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Drawing a Path towards Circular Construction: An Approach to Engage Stakeholders

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Abstract: The activities conducted in the building and construction sector should be guided by circular economy principles, which will result in the implementation of greener practices fostering both the development of economy and protection of the environment. This work proposes and discusses an innovative approach based on a concerted strategy between stakeholders to accelerate the transition to a circular construction paradigm, which involves, as sustainable development, the definition of three dimensions to guide the process: (a) the assignment of key roles to the government and construction professionals; (b) the improvement of the industry to perform a proper management of construction and demolition waste; and (c) the development of sustainable practices at the construction site. In addition to the discussion about the different stakeholder partnerships that must exist, key ideas that should be adopted by industry to deliver recycled materials and products to the building and construction sector are proposed in this work. Moreover, measures to assist in the management of both the traditional and innovative materials and products incorporating recycled waste at the construction site are suggested targeting the implementation of more sustainable practices within this context. A broad use of the ideas proposed in this work in the building and construction sector may lead to encouraging outcomes in the next decade.

Keywords: sustainable development; building and construction sector; circular construction; construction and demolition waste management; sustainable practices at the construction site

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1. Background

The prosperity and welfare of society is attached to the consistency of the solutions that are being delivered worldwide among the different industrial sectors in order to achieve the highly desired sustainable development, which is, in its essence, a development that complies with the current demands but does not endanger the future of upcoming generations [1].

The efforts to meet sustainable development are being conducted by a large number of countries in accordance with the premises of the United Nations 2030 Agenda for Sustainable Development [2], which set 17 Sustainable Development Goals. The balanced use of natural resources and energy and the development and implementation of innovative sustainable materials and products are some of the expected outcomes of the aforementioned Agenda.

These challenges are especially highlighted in the following Sustainable Development Goals: 7—"Ensure access to affordable, reliable, sustainable and modern energy for all"; 9—"Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"; and 12—"Ensure sustainable consumption and production patterns" [2].

The circular economy emerged as a paradigm to boost sustainable development. In brief, the aim is to extend the lifetime of materials and products as much as possible, promoting resources and energy efficiency as well as the reuse, recycling and recovery of waste [3–6].

Circularity must be a cross-cutting principle to be considered in all sectors of the economy, especially in those whose activities include the use of large amounts of natural resources, are high energy-consuming and are responsible for generating significant volumes of waste. The building and construction (B&C) sector, which plays a relevant role in society in the sense of aiding the population to have a better quality of life and has positive repercussions for the economy, fits the profile of the vast majority of industrial sectors whose activities and tasks leave a considerable carbon footprint. For this reason, efforts should be conducted in order to introduce more sustainable procedures into the activities that are performed within the B&C sector on a day-to-day basis.

Statistics are a fundamental tool to understand the negative effect of the B&C sector on the environment. A total amount of 2337 million tonnes of waste was generated in European Union in 2018, being construction and demolition (C&D) waste one of the most impactful waste stream, accounting for roughly one third (35.9% in weight) of the generated waste [7]. This considerable proportion supports the idea that turning C&D waste into a resource should be a global priority.

One important aspect is that this waste stream has a very heterogeneous composition [8–10] (e.g., concrete, steel, wood, bricks, glass, tiles, or soil), which might benefit the potential development of a wide variety of alternative materials and products in the case of the existence of a selective process of collection of the waste at the places it is generated. More so, there are clear targets within this context: for instance, in European Union, the Directive 2008/98/EC of the European Parliament and of the Council [11] set that, from 2020 onwards, at least 70% in volume of the generated non-hazardous C&D waste should be introduced into valorisation chains including reuse, recycling or recovery.

In the European Union, the new Circular Economy Action Plan [12] arose as a tool to boost the transition to a circular economy, in which a proper consumption of natural resources and a significant improvement of circular materials use rates are expected goals. Prior to the release of this document, a Management Protocol dedicated to the C&D waste [13] was also developed targeting the definition of a set of principles and guidelines to help improving the recycling and reuse rates of this waste stream. Although both documents present key ideas and strategies towards the implementation of sustainable practices within the B&C sector, the truth is that it seems not only to be necessary to assign specific roles to the B&C sector agents but also to define tangible practices at the construction site.

Several issues related to the aim of achieving a more sustainable construction have been addressed previously. The research works included the identification of indicators or the study of assessment or certification methods [14–18], such as life cycle assessment (LCA) or Leadership in Energy and Environmental Design (LEED®); the use of Building Information Modelling (BIM) [19–23]; or the management of C&D waste [24–28]. All these topics are of the utmost importance to boost the transition to sustainable construction. However, it appears to be consensual that there is a barrier to be overcome: strong motivation and interactions between the several stakeholders are required in order to achieve the desired goal [15,16,28–33].

It is true that some research work within the domain of sustainable construction has been conducted and that important measures, such as legislative processes, funding instruments or investment in research and development activities have been implemented over the last years. However, a concerted strategy between stakeholders involved in the B&C sector has not yet been determined. This work is intended to help fill that gap by providing insights into the steps that should be conducted by the several agents working in the B&C sector to boost the transition to a circular construction paradigm, in which the use of recycled C&D waste as raw materials must be the rule rather than the exception.

For attaining this purpose, an innovative approach defining the three dimensions of circular construction is proposed. This novel conceptualization depends on the existence of different stakeholder partnerships that should be exploited to prepare the industry to new challenges involving the development of disruptive materials and products made from recycled C&D waste targeting their use in the B&C sector as well as the implementation of sustainable practices at the construction site. The principles that should guide the industry to accomplish these outcomes are displayed in this work, which also provides suggestions of practices to be followed at the construction site, not only to deal with the materials and products used during the construction processes but also to manage the waste that is generated during the C&D activities.

2. Methodology

The understanding considered by the authors during the development of this work is that a loose set of ideas, however valid they might be, will not be truly useful if they are not integrated into a holistic approach. The literature review that was performed revealed the existence of approaches, legislation, measures, documents and guidelines that are currently used to implement sustainable practices in the B&C sector. However, there is a research gap in the sense that an approach discussing simultaneously the path towards circular construction at three different dimensions—government and construction professionals, industry and construction site—does not seem to exist.

To accomplish the research aim of this work, we decided to design a model that could be capable of giving answers to the demands of a circular construction. The model was based on the three previously mentioned dimensions. Peculiarities associated with each one of those dimensions and ideas as well as the interactions occurring between them will be discussed in order to understand how the model could work. In addition, we discuss what roles should be assigned to the government and construction professionals and what should be the understanding at both the industry and construction site to close the loop and to ensure the existence of a truly circular construction paradigm. The methodology included in this work was drawn to respond to the following questions:

- What model could be designed to boost the transition to a circular construction paradigm?
- What are the dimensions to be considered within the framework of that model?
- Who has greater responsibilities and what roles should they assume?
- How waste should be managed in the B&C sector?
- Should that waste be given noble roles?
- What are the requirements and strategies to be implemented at industry?
- What measures should be conducted at the construction site?
- What mechanisms should the B&C companies adopt to implement a more sustainable construction?
- What are the needs downstream of the construction site to close the loop on the materials and products employed in the B&C sector?

3. The Three Dimensions of Circular Construction: A Novel Conceptualization

The path towards circular construction involves, inevitably, establishing a far-reaching understanding between government and the construction professionals, namely, designers, entrepreneurs, manufacturers, contractors, engineers, architects and researchers. Although this is a consensual idea [15,16,28–33], the need of defining dynamics to assist the aforementioned stakeholders in the decision-making appears to exist. The success of implementing circular economy in this specific sector will depend on the synergies occurring between industry and the construction site, which should be boosted and properly managed by the government and construction professionals.

An innovative vision can be drawn in view of this reflection. Figure 1 displays an illustration of the three dimensions that should be considered within the context of circular construction: (1) the assignment of key roles to the government and construction professionals; (2) the development and/or improvement of facilities to manage C&D waste; and (3) the existence of sustainable practices at the construction site. These three dimensions designed for circular construction are framed by the spirit of the dimensions associated with sustainable development, namely the economic, social and environmental [34–36].

According to the cogitation provided in this work, the interactions occurring between the government, construction professionals and the staff responsible for implementing the strategies (representing the social dimension), the industry associated with the B&C sector to treat C&D waste and to develop disruptive materials and products using this waste stream as raw material (the economic dimension) and the performance of C&D activities at the construction site based on greener practices (major step within the framework of the environmental dimension) will command the outcomes of this novel conceptualization for accomplishing an effective circular construction. We considered that the more developed and calibrated the premises enclosing these three dimensions are, the faster the implementation of such an outlook.

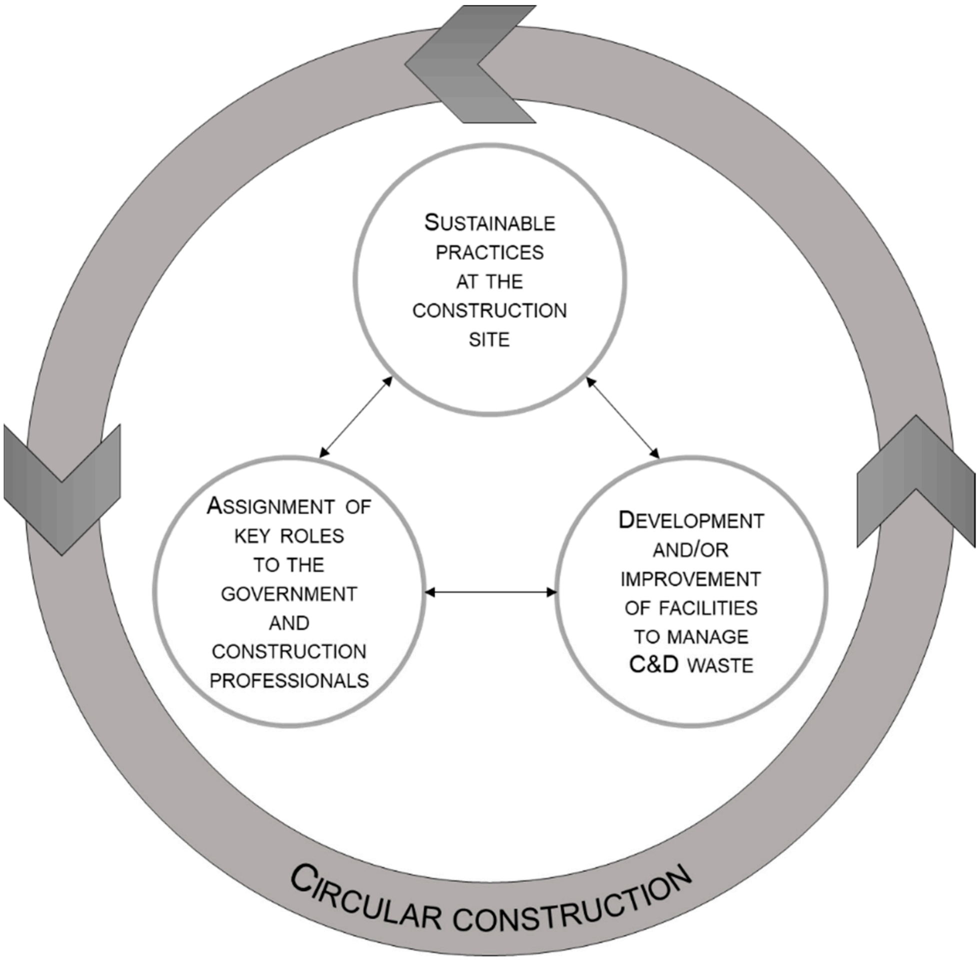

Figure 1. The three dimensions of circular construction: a novel conceptualization.

Although the model depicted in Figure 1 is intended to be dynamic over time, it is important to define a starting point. The dimension associated with the government and construction professionals will trigger the flow of the process. It is important to clarify the roles of these stakeholders, which will be responsible to design strategies targeting the involvement of the industry in the development and/or improvement of facilities to manage C&D waste. The management of C&D waste includes both the treatment of C&D waste passed from the construction site [24,27] and the challenge of manufacturing innovative materials and products resulting from the use of that waste stream [25,26].

The chosen strategies and the way they will be implemented to conduct both the C&D activities will have a major impact on the desired outcome of developing sustainable practices at the construction site. It is of paramount importance that teams working in the field are aware of the need for following not only the guidelines arising from the discussions conducted by the government and construction professionals at the beginning of the process but also those resulting from the procedures developed at the industry to manage C&D waste. As can be noticed, the more persistent the synergies between the three dimensions are, the higher the probability of achieving the expected outcomes within the shortest period of time.

A natural regulation of the three dimensions is expected to occur when the model becomes fully operational, i.e., the ideas, contributions and strategies will be delivered by each one of those dimensions without an established order. This will be an important milestone leading to the adjustment and the improvement of plans being conducted in the B&C sector within the context of circular construction. In the next three sections, we discuss, on the one hand, the aspects associated with the government and construction professionals and the role of industry in the development of raw materials resulting from recycled C&D waste and, on the other hand, the strategies to be implemented at the construction site in order to achieve more sustainable and circular practices.

4. The Expected Mindset of the Government and Construction Professionals

The most challenging task towards a circular construction is a full commitment of the stakeholders with the premises of circularity. The leading figures of the B&C sector must bear in mind that the use of traditional building materials and constructive systems should not be the unique solution within the context of the practices conducted in this sector. There should be a strong will in order to acknowledge waste as a resource, assigning it more noble roles, such as reuse and recycling. Stakeholders must work towards the increase of the waste recycling numbers, whose rate of progress was quite positive in recent years in the case of the European Union; however, this is currently slowing down [37]. On the other hand, the amount of C&D waste sent to landfill in United States of America remains significant [38].

The government plays a key role within this context. It is a government's responsibility for the development and implementation of policies targeting the transition to a circular construction in which an expected outcome is the increase of the waste reuse and recycling rates. In addition, tools should also be developed to monitor both the progress of the transition and whether the B&C sector is complying with the policies that will be in force. There are environment agencies around the globe (e.g., the European Environment Agency [39], United States Environmental Protection Agency [40] and NSW Environment Protection Authority [41]) that monitor the progress rate of indicators associated with sustainable development; however, it seems that additional efforts should be promoted to supervise the processes conducted at companies within this context.

Considering the properties of the recycled materials, which should be fully characterised within the framework of research and development activities, architects and designers should boost the use of these resources in engineering projects as much as possible, without neglecting the proper behaviour of the applications in which they are going to be applied. As usual, designers should develop manuals explaining how the materials should be applied and alerting to the concerns to be considered. The goal should not be the revolutionary replacement of the traditional materials and components by recycled materials but instead a progressive use of these resources as confidence and reliability on their performance increases.

It seems to be reasonable that, in the first phase, priority should be given to investigations comprising the incorporation of recycled materials in non-structural applications, where the outcomes must reveal an absence of risks to the environment. The implementation of such solutions would be easier, since there will be no reasons to foster the discussion about the existence of potential threats to both the stability of the applications and the surrounding environment in which the innovative solutions might be employed.

5. The Role of Industry

New challenges offer new opportunities, and industry needs to adapt to the current circumstances: the use of waste as a resource. However, supportive policies should be promoted. The development of legislation and standards will be an important contribution to regulate the activity of the industry leading with C&D waste [26,27]. On the other hand, the availability of public funds or fiscal incentives are always important measures within this context of developing more sustainable solutions [24,29]. These types of incentives will aid the industry to invest in staff, facilities and equipment dedicated to the development of disruptive materials and products incorporating waste.

Business opportunities will be boosted for the entrepreneurs who work with/for the B&C sector. However, these leading figures will have to overcome several obstacles since the development of innovative solutions based on research and development activities always involves challenges and risks. Therefore, strategies should be designed to cope with this scenario. More so, there are four fundamental priorities within this context: (a) the development of suitable equipment to deal with the waste and to manufacture the final materials and products; (b) the establishment of good manufacturing practices; (c) the training of staff; and (d) quality control.

The manufacturing of innovative solutions involving the use of waste may force the design and development of new equipment, and these represent a significant financial investment due to the time and resources required to accomplish such task. In addition, the initial setup and adjustment of the equipment is a reality that may produce negative effects on the pace of the production lines. The development and implementation of principles and guidelines of good manufacturing practices are essential tools in order to ensure that the materials and products developed at the production lines fulfil the intended requirements.

The *in situ* performance of the resulting materials and products over time highly depends on the manufacturing process and the process of quality control. The investment in the training of the technicians should also be a priority: the expectation is that, the better prepared the technicians are, the better the quality of the resulting materials and products. The training process will involve the practices associated with the management of the raw materials (from natural sources or waste), the setup of the equipment and the operation of the production lines and the handling and packaging of the final materials and products to be used at the construction site.

Finally, the resulting materials and products should comply with certain properties, which implies the creation of a quality control process based on new guidelines in order to attest those required properties. At the end of the process, a technical sheet revealing the properties of the materials and products should be generated. This process of quality control will assist the decision-making associated with the intended use of those materials and products. Figure 2 displays the stream that fits into the previously mentioned vision, from the identification of some stakeholders, to the delivery of the disruptive materials and products incorporating recycled waste to the B&C sector.

To increase the reliability on the use of recycled materials and products further actions will be required. Within this context, it will be important to perform the LCA analyses, a tool that will provide information on the environmental impact of the materials and products throughout their life cycle [42–46]. An aspect of great significance is the evaluation of the potential release of harmful substances into the environment by the innovative solutions incorporating recycled waste.

Thus, leachate tests should be conducted to understand the existence of hazardous substances in the constituents of the recycled waste used for developing those solutions (methodologies and findings within the context of this type of evaluation can be found in literature [47–51]). Investments in research and development activities should also be applied in the investigation of both the short-term behaviour and the durability of the new noble recycled materials and products. The latter is a matter of concern even for the traditional widely used building materials, such as concrete or steel. Long-lasting materials imply less maintenance and later replacement works, allowing the use of less natural or recycled resources. There are no doubts that a way to increase circularity is having reliable long-lasting materials and products available in the market.

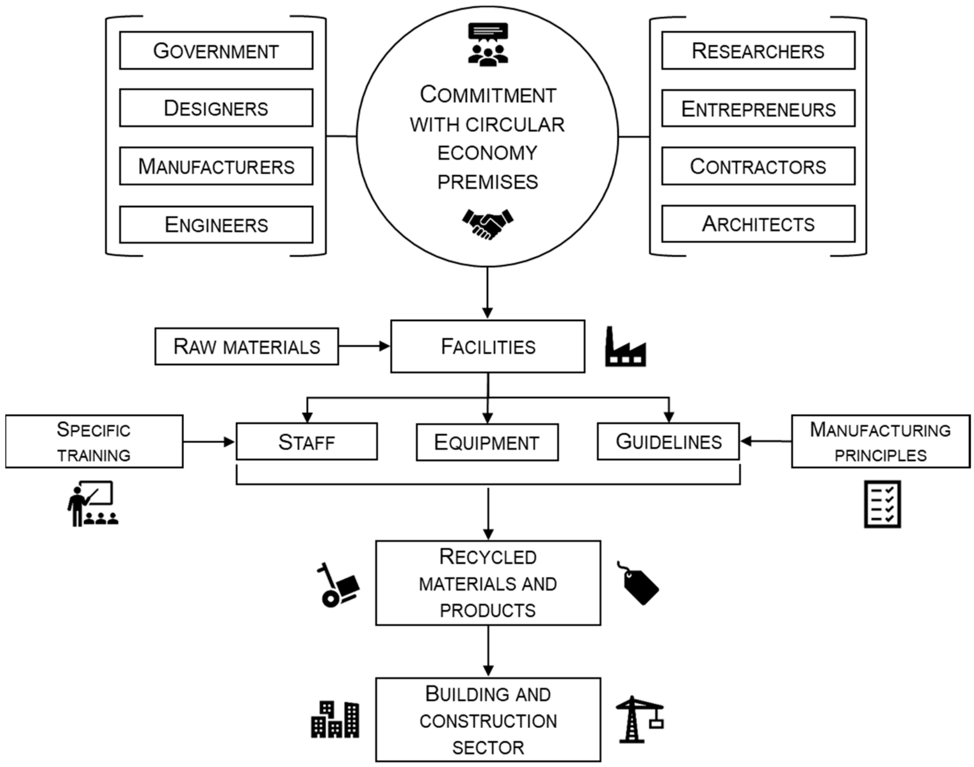

Figure 2. Development of recycled materials and products to the B&C sector.

6. Measures to Improve Circularity at the Construction Site and Downstream C&D Waste Treatment

The construction site is the place where ideas and strategies take shape. Good planning usually means good outcomes. In the case of considering other variables, such as the use of disruptive materials and products or the management on-site of generated waste, efforts should be conducted to avoid undesirable drawbacks in the course of construction works. Therefore, planning carried out by project managers must include the identification of tools that should be implemented at the construction site to handle the management of all (traditional and disruptive) materials and products that flow over time. In addition, strict plans should be designed to properly forward the generated waste to valorisation chains.

This work includes installing warehouses to store the materials and products as well as nominating staff to manage the admission, measurement and accommodation of the materials and products. Special attention should be given to the leftover materials and products and to the waste generated. These resources should be properly accounted for and forwarded to different locations, depending on the intended usage, i.e., if it is planned their use in the course of the construction works, they should be measured and accommodated in the respective warehouse; by contrary, if no further activities including their use are planned, they should be forwarded to provisional collection areas [52] or recycling plants [24,53], which might be placed at the construction site [27].

The technicians, to whom training must be provided, should be aware of the need of using the available resources on-site carefully, including the leftover materials and products and the generated waste. If applicable, they should comply with the correct guidelines provided by the designers and the manufacturers while installing the recycled materials and products. The construction oversight team will also play an important role, since it will be responsible to ensure that all the practices within this context are being well implemented.

A team composed by engineers, technicians and oversight construction staff will also be responsible to implement the best practices within the framework of demolition activities. This is a key step targeting the increase of the reuse and recycling rates of demolition waste. One of the main problems is the lack of quality of the waste resulting from those activities, whose very heterogeneous composition hinders its potential use in recycled materials or products. Therefore, the implementation of selective demolition/deconstruction processes [28,52,54,55] is of the utmost importance and will aid in both the work of the recycling plants and the industry facilities dedicated to the development of recycled materials and products using C&D waste.

A network of recycling plants should be implemented and prepared with staff and equipment to forward the waste coming from the C&D activities to proper treatment processes. If not performed before, the sorting of the different waste materials and products according to their composition will take place at the recycling plants. This task is of utmost importance in order to avoid the contamination of the recovered waste [54,56,57], which can be a serious obstacle to deliver greater added value to this resource.

It should also be considered the possibility of these recycled centres attest the quality control of the materials that are produced, which will be a positive aspect targeting the increase of the reliability on those recycled materials. It is expected that the manufacturers responsible for developing materials and products involving the use of waste will have their own recycling facilities in the future to turn the C&D waste into a raw material. However, in the case of the nonexistence of those facilities, the recycling plants are going to be responsible to provide good quality recycled raw materials to the manufacturers.

If the aforementioned ideas, measures and practices are implemented, or, at least, some of them, then steps are being taken to close the loop for materials and products that will be manufactured and used in the B&C sector. A schematic representation of the stream including how the ideas, measures and strategies discussed in this section can be put into practice is displayed in Figure 3. The belief is that these guiding principles are a tool to improve circularity, and the goal of achieving more environmentally-friendly solutions towards sustainable development will be closer.

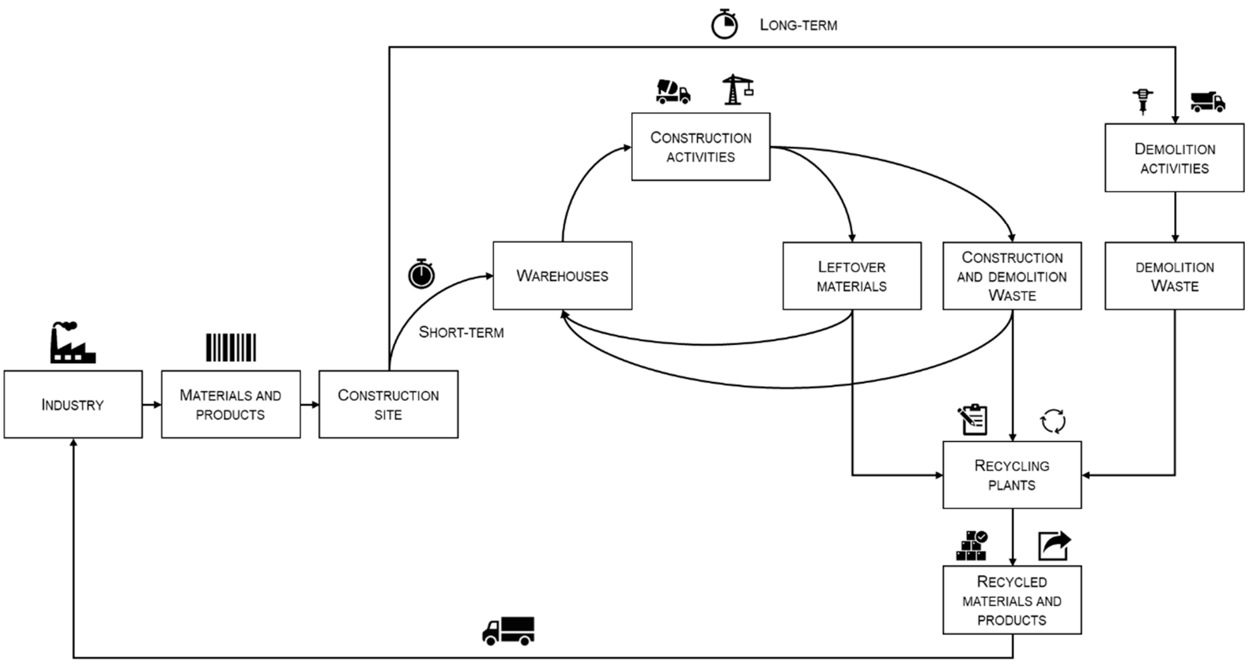

Figure 3. Closing the loop on the materials and products used in the B&C sector.

7. Overview on the Impacts of Implementing the Proposed Approach

The implementation of such a broader approach will naturally result in economic, social and environmental impacts. The steps including a wider intervention by governments and construction professionals and the accommodation of industry to the current needs involve investments at different levels.

One of the issues that always comes up at the top of the problems of any new project to be developed, regardless of the economic activity, are the financial resources. In the case of the approach proposed in this work, there are no doubts that efforts should be undertaken in order to assist industry and the B&C sector to implement the solutions that are required. This support can be granted by means of funding instruments, such as public investments or green fiscal policies, which should be studied and developed by governments, or by the allocation of capital by investors.

However, industry must be aware of the need of carrying out its own investments on research and development activities in order to develop more sustainable practices. Equally important is, on the one hand, the development of legislation that forces companies to comply with greener and sustainable practices and, on the other hand, standards framing issues like the use of waste as raw material. In addition to the action of governments, working groups and technical committees should be formed to work on the development of those instruments. Existing or upcoming institutions/agencies should monitor the implementation of the resulting outcomes.

The upcoming challenges involving the study and development of new commercial materials and products including waste will offer the opportunity of both improving the knowledge and foster the creation of new companies. Academic institutions should have an important focus on research topics dedicated to the implementation of sustainable solutions. As previously mentioned, it is important that industry has its own innovation centers, laboratories and technopoles. Partnerships between academy and industry are required in order to develop solutions that could be viable in the short-medium term. For instance, solutions involving the combined use of natural resources and recycled waste appears to be an interesting starting point.

These dynamics will boost new job opportunities for both research and industry positions. However, it is expected the need of additional and proper training in accordance with the new circumstances and the development of good practices guides (designers will have an important role during these processes).

Reluctance from designers, engineers and contractors is expected. The use of new materials and products, different types of designing approaches or new operational processes will not be fully welcome. On the one hand, their confidence must be conquered by the work developed by governments, industry and academy. On the other hand, they should be aware that there is a work of adaption that should be accomplished by themselves. BIM should be a wider reality in order to, for example, optimize resources. The introduction of circular economy concepts during the design phase could be a contribution, for instance, to understand the reuse percentage of the materials that are going to be applied during each project [58].

Planning is essential: waste management should not be performed only at the construction site. Executive projects and descriptive and constructive memories should be developed by the designers for all engineering disciplines. These documents should include plans for a proper *in situ* waste management and, if possible, instructions for the selective demolition/deconstruction processes. The oversight teams should be fully aware of these projects and documents in order to ensure that no deviations from what the designers envisioned will be observed. The understanding of the authors is that these are relevant strategies to implement the principles of circular construction.

Finally, are the environmental issues. The first issue that can be addressed is the management of the natural and recycled resources. The excessive use of natural raw materials by the B&C sector is responsible for generating impressive environmental impacts that seem to be difficult to be recovered. The use of natural resources can be remarkably decreased in case of using recycled waste as raw material, which is a major step to stop that serious drawback. In addition, the introduction of waste into valorisation chains avoids its landfill, mitigating the negative financial and environmental impacts induced by such solution.

It is expected that the adoption of sustainable practices by the industry including the use of waste as raw material would be a contribution to decrease energy consumption. The use of energy in a linear model of resource consumption is very significant during the steps involving the extraction of the raw materials from the environment and their transformation into commercially solutions [4]. Both reductions in the use of natural resources and energy consumption are important measures in order to reduce the carbon footprint caused by industry.

Another important aspect is that the development of materials and products made from recycled waste to be used in the B&C sector is going to have a positive effect on the waste reuse and recycling rates, which must be improved as much as possible. All these measures are contributions (some are important, while others are not so impactful) to combat climate change that is mainly caused by human activities and to achieve some of targets of the Sustainable Development Goals included in the United Nations 2030 Agenda for Sustainable Development [2].

8. Final Remarks

The path towards circular construction involves different stakeholder partnerships. Documents providing guidelines to boost the reuse and recycling of C&D waste have been developed over recent years, and some solitary measures targeting sustainability have been put into practice at the construction sites. However, it seems that additional steps should be conducted in order to fulfil such outcome, i.e., a concerted strategy between stakeholders should be implemented in order to attain a circular construction paradigm. The previously mentioned concerted strategy and the respective particularities of the innovative approach displayed in this work, which discusses simultaneously the transition to a circular construction paradigm at three different dimensions, namely government and construction professionals, industry and construction site, are the main contributions to the body of knowledge.

The insight delivered in this work provides key ideas to help clarifying the roles to be assigned to the government and construction professionals as well as some practices to improve sustainability at the construction site, which deals with a lack of planning in the use of materials and products, mistakes in the management of the C&D waste that is generated and an absence of projects and guidelines to perform the correct operational processes.

The development of strategies for achieving a circular construction should be based on three dimensions: (1) the assignment of roles to the government and construction professionals; (2) the development and improvement of industry to deal with C&D waste; and (3) the implementation of sustainable practices at the construction site. These three dimensions are related to their counterparts associated with sustainable development (society, economy and environment).

The study performed in this work allows us to conclude that the proper transition to a circular construction paradigm involves the creation of legislation and standards, the availability of funding instruments, such as public investments or green fiscal policies, the motivation by construction professionals to develop and implement innovative but reliable solutions, well-trained staff and technicians, facilities with proper conditions to deal with recycled materials and the correct management of waste resulting from C&D activities.

In addition, existing or upcoming institutions/agencies should monitor both the rate of the progress of the implementation of circular sustainable measures in the B&C sector and whether this sector is complying with the legislation, standards and strategies within this context. Another important step to be considered would be the validation of the model displayed in this work, which might be accomplished considering examples encompassing the application of the principles supporting that model. This process of validation is currently in its starting phase, and some conclusions are expected to be presented in the future.

We presume that, with the commitment and determination of stakeholders around these strategies, the achievement of a circular construction paradigm might become a reality in the next decade. However, an important message should be highlighted: the approach included in this work aims to have a global reach, i.e., major efforts should be undertaken in order to support developing countries the transition to a circular economy paradigm within the framework of their own B&C sectors. Future research works involve the conceptualization of strategies and measures and the definition of synergies between developed countries to assist the B&C sectors of developing countries in the implementation of a circular construction paradigm.

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