume in Europe having reached 1.069 Mtons, and a steady growth in 2015 at a rate of 2.5%. Around one-third of the whole production volume is manufactured for the transport sector (cars, commercial vehicles, boats and to a lesser extent, and aircraft), and another one-third for the construction industry (buildings, infrastructures, and wind turbines). Most carbon fiber is processed for carbon fiber-reinforced plastics (CFRP), with a demand of 83,000 tons in 2014 and an average annual growth rate of 11%, leading to a forecast of 175,000 tons in 2021 [1]. The total turnover achieved worldwide with carbon fibers makes up around 1.98 billion US dollars for 2014. The aerospace industry, including defense, is the most important sector for CFRP with 32% of total global demand, followed by the automotive industry, which currently makes up around 21.8% of the total demand.

In light of the above, the economic impact of the composite sector clearly appears huge, and the application of the Circular Economy principles to composites is one of the challenges of modern manufacturing industry. Within this perspective, FiberEUse project is implementing the Circular Economy principles of Reduce (use of virgin fibers); Repair (e.g., blades and car parts); Reuse (car components); Refurbish and Recycle (fibers), and is obtaining the End of Waste concept. The main innovation actions introduced by the FiberEUse project are tackling the primary barrier for an extensive Europe-wide CF and GF recycling practice, namely, increasing its profitability. It includes

- bringing together cutting-edge inspection, repair, and remanufacturing technologies for the composite sector in a new holistic approach;
- reducing the costs due to collecting and sorting of recyclates (currently two-thirds of the overall recyclate costs), that is, optimizing logistics (including investigation on locating recycling facilities near waste generation and recyclate demand) and considering proper fiscal and legislation incentives;
- generating cross-sectorial market opportunities for recyclates, with the organization and documentation of the properties and market value of GF and CF remanufactured goods in an accessible and user-friendly manner so as to enable (i) enhanced decision-making on EoL scenarios of recyclates and (ii) symbiosis between sectors such as energy, automotive, aircraft, and marine watercraft, consumer goods; and
- realizing several demo-cases with wide participation of industrial end-users and stakeholder associations, actively involved in the co-design of the remanufactured products.

2. FiberEUse Project

The FiberEUse project is funded by the H2020 program, in the call H2020-IND-CE-2016-17/H2020-CIRC-2016, under Grant Agreement 730,323. The activity started in June 2017 and will last a further 4 years, with a total funding of 12 M euros, and is performed by a Consortium of 22 organizations from seven EU countries (Figure 1a) and representing five different European manufacturing sectors. The aim of the project is to integrate in a holistic approach different innovation actions aimed at enhancing the profitability of composite recycling and reuse in value-added products. The idea is to boost the transition to the Circular Economy System realizing three macro use-cases (Figure 1b), further detailed in eight demonstrators, and to enable and support the interconnections among them through an innovative cloud-based IT solution.

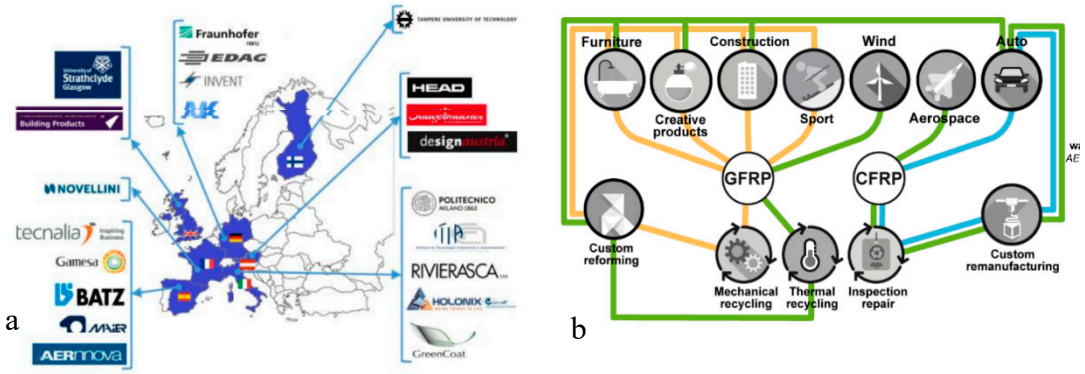


Figure 1. FiberEUse Consortium (**a**); FiberEUse use cases (**b**).

The FiberEUse holistic approach is based on the implementation of three large scale use-cases shown as yellow, blue, and green lines in Figure 1b. Each of them had generated several demo-cases to close the loop of composite lifecycle in different industrial and interconnected sectors from a circular economy viewpoint, which in use-cases 1 (yellow) and 2 (green) involve the Construction sector.

The FiberEUse IT solution supports the project to answer to the objective two, which is described in the Description of Action of FiberEUse project: "The development of an innovation strategy for

mobilization and networking of stakeholders from all the sectors related to composites." This objective is addressed through many aspects of the project, including business modeling, scouting of new markets, analyzing environmental and costing impacts, co-designing of innovative products, and supporting the information exchange with an IT solution.

TheFiberEUse IT solution gives its stakeholders features such as free company and objects descriptions, matchmaking, advanced search of processes, circular entities and services, awareness creation about the new ecosystem creation, and support to the open innovation with designers.

The project is oriented to the industrial demonstration of the solution. WP6, which lasts two years at the end of the project, in fact, is dedicated to the full adoption of the results obtained in the first part of the project. All industrial partners will test in real environment their innovative solutions, and they will also collaboratively and actively adopt the FiberEUse IT solution. This will test and validate the operative functionality of the platform and also its business model for future exploitation.

3. The FiberEUse IT Solutions

3.1 Requirements Collection and Software Development Methodology

The requirements collection and the software development can use standardized methodologies and proceed across standardized steps designed for consistency, as reported and compared by SoobiaSaeed et al. in Analysis of Software Development Methodologies [2].

Collecting requirements is the process of determining, documenting, and managing stakeholder needs and expectations to meet project objectives. In the IT domain, the requirements are multifaceted as they have to cover technical, financial, and operational elements, and are also subject to perception and stakeholder interests. As such, the requirements collection process must incorporate and address all these realities to identify requirements at all levels and perceptions. As FiberEUse is an innovative project, and as its context of application is also innovative, it is a must to choose a requirements collection process which is equipped with built-in flexibility and oriented to the new group of stakeholders and stakeholders' needs.

According to Mihai Liviu Despa, "no methodology will fit perfectly the profile of a specific project. Then the best matching methodology should be used or in the case of experienced project teams and project managers a combination of methodologies could be introduced. In the case of innovative software development projects a new methodology is required" [3].

In FiberEUse, an additional point of complexity is given by the nature of the innovative domain of the Circular Economy, which is mainly unknown and provides inputs which are not common in IT developments. Those need to be brought out and checked carefully. FiberEUse IT platform development is therefore building on existing methodologies, to go further and proposing a flexible, agile, and user centered-application example of requirements collection—development and testing of innovative solutions.

3.2. Stakeholders Needs

Being an innovative context, it had been a must to reach the definition of the stakeholders needs through a cyclic validation of the requirements collected through different stages of validation and approval by the end-users and by the stakeholders. The approach adopted in all the validation and approval steps had been user-centered, creating workshops, focus groups, and active participation to the activities, with the intention to integrate User Experience Methods into an Agile Software Development [4,5]. During FiberEUse project many workshops had been conducted. At each of them, the requirements collected and the structure proposed had been tested and verified with stakeholders, until a final validation and the development of the platform. The stakeholders' needs had been grouped as follows.

1. Waste provider and ByProduct provider:
    - Need to dispose the end of life of the products:
        - Need to reduce costs
        - Unallowed landfilling of materials

    - Desire to end product life in a sustainable way
  - No knowledge about:
    - Who to offer or send products
    - If objects should be preprocessed
    - How objects should be treated
2. Producer, manufacturer:
  - Interest in producing new products with different materials having specific characteristics:
    - Less expensive materials
    - Different material with same property values
    - Not traditional materials
    - Right availability of materials according to needs
  - No knowledge about:
    - Possibility to compare traditional and new materials
    - How to purchase
    - Who can provide the material
3. Process provider who has the possibility to process end of life products:
  - Capacity to create new materials
    - Innovative processes
    - Innovative materials
    - Same processes or materials used in an innovative way
  - No knowledge about:
    - Who can provide the waste, or material to be processed
    - Who can be interested in the new material obtained with the new process
    - Who can be interested in the new technology to be used as third parties
4. Service and logistic operators:
  - Capacity to preprocess end of life products
  - Capacity to organize on EU wide level
  - Knowledge about the materials, processes, and sector
  - No knowledge about:
    - Who is interested in the new services

3.3 The Needs of Circular, Collaborative, and Open Information Management

The two main elements which emerged from the workshops with stakeholders were the need to manage circularity of products keeping up their history, and the interest in collaborating and sharing information among different stakeholders.

Figure 2 shows how the management of the information becomes circular: objects are no more managed from the concept of a new product to the end of life, but they are managed through cycles from object to object. From the functional point of view, this means that the solution have to create knowledge and match needs of stakeholders to let them know if, how, what, when, they can use, reuse, recycle, remanufacture, or re-something again. This can be obtained through functions which allow people know, and be aware, search, enter in touch with others, comment, match needs, suggest themselves or others, visualize, and keep history tracked. From the IT point of view, this is reflected in the use of the recursion [6], which adopts the Matrioska approach [7].

The FiberEUse IT solution had been developed into two different periods of time, according to the project's needs:

- a first solution, called Idea Manager, to support stakeholders in the co-creation of new products in collaboration with designers
- and the FibeEUse IT platform, to give users a virtual place to share information among those who are approaching the new circular economy system.

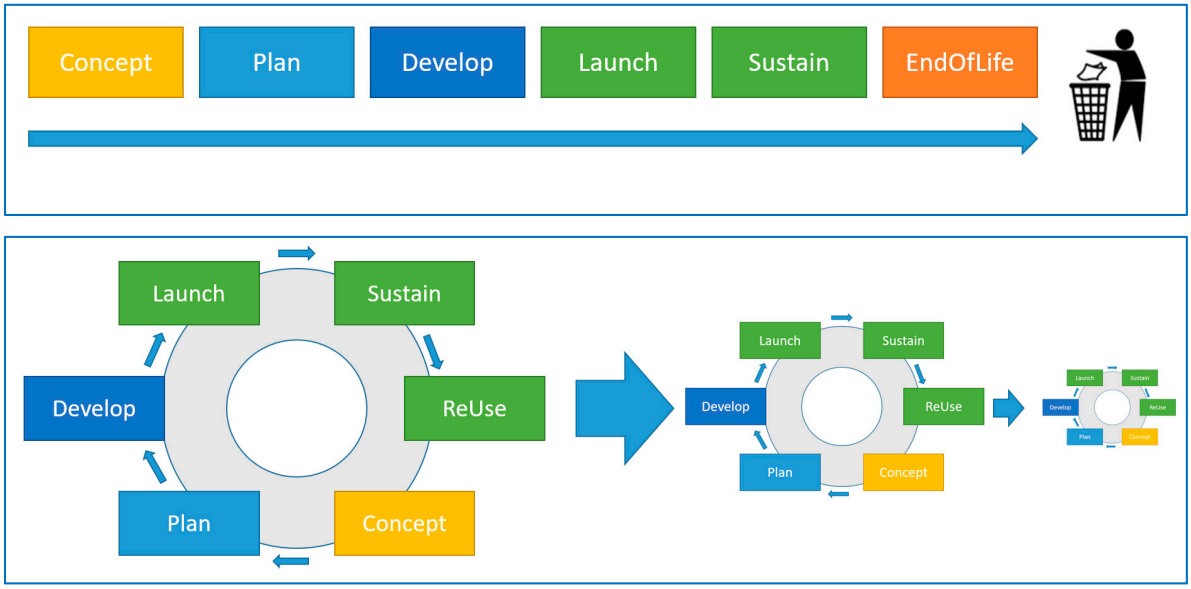
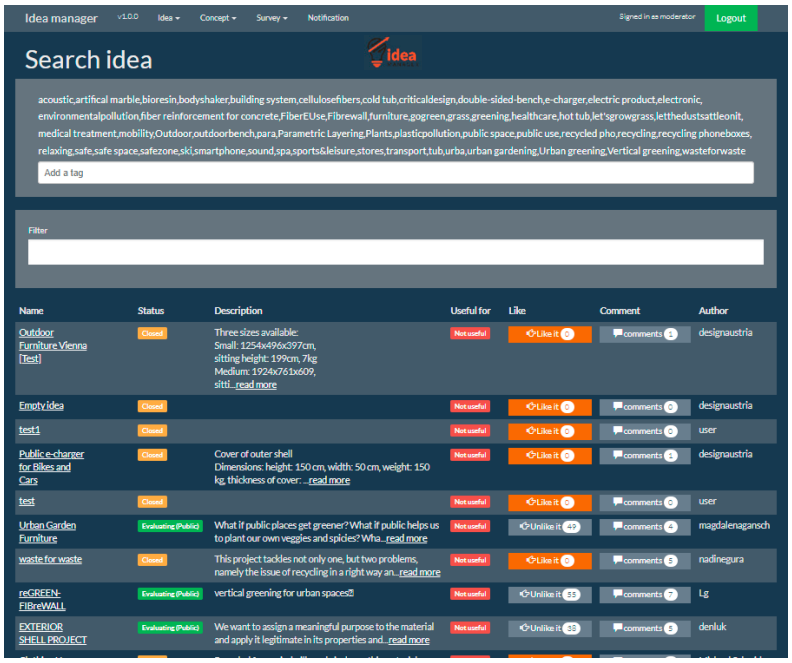


Figure 2. Linear vs. circular information management circle.

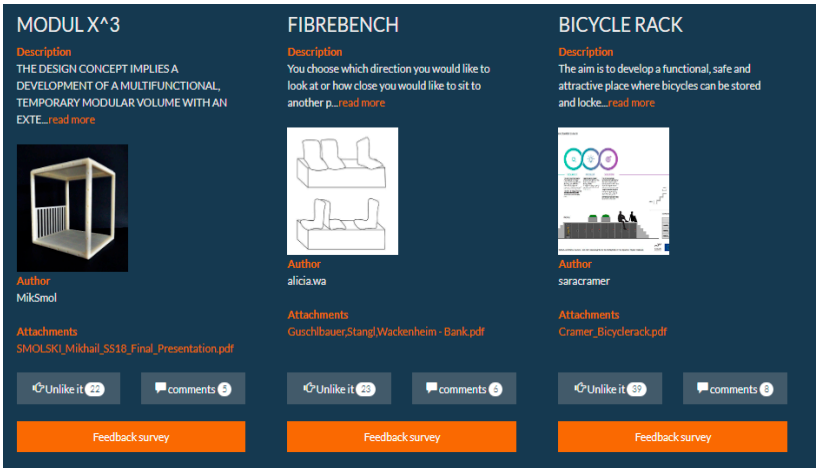
3.4. Idea Manager Solution

The Idea Manager is a web-based software tool designed to provide and support activities along the idea generation process, which is part of the open innovation approach. It is not company-centric, but it is thought to be multi-actor, being able to involve employees, designers, customers, providers, and the interested community in general.

Figure 3 shows the part of the tool referred to the functionality of searching and processing different ideas coming from designers (a) (interesting, public, private, under evaluation, etc.) and collaborating on three designer's ideas (Modul X³, Fibrebench, and Cicycle Rack), giving feedback, votes, and answering surveys (b).



a



b

Figure 3. Idea manager tool: search and process ideas (**a**) and collaborating on ideas (**b**).

3.5. FiberEUse IT Platform Solution

The FiberEUse IT platform is a Multi-Sided platform [8]. This means it is a solution which connects two or more interdependent user groups by playing an intermediary or a matchmaking role. This kind of solution plays an important role throughout the economy, as they minimize transactions costs between market sides. In FiberEUse one of the innovative aspects is the fact that the platform is intended to be also cross-market and cross-sector, involving directly companies of different and wide extraction. In the case of FiberEUse, the solution is based on the type of material, and this is the element able to connect different users from different sectors in the same place.

It has to consider the involved companies, describe them, share the details of the products, catch the history of their cycles, display the key steps in the transformation journey, and take into account the involved ecosystem parties. The solution proposed is based on a list of functions that allow the users to manage circular entities along the steps of their circular transformation and to handle them in all the interactions with different processes and transactions with other companies.

Beside the functionalities provided in the standard menu, it is important to highlight the introduction of three pivotal features, shown in figure 4:

- Circular Entities and recursion
- Expandable Attributes and Polymorphism
- Value Chain Eco-System chart

Those are values that provide innovative characteristics to an object, making the platform substantially different from a common product lifecycle management platform. Those features required an ad hoc architectural design which is able not only to represent the key differentiating functionalities but also to the IT complete support.

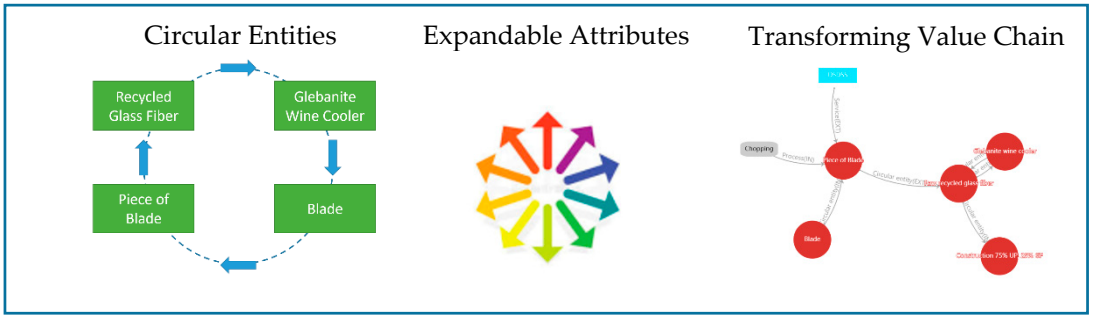


Figure 4. FiberEUse pivotal features.

3.5.1. Circular Entities

In modeling an application or an information system, "Entities" are defined as representation of categories of objects or set of objects with similar characteristics.

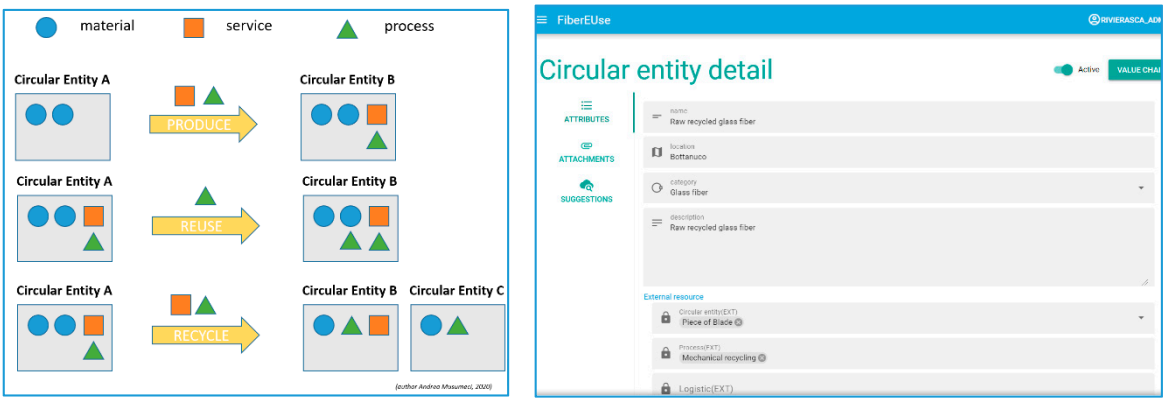
In traditional applications for product lifecycle management, i.e., applications that follow the lifecycle of a product from the prototype to the end of life, the entity is the product itself, that does not change its characteristics during its lifecycle.

In our case, in a Circular Economy, we are also managing objects which are generally unknown, because usually they are new. Those objects can be waste (if thought in linear economy), materials, preprocessed material, new processes and machinery, new final products, prototypes, etc. According to the circular economy definition, all those kind of objects are part of a cycle and cannot be classified as waste, material, or final product anymore [9]; they are all Circular Entities.

In our IT platform the concept of circular entity replaces and goes beyond the concept of a static product entity. It is designed as circular entity, i.e., an entity that can be whatever, even though it has not been defined before from anyone else, and which can be described through its history and through its parameters.

The history of the circular entity can be reported through its internal resources, coming from the same company, or external resources, coming from other companies. In the case of external resources, they require a previous negotiation and a contract with the parties providing the resources, enabling advancement in the value chain and a more sustainable path. From an IT standpoint, such kinds of circular entities are designed to satisfy specific architectural requirements in order to be dealt with the needs of changing parameters. Information can be public or private, according to the company.

In Figure 5a is represented the theory behind the recursion of the circular entity, while in Figure 5b is shown the correspondent functionality in the FiberEUse IT platform.



(**a**) (**b**)

Figure 5. FiberEUse circular entity: theory (**a**) and implementation (**b**).

3.5.2. Expandable Attributes and Polymorphism

Circular Entities and free attributes which describes the circular entity in the way the company prefers, are together a fruitful and complete combination to describe every kind of object. This reflects the concept of Polymorphic data [10].

Polymorphism of data defines data as extensible and able to serve different product histories without the ambition to create a common and classic entity relationship schema but thinking by high-level object-oriented design. Polymorphism usually is the way by which an object can be described through its different interfaces of use. However, also taking in consideration attributes sets (subsets of all attributes of the same object class), we can define polymorphism of data saying that an entity has many point of view considering the actor which observes it. For example, as shown in Figure 6, for a producer, a shirt has different attributes than the same shirt has for a logistic or waste collector. In the FiberEUse IT Platform, this is given by the possibility to insert free additional attributes to the

Circular Entities, described as the company prefers through an attribute name and one or more values.

Figure 6. Polymorphic data example.

3.5.3. Value Chain Eco-System Chart

To achieve and sustain a competitive advantage, and to support that advantage with information technologies, companies should understand every component of their value chains and value systems. A value chain is commonly described as a set of activities that a company operating in a specific industry performs in order to deliver a product (or a service) for the market. A company's value chain forms a part of a larger stream of activities, named "Value system" after Porter [11].

Traditional noncircular value systems take into account the suppliers and the ecosystems of third parties that provide the inputs needed to the company to understand their value chains (i.e., logistics, distribution, etc.). All parts of these chains add value to the value system.

To support companies in the understanding of the value chain in a circular economy environment, FiberEUse IT platform overtakes the limits of not circular value chains and provide the users with the possibility to visualize the ecosystem of circular entities, processes and services, and to visualize them at a glance. A small extract of the Value Chain Eco-system chart is in Figure 7.

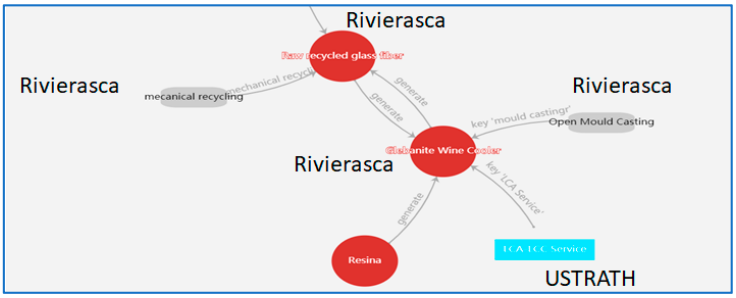


Figure 7. Value Chain Eco-System chart extract (circular entities: red, processes: gray, services: light blue).

4. Conclusions

The overall ambition of the FiberEUse project is to support the stakeholders, which are interested in boosting the systematic development and implementation of cross-sectorial circular value-chains in Europe, by exploiting a valid and circular information management.

The proposed IT solutions which specific and innovative capabilities and the related services, support solving the current information asymmetry bounding the transition to circular business. The demonstration of FiberEUse services and capabilities will be performed through the real adoption of the solutions in the use cases.

Construction, in particular, currently suffers a lack of sharing of data and a discontinuous and unstructured material flow, strongly limiting the recycling opportunities of end-of-life products. According to this, the co-creation approach supported by the Idea Manager tool should support companies in creating new materials coming from a Circular System, to be used in the construction sector and maybe coming from other unexpected sectors (sport, automotive, wind blade, etc.). It should, however, also support companies in getting end of cycle materials from the construction sector to be reprocessed for other sectors.

The connections, the matchmaker, the awareness of the new eco-system which grows step by step, and the availability of information and knowledge, lets stakeholders go beyond the barriers and become competitive in a new systemic circular approach.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. *AVK Composites Market Report;* Elmar Witten: Berlin, Germany, 2015;
2. Saeed, S.; Jhanjhi, N.; Naqvi, M.; Humayun, M. Analysis of Software Development Methodologies. *Int. J. Comput. Digit. Syst.* **2019**, doi:10.12785/IJCDS/080502.
3. Mihai Liviu DESPA. Comparative study on software development methodologies. *Database Syst. J.* **2014,** *3*, 38—56.
4. Hinderks, A. A Methodology for Integrating User Experience Methods and Techniques into Agile Software Development, volume 2370, 31—42. Available online: http://ceur-ws.org/Vol-2370/paper-04.pdf (accessed on 1 October 2020).
5. da Silva, T.S.; Martin, A.; Maurer, F.; Silveira, M. User-Centered Design and Agile Methods: A Systematic Review. In Proceedings of the 2011 AGILE Conference, Salt Lake City, UT, USA, 7–13 August 2011; pp. 77–86.
6. Rubio-Sanchez, M. *Introduction to Recursive Programming*; CRC Press: Boca Raton, FL, USA, 2017.
7. Corballis, M.C. *The Recursive Mind: The Origins of Human Language, Thought, and Civilization—Updated Edition*; Princeton University Press: Princeton, NJ, USA, 2014.
8. Sánchez-Cartas, J.M.; León, G. *Multisided Platforms and Markets: A Literature Review*; Madrid, 2018. Available online: https://www.researchgate.net/publication/325225786_Multisided_Platforms_and_Markets_A_Literature_Review (accessed on 1 October 2020).
9. Waste and Circular Economy. Available online: https://ec.europa.eu/jrc/en/research-topic/waste-and-recycling (accessed on 1 October 2020).
10. Stroustrup, B. *Polymorphism—Providing a Single Interface to Entities of Different Types*; 2007. Available online: https://www.stroustrup.com/glossary.html#Gpolymorphism (accessed on 1 October 2020).
11. Porter, M.E. *Competitive Advantage*; The Free Press: Cambridge, UK, 1985; Chapter 1, pp. 11–15.