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Review

Design, Materials, and Extrusion-Based Additive Manufacturing in Circular Economy Contexts: From Waste to New Products

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Abstract: The transition toward circular economy models has been progressively promoted in the last few years. Different disciplines and strategies may significantly support this change. Although the specific contribution derived from design, material science, and additive manufacturing is well-established, their interdisciplinary relationship in circular economy contexts is relatively unexplored. This paper aims to review the main case studies related to new circular economy models for waste valorization through extrusion-based additive manufacturing, circular materials, and new design strategies. The general patterns were investigated through a comprehensive analysis of 74 case studies from academic research and design practice in the last six-year period (2015–2021), focusing on the application fields, the 3D printing technologies, and the materials. Further considerations and future trends were then included by looking at the relevant funded projects and case studies of 2021. A broader number of applications, circular materials, and technologies were explored by the academic context, concerning the practice-based scenario linked to more consolidated fields. Thanks to the development of new strategies and experiential tools, academic research and practice can be linked to foster new opportunities to implement circular economy models.

Keywords: product design; additive manufacturing; circular materials; material recycling; recycling and reuse; design for sustainability; 3D printing

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1. Introduction

The linear economy model is actually recognized as being unsustainable, especially considering the global exploitation of fossil derivatives due to human activities. To this purpose, a transition toward more sustainable models is increasingly encouraged from policymakers, industries, and academic research [1,2]. In this emerging context, the circular economy can generate closed loops of material and energy flows conventionally involved in linear models [3,4]. Contrarily to the linear take-make-waste model, a circular economy aims to preserve the economic and environmental value of these flows thanks to different strategies, i.e., the reuse of products, components, and materials, or their remanufacturing, refurbishment, and repair [5–7]. In more detail, these hierarchical strategies are known as "R-imperatives", and their conceptualization is still a debated issue in the academic field. Recently, the concept of 10R-imperatives has been emerging, considering not only the starting 3Rs (reduce, reuse, and recycle) but also other established principles, i.e., repair or repurpose [8,9]. Despite the open challenges that a circular economy has to overcome in the next years, this new model allows to adopt a systemic approach that considers the production of a specific product and its whole life cycle with better use of resources, waste, and leakage [1,5].

New circular economy models should be investigated to reduce the human impact on earth. In particular, business models can strongly affect not only the circularity of specific products or services but also the internal organization of firms and companies, which generated new closed-loop strategies (i.e., waste materials as raw resources, or product utilization versus ownership) [1,5]. Within this framework, designers play a crucial role in the implementation and development of these approaches. Therefore, a new set of interdisciplinary skills is required to foster this transition and build a methodology for circular design [7,10–12]. As a matter of fact, the early stages of design strongly influence the impacts of a product during its life cycle, and designers should be not only aware of it but also properly trained [13,14].

A strong connection between a circular economy and materials is clearly legible since the latter underpins several closed-loop strategies (i.e., reuse, recycle) [15,16]. Ideally, cyclical material flows should eliminate the use of virgin resources or promote renewable ones [5]. To this purpose, new hybrid design practitioners focused on these aspects are emerging, namely "material designers" [17]. In addition to a clear understanding of circular economy principles, a material designer needs to deal with the materials from a theoretical point of view and directly experience them. Accordingly, different experiential learning methodologies have been emerging in the last few years [18,19], and the concept of "tinkering with materials" is gaining increasing amounts of attention both in design research and practice [20]. In this way, the material designer has the opportunity to understand how to apply material through a learn-by-doing approach properly. This is aimed to increase the knowledge of conventional materials and the individual or collective self-production of new materials according to the specific project requirements. This approach is better known as Do-It-Yourself (DIY) materials, and it often begins with the creative use of organic or inorganic waste as ingredients to develop new materials [21]. Accordingly, the DIY-materials approach seems to be really prone to implement closed-loop strategies and, consequently, new circular economy models.

Similarly, digital technologies can potentially contribute to this framework. Among those, Additive Manufacturing (AM) appears as one of the most promising technologies [22,23]. From 3D models, AM can produce complex customized pieces by adding material "layer-by-layer". Firstly, AM is able to create circular economy strategies based on distributed and local manufacturing systems thanks to its paradigm-changing nature [24]. Furthermore, the AM flexibility allows the optimization of the material flows by incorporating or reusing waste from other industrial loops, fostering industrial symbiosis. Particularly, the Material Extrusion AM category is increasingly used in this framework [25,26]. Material Extrusion AM, hereinafter extrusion-based AM, selectively dispenses a material through a nozzle or orifice [27]. Although Fused Filament Fabrication represents the most famous process (FFF, also known as Fused Deposition Modeling or FDM®), other emerging processes belong to this category, i.e., Direct Ink Writing (DIW). Differently from FFF, DIW allows the deposition of viscous materials at room temperature and enlarges the range of choice to ceramics, concrete, thermosetting, and composites. Meanwhile, different production scales and process applications for AM have been investigated, confirming the exploitation of this technology both in the academic and practitioner contexts. [28,29].

Therefore, the individual contribution of design, materials, and extrusion-based AM to develop new circular economy models is recognized. However, the relationship between these four aspects is still unclear, and different scenarios distinguish the academic and the practitioner contexts. On the one hand, the literature mainly shows engineering-oriented publications related to the characterization of new bio-based or waste-based materials for AM. Only a recent work started to investigate this relationship from a design-oriented perspective [30]. On the other hand, design practice has begun to jointly consider these aspects in the past decade [31,32]. This research aims to fill the gap between these two apparently diverging realities by analyzing the practical outcomes of the two contexts. One of the first examples in the design practice is represented by the work of Dirk van der Kooij. In 2011, he hacked and developed a large format FFF system to process the polymer waste of End-of-Life (EoL) refrigerators. With this manufacturing process, he produced new furniture products, such as chairs or lamps (Figure 1a,b) [33,34].

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

Figure 1. Early applications of waste-based thermoplastics with material extrusion AM processes by Dirk Van Der Kooij (Reprinted with the permission of Kooij): (**a**) "Endless" chair (2011) [33]; (**b**) and "Fresnel" light (2014) [34].

This paper aims to collect and review the case studies based on closed-loops for waste valorization that link design, materials, and extrusion-based AM. In detail, this review aims to answer the main research question (RQ1): "What is the current situation in the academic and practice-based contexts at the intersection of design, materials, extrusion-based additive manufacturing, and a circular economy?". The following two additional sub-questions emerged at the beginning of the literature review:

- RQ 1.1: "What are the similarities and differences between the two contexts?"
- RQ 1.2: "What are the emerging trends related to this research intersection?"

After the research methodology (Section 2), the general framework is given through a general analysis of the different patterns from the academic and practice-based contexts (Section 3.1, RQ 1). The best practices are then presented according to the application fields, materials, and extrusion-based AM technologies (Sections 3.2 and 3.3, RQs 1 and 1.1). Some general trends are depicted, and some considerations are made on how to foster a virtuous circle between academic research and practice (Section 3.4, RQ 1.2). Similar to DIY-materials and material tinkering, new experiential tools can be developed with the following two main goals: (i) creating a link between academic research and practice for new synergies in circular economy contexts; and (ii) promoting the knowledge of new circular materials for AM, as well as new AM-based strategies for the design of new products.

In particular, this review differs from the other works for the following two reasons: (i) the holistic intersection between the aforementioned four aspects and (ii) the extension of the review to the most relevant projects from the practice context. Therefore, this work depicts the current situation of the academic and design practice contexts, stimulating future research works related to this topic toward a more holistic approach.

2. Materials and Methods

The literature review of this paper aims to detect and analyze all the best practices that link design, materials, extrusion-based AM, and a circular economy. As mentioned before, several trends may act as facilitators of this interdisciplinary connection both in academic research and the practitioners' activity. The review was therefore conducted by searching not only academic databases, but also other repositories linked to the practitioners' activities, and the following two different contexts were defined for the literature review (Table 1): (i) academic research and (ii) practice.

Table 1. Search organization of the literature review presented in this work: selected contexts, searched repositories and databases, selected keywords and eligibility criteria.

Context	Repositories and Database	Keywords	Eligibility Criteria
Academic research	Scopus DRS Digital Library Google Scholar	"Additive Manufacturing" "3D Printing", "Recycled," "Reprintable", "End of Life", "Waste-based", "Upcycling", "Reuse", "Repurpose", "Reverse", "Recyclables"	- Well-defined applications with tangible artefacts; - Details of the materials and the waste/scraps; - Details of the technology (Material Extrusion AM).
Practice	Dezeen.com 3DPrint.com Materialdistrict.com	"3D Printing", "Recycled", "Recyclable", "Waste","3D-Printed Products", "Upcycling", "Reuse", "Repurpose", "Reverse", "Recyclables"	- Well-defined applications with tangible artefacts; - Possibility to detect the waste, material and technology (Material Extrusion AM);

The review presented here includes only studies and projects from 2015 to 2021. As a matter of fact, a restricted number of case studies were found before 2015 according to the eligibility criteria. Furthermore, the ongoing funded research projects and industrial initiatives were helpful to highlight some general trends for future research. In particular, the following three main phases were followed:

1. Analysis of the repositories for the academic context.
2. Analysis of blogs and sites of design projects for the practice-based context.
3. Analysis and comparison of the results from the two contexts.

The analysis of the first phase was based on the leading publications searched in academic databases (journal articles, conference proceedings, and book chapters). In particular, an exploration was carried out for the terms "circular economy" before and "additive manufacturing" after. The pre-defined keywords shown in Table 1 were added in turn to the results, which were preliminary filtered to remove the duplicates. The abstract of the filtered results was then read, and a further step of selection was carried out according to the eligibility criteria of Table 1. At the end, a resuming matrix was created with the selected works according to the year, the application, the material, the AM technology, and the R-imperatives (Table A1, Appendix A).

The analysis of the second phase considered other repositories of design projects and existing applications. In this way, relevant practical case studies from design activities, industries, and self-production were also considered to depict a more realistic framework. The same steps of the first phase were followed for this analysis, although the specific sites listed in Table 1 were searched instead of the scholar repositories. These data were further checked by reading the reference descriptions and by visiting the project/designer websites. As for the first phase, a resuming matrix was created (Table A2, Appendix B).

In the third phase, a general analysis of the two contexts was carried out by employing the two matrixes of the previous phases and described in Section 3.1. The general patterns were detected by creating specific graphs. Subsequently, the comprehensive analysis of the academic and practice-based context was carried out (Sections 3.2 and 3.3).

Different eligibility criteria were established for the analysis of the academic and practice-based contexts because of their data heterogeneity. The presence of tangible artefacts as real applications and the use of one "Material Extrusion" AM technology [27] were included in both cases since a wide range of new waste-based materials may be potentially developed for this category [26,35]. On the one hand, only scholarly works with a clear description of the material (i.e., starting waste, category, composition) and the technology was considered for the academic context. On the other hand, the possibility to detect them by directly analyzing the source (i.e., from images and further embedded links) was considered enough for the practice context. For example, "Material Extrusion" AM technology is visually distinguishable by its layer-by-layer solid appearance with respect to other 3D printing technologies. Additionally, a specific waste may be an implicit indicator of the new material category.

3. Results and Discussion

3.1. General Analysis

As the main RQ of this review was "What is the current situation in the academic and practice-based contexts at the intersection of design, materials, extrusion-based additive manufacturing, and a circular economy?", the general analysis aimed to depict the main framework. At first, the study focused on searching for works from the past eleven years (2010–2021) to depict a general overview. Since only four case studies were detected from 2010 to 2014, the review was limited to the timeframe from 2015 to 2021. The lack of eligible case studies in the previous part of the decade may be affected by the trends' diffusion- of extrusion-based AM technologies. Only the expiry of the first patents has fostered the development of new 3D printers, materials, and new applications. Moreover, 3D printing was initially seen as a tool for rapid prototyping rather than a proper manufacturing process [22].

As visible in Figure 2, 74 works satisfied the eligibility criteria. In detail, 31 works were related to the academic context, whereas 43 projects were found within the practice-based one. Despite the slight difference, a great interest in both cases is clearly noticeable. The number of works increased more than five times between 2018 and 2021, and only nine works were found in the previous three-year period. A big gap is visible between 2017 and 2018. Only 6 works were found in the former case, whereas 29 works were counted in the latter year. This may not simply be related to the existence of a restricted number of works before 2018. As mentioned in the previous section, the eligibility criteria set in this paper excluded projects and publications without enough data about the applications, materials, and technologies. Therefore, this could mean that other works or projects can be found, but the lack of further details did not allow us to consider them in the review.

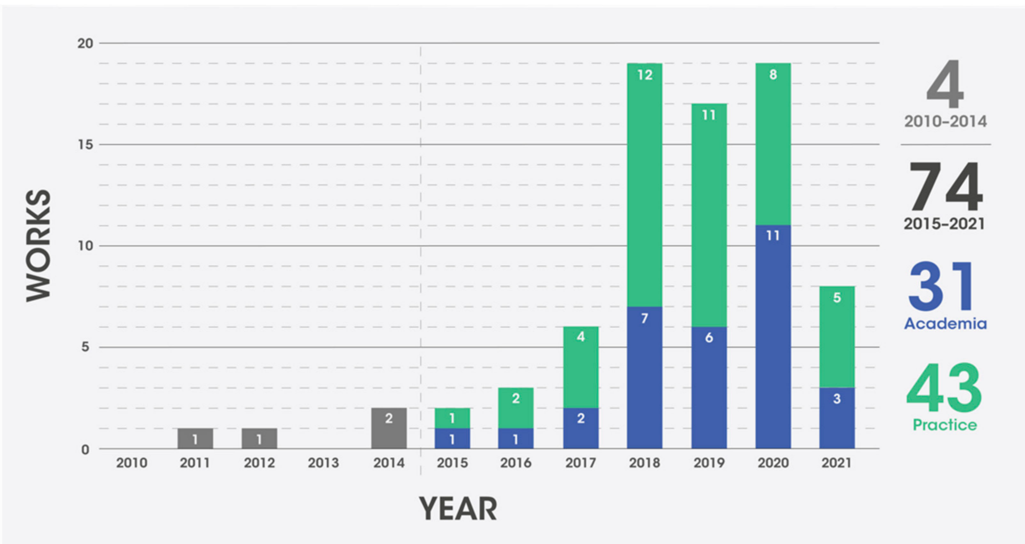

Figure 2. Overview of the works linking real applications to waste-based materials and extrusion-based AM from 2010 to 2021, highlighting the academic published works (in blue) and the developed projects from practice (in green) for the reviewed period (from 2015 to 2021).

Afterwards, the works were analyzed according to the following:

1. Their application field;
2. The R-imperatives strategies;
3. The extrusion-based AM technology and scale;
4. The valorized waste (secondary raw material);
5. The new recycled material.

In this case, the analysis was performed by dividing the academic and practice-based contexts to detect some general patterns, as shown in Figure 3.

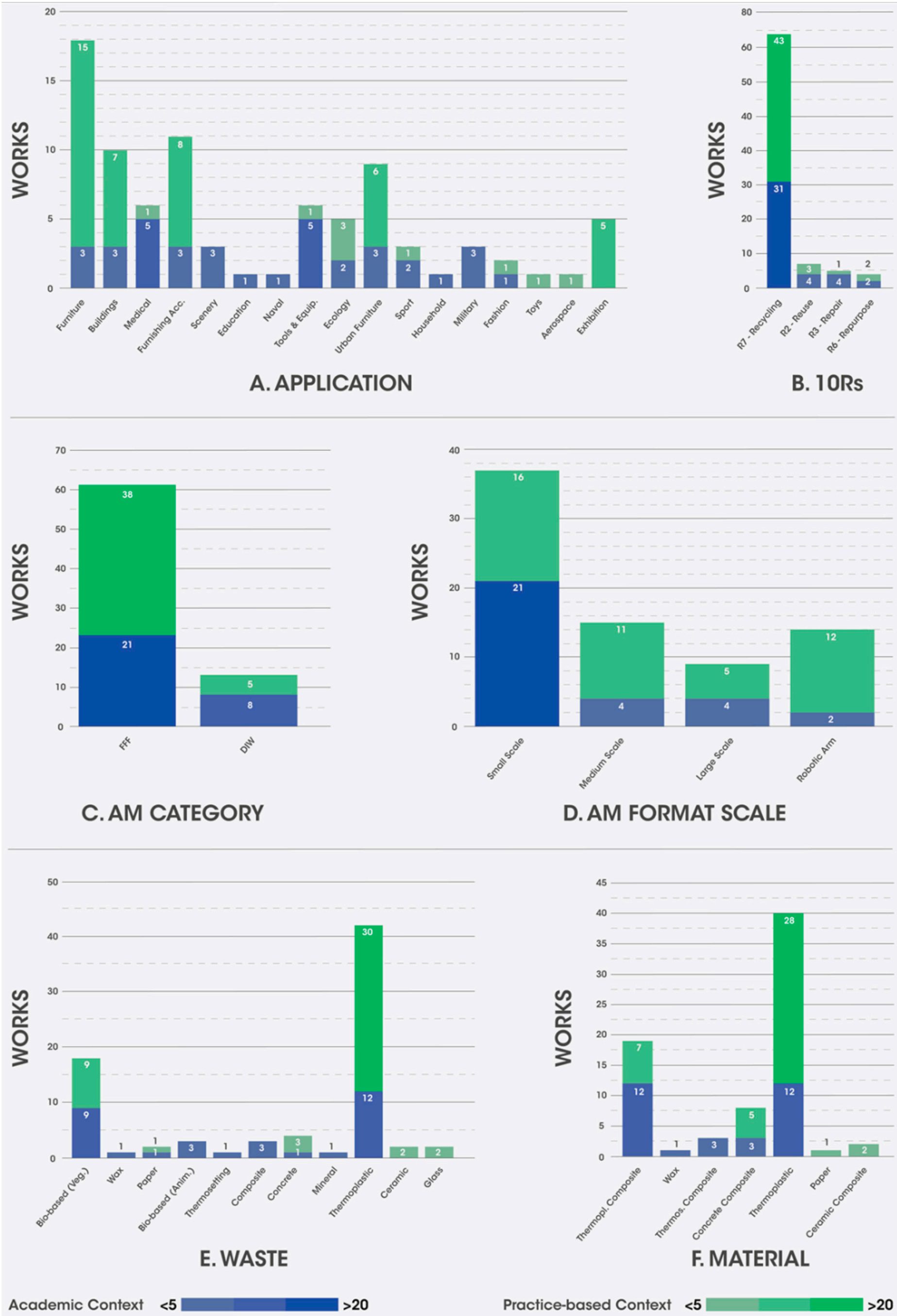

Figure 3. Visual analysis of the references in the academic (in blue) and the practice-based context (in green): (**A**) main applications, (**B**) R-imperatives strategies, (**C**) material extrusion AM processes and (**D**) process scale, (**E**) secondary material (waste and/or scraps), and (**F**) new recycled materials.

According to Figure 3A, a fragmentation of the application fields is clearly noticeable in the academic context, where 14 fields were detected. Among those, there is not a prominent field considering the number of works for each field. Although 12 fields were detected from the practice-based context, the following four sectors showed a high number of works: furniture (15), furnishing accessories (8), urban furniture (6), and building (5). On the one hand, academic research seems to have the opportunity to explore a broader number of technical application fields. On the other hand, practice seems to mainly exploit the sectors with an established tradition in the design practice (i.e., furniture-related fields).

In both contexts, recycling (R7) represents the most diffused R-imperative strategy within the analyzed works (Figure 3B). As a matter of fact, waste valorization intrinsically means to recycle and/or reprocess new materials from End-of-Life products, wastes or scraps. However, other R-imperatives were considered as secondary strategies in addition to recycling, which means reuse (R2—7 works), repair (R3—5 works), and repurpose (R6—4 works). For instance, some works aimed to repair an existing product by 3D printing new pieces made with waste-based materials (R3 + R7).

For those that concern Additive Manufacturing, the analysis was divided in two parts. The first one aimed to evaluate the different kinds of technologies used in the selected works (Figure 3C), while the second one had the goal of evaluating their production scales (Figure 3D). Fused Filament Fabrication technology was demonstrated to be well-established in both contexts (21 works in academic research and 38 in practice). Direct Ink Writing was less common, even though a slightly higher number of works was counted in the academic context (eight). A higher diversification in the production scales was present in the practice context, where the use of robotic arms is more common (12 works). However, the small—or desktop-size—scale is still spread in both contexts (21 works in academic research and 16 in practice). This may be linked to the fact that the scale-up issues are primarily tackled by practitioners rather than by researchers. Moreover, the small scale is more prone to the preliminary development and characterization of new materials.

Similar to the application fields, the academic overview of the secondary raw materials seems more fragmented concerning the practice-based scenario. Different kinds of waste were considered to develop new circular applications, such as composites, thermosettings, and concrete, as visible in Figure 3E. Vegetal-derived waste also gained attention in both contexts, with nine works for each field. Nevertheless, the prominent category consisted of thermoplastic waste in both cases (12 works in academic research and 30 in practice), i.e., polyethylene terephthalate (PET) from bottle waste. Especially for the practice-based scenario, this may be linked to the widespread use of FFF that mainly processes thermoplastics. In the same way, the most commonly recycled material was represented by thermoplastics (12 works in academic research and 28 in practice) as shown in Figure 3F. However, thermoplastic-based composites were quite widespread in the academic context (12 works). Additionally, in this case, FFF strongly affected the composition and diffusion of new circular materials. In light of the above, an interdisciplinary collaboration between the two contexts may allow the scaling-up of new emerging technologies, the spread of new application fields, and a more comprehensive range of circular materials.

To sum up, a wider range of applications, wastes, and materials were found in academic research, while the practice-based context was linked to larger scales and more consolidated applications or materials. Contrarily, the two contexts were mainly related to the recycling strategy.

3.2. Academic Context

This section briefly describes and discusses the 31 case studies from the literature review of the academic context to answer to the main RQ and RQ 1.1, “What are the similarities and differences between the two contexts?” The data from the selected works are chronologically resumed in Table A1 (Appendix A). In particular, the application fields, the materials, and the extrusion-based AM technologies are listed to create a general comparison. In principle, this topic demonstrates an interdisciplinary nature, also confirmed by the different academic disciplines of the publications.

The first work in the academic context is represented by a publication of Mogas Soldevila and Oxman in 2015. A temporary large-scale architectural structure was successfully 3D printed utilizing a customized Direct Ink Writing multi-nozzle robotic arm with a reprintable water-based chitosan mixture [36]. A complex wax formwork for prefabricated parts was obtained in the following year by Gardiner et al., allowing 3D-printed molds to be recycled [37]. In 2017, Canavarro et al. designed a set of coffee cups with a casting mixture composed of Polylactic Acid (PLA) and coffee grounds in 3D-printed molds from FFF [38]. Similarly, Petruzzi et al. focused on furnishing by repairing broken ceramic vases through using the thermoplastic filaments from old electronic devices [39].

Several application fields were found in the publications of the next year. Hart et al. developed a low-density polyethylene (LDPE) filament from the packaging waste of military ready to eat meals for new medical finger pots [40]. Within the military context, Zander et al. produced new long-lead parts (i.e., radio brackets) from filaments derived from PET waste [41]. Zhong and Pearce used post-consumer acrylonitrile butadiene styrene (ABS) for the 3D printing of photographic equipment through Fused Filament Fabrication [42]. ABS from discarded electronics was also the main material for the 3D-printed pipe connectors developed by Mohammed et al. [43]. Focusing on the naval sector, Gardner et al. 3D printed some tooling molds for local boat builders with a thermoplastic-based composite filled with wood flour and cellulose nanofibrils [44]. With a similar approach, Pringle et al. produced a PLA-based composite filament for small furniture elements by grinding and milling wood board scraps [45]. Meanwhile, a soil fertilizer flowerpot was developed by Sauerwein and Doubrovski through a custom DIW system with a reprintable water-based paste filled with mussel shells [46].

In 2019, new waste-based thermoplastic filaments were produced. Reich et al. tested the use of recycled polycarbonate (PC) for new applications, i.e., replacing parts for household appliances (Figure 4a) [47]. Similarly, Depuydt et al. used bamboo and flax fiber-reinforced PLA filaments for biking brake levers (Figure 4b) [48]. New sport equipment was designed and 3D printed from recycled polypropylene (PP) and ABS pellets by Byard et al. (Figure 4c) [49]. Other scenarios were also considered from the works of this year. Dunn et al. designed a preliminary 3D-printed mold for casted marine bio-shelters with oyster shells [50]. Large scale 3D printing was also used by Zhao et al. for the development of a podium support of PLA filled with poplar fibers [51]. A novel glass fiber reinforced polymer from the construction sector was preliminary developed by Mantelli et al. for the production of amusement park and scenery elements through UV-assisted DIW [52].

A larger number of works were found in 2020, especially for thermoplastics and waste-based composites. Novel applications (i.e., prosthetic fingertip grips) of End-of-Life windshield wipers were developed by Dertinger et al. [53]. Calì et al. designed produced patient-specific medical devices with a filament made of PLA and hemp shives (Figure 4d) [54]. A recycled PET-based filament was used for new military and medical applications by Little et al. [55]. A similar secondary raw material was also chosen by Niemand et al. for the development of a working quadcopter [56], and for modular process chain tools for learning environments by Juraschek et al. [57]. Meanwhile, Schiavone et al. developed a new PLA-based filament filled with pozzolan waste powder that was then tested to produce a smart irrigation system [58], and concrete waste was used by Xiao et al. to 3D print a room module [59]. Recycled PLA and ABS were used in the furniture sector for customized wall tiles by Bruce et al. [60], and for the manufacturing of architectural shading modules by Esirger and Örnek [61], respectively. From EoL wind blades, Romani et al. developed a new glass fiber reinforced polymer for the UV-assisted DIW of urban furniture (Figure 4e) [62]. Additionally, Sauerwein et al. produced furniture and fashion elements with reprintable sodium alginate-based paste filled with mussel shells (Figure 4f) [63].

Three publications were found in the first part of 2021. In particular, they are mainly focused on the valorization of organic waste or EoL composites. Ly et al. developed a set of

3D printable mixtures made of cements and geopolymers filled with recycled sands. This new material was then used to fabricate artificial reefs immersed in the Atlantic coast [64]. Mantelli et al. used a recycled glass fiber reinforced polymer from dismantled wind blades for 3D printer components, i.e., an extrusion head support [65]. Personalized anatomical models of vertebrae were 3D printed with PLA and a thermoplastic potato starch filament developed by Haryńska et al. [66].

To sum up, a wide range of applications of circular materials for AM have been investigated within the academic context, despite a predominant engineering-based approach. First of all, the range of the application fields has been progressively enlarged. As a matter of fact, the first works focused on the building sector (2015–2016) [36,37], while new applications were considered in the following years. In particular, the study of technical applications (i.e., medical, ecology, military sector, the development of tools, and equipment) significantly increased. This could be linked not only to the customization that additive manufacturing allows for the creation of unique pieces (i.e., patient-specific orthoses) [54,66], but also to the development of new recycled materials from less common waste (i.e., glass fiber composites, mussel shells) [46,53,58,62,63]. An increasing amount of attention has been given to bio-based or reversible solutions in order to foster multiple closed-loops [45,46,48,51,63], as well as to alternative processes (i.e., DIW) and scales [51,59,61,63,65]. Even though the role of material engineering seems to be predominant with respect to the other fields, the design discipline could find a meaningful way to valorize these new materials and technologies, acting as a driver for their development.

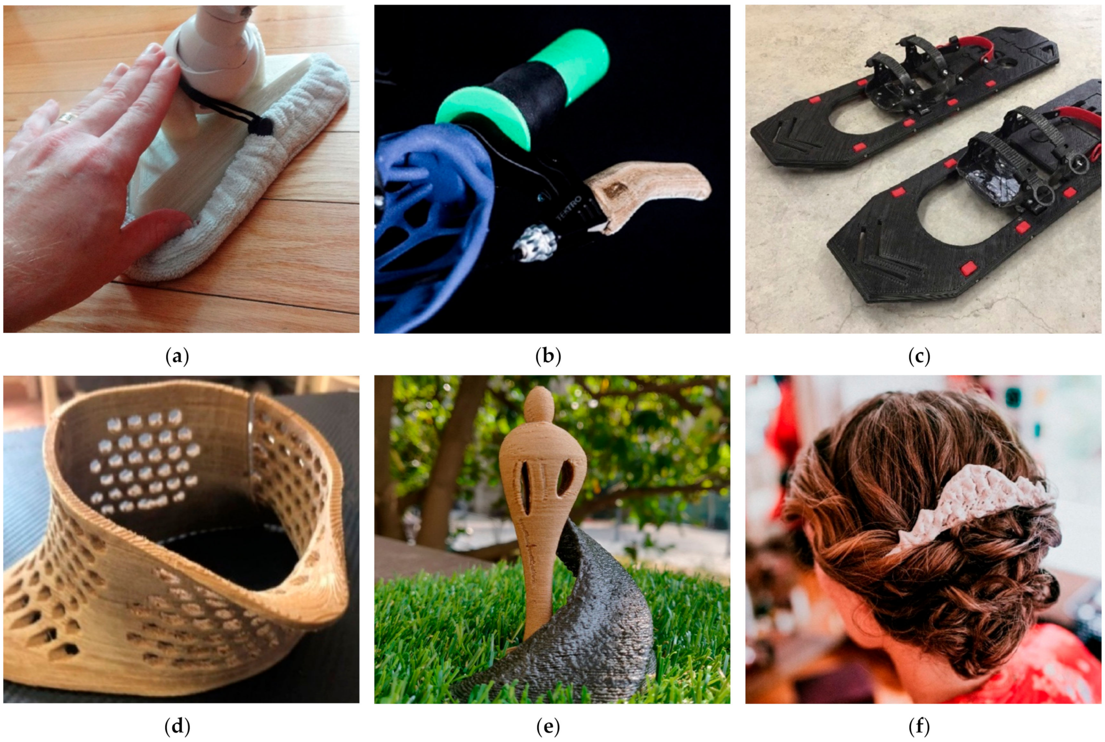

Figure 4. Different products and field of application for the waste-based materials from the academic published works: (**a**) Replaced part of a vacuum cleaner made in FFF with recycled PC [47]; (**b**) Biking brake lever made from bamboo and flax fibers thermoplastic-based composite for FFF (Reprinted with the permission of John Wiley and Sons) [48]; (**c**) Snowshoes printed with the FFF process from recycled ABS and PP (Reprinted with the permission of Elsevier) [49]; (**d**) Customized neck orthoses made with Hemp Bio-Plastic® through FFF [54]; (**e**) Freeform fountain made with mechanically recycled glass fibers from EoL wind blades through UV-assisted DIW [62]; (**f**) Hairpin from reprintable sodium alginate composite with mussel shells for DIW [63].

3.3. Practice-Based Context

An overall framework of the 43 practice-based case studies from the contextual review is resumed and discussed in this section to answer to RQs 1 and 1.1. Similar to Section 3.2, the data are summarized in chronological order, as shown in Table A2 (Appendix B). Additionally, in this case, the application fields, the materials, and the extrusion-based AM technologies were the selected criteria for the analysis. Within this context, design activities and self-production of practitioners and industries constituted the majority of the selected best practices. In some cases, these works represented a collaboration between scientists and designers.

In 2015 and 2016, plastic waste was mainly used as secondary raw material in practice-based projects. "Project Seafood" aimed to transform the collected plastic waste from coastlines into new products, i.e., sunglasses [67]. A similar approach was adopted for the preliminary production of honeybee boxes from End-of-Life bottles by the Australian startup HiveHaven [68], and, within the "Print Your City" project in Amsterdam, for the production of new urban furniture elements from citizens' plastic waste [69].

From 2017, other kinds of waste were also taken into consideration. The "Dolphin Board of Awesome" project experimented with bottle waste and algae-filled PLA to develop a surfboard [70]. The designer Guillaume Credoz exhibited a set of concrete tiles with recycled glass and rubble derived from 3D-printed molds at Beirut Design Week [71]. A set of customized building façades made with recycled plastic waste (i.e., bottles) was designed by DUS Architects [72]. The "Algae Lab" project developed a bio-based polymer from algae that was 3D printed for new exhibition products for the Musee Departemental Arles Antique in France [73].

As for the academic context, an increasing number of projects and applications were found in the following few years. In 2018, the "Million Waves Project" aimed to 3D print upper limb prostheses from ocean plastic [74]. A custom Fused Filament Fabrication 3D-printed and plastic recycler from Tethers Unlimited Inc. was installed on the International Space Station to manufacture spare parts on-demand [75]. Waste-based concrete materials were also used for new large-scale applications in the same year. In the "Living Seawall" project, a mixture of concrete and recycled plastic fibers was cast in 3D-printed molds to create a marine habitat wall (Figure 4d) [76]. The contiguous facades and the roof of the "Cabin of 3D Printed Curiosities" project were primarily made of 3D-printed tiles with ceramic waste [77]. A 3D-printed 100 m^2 house using recycled concrete debris was exhibited during Milan Design Week in 2018 [78]. Furthermore, "Gaia", a 3D-printed house, was produced with a large-scale system that allows for the use of natural waste materials, such as industrial rice scraps [79].

New custom FFF systems were used within the following two participatory design projects: "The Robotic Playground" for urban furniture and park toys from recycled PLA [80], and "Print Your City" in Thessaloniki for new urban furniture from citizens plastic waste [81]. Meanwhile, Beer Holthuis developed a custom Direct Ink Writing system for the 3D printing of furniture elements from recycled paper pulp [82]. In addition, other projects focused on plastic recycling through FFF processes, such as the "Not only hollow" cabinet made from EoL CDs [83], the "Botella light" 3D printed with the recycled PET of about two bottles [84], and "Second Nature" for the production of tableware from locally sourced old fishing nets [85].

In 2019, different projects were mainly focused on large scale applications. Considering the building sector, the following two projects were found: a 3D-printed house module, "Tera", made of basalt waste-filled plastic [86], and the "GENESIS Eco Screen" wall installation for new plant and insect urban habitat made from recycled PET [87]. Similar results were found for a custom exhibition design. "The 3D Bar", exhibited at Milan Design Week in 2019, was primarily made of recycled PLA from coffee cups [88]. A 3D-printed pavilion, "Deciduous", was presented for the Dubai International Financial Center. In this way, about 30,000 discarded water bottles were upcycled for the production of the pavilion [89]. The

"Conifera" project aimed to use PLA filled with wood waste to 3D print the architectural installation exhibited at Milan Design Week [90].

Moreover, different furniture products and furnishing elements were 3D printed from waste-based materials. The "Strats" collection was composed of 3D-printed furniture elements from local plastic waste [91]. The "Beyond Digital" 3D-printed office desk was derived from PP industrial scraps [92], whereas a series of lamps from plastic bottles waste was designed by Plumen and Batch works [93]. A set of 3D-printed chairs were developed in the "Ice-Dream" project from thermoforming industrial wastes (Figure 5a) [94]. Better Future Factory created tables and stools from End-of-Life plastic bottles for AVR company [95]. Finally, the "Feel The Peel" project aimed to develop new 3D-printed tableware from orange peels [96].

A smaller number of case studies were counted in 2020 compared to the previous two years. Considering plastic waste, the following two projects were found: the "Second Nature" 3D printed benches from fishing and shipping ropes [97], and the custom furniture from EoL toys of the "Let the waste be the hero" project [98]. Furthermore, new waste-based composites for 3D printing applications were developed. The designer Nataša Perković used a mixture of PLA oil palm tree fibers to create chairs with FFF [99]. Similarly, Model No. 3D printed new tables and benches with a bio-polymer from agricultural waste [100]. "Volta" furnishing accessories were 3D printed with recycled PETG filaments [101]. "Reprint Ceramics" aimed to develop new circular economy strategies with clay and ceramic 3D printing by using ceramic scraps for new furnishing elements (Figure 5b) [102]. Finally, new thermoplastic composites from coffee grounds and orange peels were developed for the 3D printing of tableware and furnishing within the "Co.ffee Era" [103] and "Was orange" projects [104], respectively.

The case studies of 2021 are mainly focused on developing large scale applications. Very recently, an eco-sustainable 3D-printed habitat called "Tecla" was produced with local soil and raw earth to reduce the environmental impact of living (Figure 5c) [105]. Post-consumer plastic waste was used to create new furniture and furnishing accessories from waste-based materials in more than one work, as follows: a self-sustainable exhibition structure called "R-IGLO" with recycled PET [106], new chairs in glass-fiber-filled recycled PET by Covestro [107], new stools and vases with recycled PET in the "91–92" project [108], and new customized dividers by Aectual (Figure 5d) [109].

Figure 5. Different products and field of application for the waste-based materials from the practice

context: (**a**) "Ice-Dream" project for new furniture elements made from thermoforming industrial scraps by WASP (Reprinted with the permission of WASP S.r.l.) [94]; (**b**) "Reprint Ceramics" project for ceramic furnishing filled with ceramic scraps by Fabrique Publique and Coudre (Reprinted with the permission of Fabrique Publique) [102]; (**c**) "TECLA" project for eco-sustainable 3D-printed habitat made from local raw earth by Mario Cucinella Architects and WASP (Reprinted with the permission of WASP S.r.l.) [105]; (**d**) Customizable interior furniture made from recycled polymers by Aectual (Reprinted with the permission of Aectual B.V.) [109].

In short, specific applications and secondary raw materials were mainly taken into account by designers and industries. The reviewed projects were primarily related to some specific application fields, such as furniture elements [82,84,88,91,100]. Moreover, the number of large-scale applications [76,79,90,94], as well as the use of robotic arms for complex shapes [80,81,85,92,109], has increased in the last few years. In particular, large-scale products seem to be mainly linked to thermoplastic recycled materials and post-consumer wastes (i.e., PET bottles, household appliances). These aspects are related to the need of industrial stakeholders to find valuable markets that are considering additive manufacturing possibilities and limits (i.e., customized and complex shapes, low production batches). However, designers seems to be prone to tinker not only with new materials, but also with new technologies [73,82,99,102]. Design practice is therefore fostering the development of new materials, and it may act as a facilitator for their future development through an experiential and application-driven approach. Finally, occasional collaborations between academic research and practice were also noticed in specific application sectors [70,76,87], as well as some projects aimed to involve users at different levels [69,80,81]. This suggests that design practice is able to give a unique contribution for the creation of new closed loops based on waste valorization through additive manufacturing technologies.

3.4. Future Perspectives

This section focuses on the last sub-question (RQ 1.2): "What are the emerging trends related to this research intersection?" Actually, this topic has been gaining much attention in academic research, and an increasing number of research projects have been funded by organizations and policymakers. Several finished and ongoing projects aim to demonstrate the value creation of closed-loop models through AM technologies, materials, or new design strategies involving both academic and industrial stakeholders [110–115]. Moreover, this aspect has been included in the calls of the Horizon Europe program [116]; hence, these kinds of projects are going to progressively increase. Different institutions and stakeholders will support research at the intersection of these topics in the academic context, especially considering specific kinds of waste that are scarcely considered at the moment (i.e., high-performing composites).

At the same time, industries and design professionals have been collaborating in new practical projects, i.e., Dassault Systemès and Mamou-Mani Architects [117]. Focusing on the current scenario, some industrial stakeholders are actually dealing with the transition from a linear to a circular model by rethinking the materials and design strategies behind their products, i.e., the "WYVE" surfboards cores made with recycled PET collected from oceans [118]. Similarly, the firm Covestro is going to move to circular economy models by making customized insoles from recycled Thermoplastic Polyurethane (TPU) [119]. In some cases, this transition is facilitated through the principles of Human Centered Design, and new virtual environments and tools have been using to engage users by customizing their own circular products. "Aectual Circular" is a digital production service for furniture that allows for the customization of several products made from recycled plastic, facilitating the emotional link with the brand [109]. The "Print Your City" project in Thessaloniki recently implemented an online customizer to raise awareness on sustainability issues by engaging citizens in defining new 3D-printed furniture elements [120]. This transition may also be influenced by the paradigm-shift derived from the COVID-19 pandemic and by the increased attention to distributed and local manufacturing [20]. As a result, alternative ways to foster new closed-loop strategies based on virtual reality will be developed in the next years within the practice-based context, and users' awareness of these topics will constantly increase by putting into practice the principles of Human Center Design. Nevertheless, further research and work should be carried out to encourage new closed loops based on materials, technologies, and design strategies.

According to the previous sections, the collaboration between academic research and design practice seems to be possible. This may generate new strategies based on the interdisciplinary link between design, materials, and extrusion-based AM. As already mentioned, other design tools and principles, such as virtual reality and Human Centered Design, may be implemented. Despite the differences that emerged in Section 3.1, new tools based on experiential learning may be developed and tested considering the interdisciplinary nature of this topic. As a matter of fact, experiencing materials allows designers professionals and researchers not only to acquire new knowledge through a learn-by-doing approach but also to define a shared language for synergic projects between academic research and design practice. At a later stage, the knowledge of new circular materials for AM and new production strategies based on AM technologies can be easily shared among designers and practitioners, paying attention to the different engagement that a specific media allows (i.e., physical, virtual, or DIY-material samples).

4. Conclusions

This paper aimed to collect and review case studies based on closed-loops for waste valorization that link design, materials, and extrusion-based AM. The main goal was to detect and collect the relevant case studies related to design, materials, and extrusion-based AM for waste valorization. A total of 74 case studies from 2015 to 2021 were reviewed and selected from the academic and the practice-based contexts to depict the general patterns related to the application fields, materials, and technologies. Furthermore, some emerging trends were found thanks to the case studies of 2021. It was easy to realize that the number of works increased five-fold from 2018 to 2021. The general aim of this research was to highlight how some new experiential tools can be developed with the following two main goals: creating a link between academic research and practice for new synergies in circular economy contexts; and promoting the knowledge of new circular materials for AM, as well as new AM-based strategies, for the design of new products. The authors wanted to emphasize that the development of new experiential tools can be a good solution to foster the link between academic research and practice, paving the way for new sustainable circular economy models.

The authors considered it essential to clarify the current situation in academic and practice-based contexts at the intersection of design, materials, extrusion-based additive manufacturing, and a circular economy. The paper addresses some general schemes. By analyzing the academic context, the most relevant research works were highlighted. The same was also carried out for the practice-based context. Subsequently, the relative merging of trends at a possible intersection between the two contexts became evident. Specifically, the paper tried to answer the need for promoting new synergies between academic research and practice for new holistic jobs/projects. In short, it is evident that academic research can explore a broader number of applications, materials, and technologies. Contrarily, the practice-based context mainly deals with well-established applications, larger production scales, the most consolidated technologies (i.e., FFF), and daily life waste such as PET bottles. However, fostering the collaboration of these two contexts may be an excellent way to scale up new academic findings and extend the potential application fields.

Afterwards, some considerations were made through the analysis of the case studies from the first part of 2021 and the presence of ongoing funded projects. In the next few years, an increasing number of large-scale applications will be developed. More designers and industries will directly address the transition to circular economy models based on new 3D printable, circular materials. Meanwhile, new ways to raise awareness of these topics for users based on Human Centered Design will be developed. Further efforts should be made to encourage new closed loops based on materials, technologies, and design strategies. New tools based on experiential learning should encourage new closed loops based on this intersection. First, this would allow for a link between academic research and the practical context for new synergies. At a later stage, the knowledge of new circular materials and AM-based strategies in the design practice can be easily shared between designers and professionals, paying attention to the involvement related to a specific media (e.g., physical and virtual samples). Therefore, the future developments of this research concern the continuous monitoring of these areas to foster the development of new experiential tools to connect the academic world and practice as well as the use of these circular materials and strategies. Furthermore, knowledge sharing between designers and professionals should be encouraged by these tools to pave the way for new applications and interdisciplinary strategies for a circular economy.

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Appendix A. List of the Selected Case Studies from the Academic Context

Table A1. List of the academic published works analyzed according to the year, the field of application, the number of citations, the R-imperatives, the secondary material (waste and/or scrap), the new recycled material, the extrusion-based AM (Additive Manufacturing) process, and the produced artifacts (R2 = Reuse; R3 = Repair; R6 = Repurpose; R7 = Recycling; FFF = Fused Filament Fabrication; DIW = Direct Ink Writing; LDPE = low-density polyethylene; PET = polyethylene terephthalate; ABS = acrylonitrile butadiene styrene; PLA = polylactic acid; PC = polycarbonate; PP = polypropylene; EoL = End-of-Life).

Year	Reference	Application Fields	Waste and/or Scrap	Recycled Material	Extrusion-Based AM Technology	Product
2015	1. 10–20 citations, R7 [36]	Building	Cellulose microfibers	Raw natural polysaccharides, fillers, low impact chemicals, and water.	DIW Robotic arm (Custom, Kuka. Water allows reprints.)	Temporary large-scale architectural structures
2016	1. 20–50 Citations, R7 [37]	Building	Wax	Wax	FFF (FreeFAB Gantry)	Molds for panels
2017	1. <10 citations, R2–R7 [38]	Furnishing Accessories	Coffee powder waste	PLA filled with coffee powder	FFF	Molds for cups
	2. <10 citations, R3–R6–R7 [39]	Furnishing Accessories	Electric and Electronic Equipment Plastic Waste	Waste-based Thermoplastic	FFF	Vases

Table A1. *Cont.*

Year	Reference	Application Fields	Waste and/or Scrap	Recycled Material	Extrusion-Based AM Technology	Product
2018	1. 20–50 citations, R7 [40]	Medical	Ready-to-eat meal pouches	Waste-based Thermoplastic (mainly LDPE)	FFF	Medical gloves, finger cots
	2. 50–100 citations, R3–R7 [41]	Military	PET from packaging waste	Recycled PET	FFF	Radio bracket
	3. 50–100 citations, R7 [42]	Tools and Equipment	ABS waste	Recycled ABS	FFF (Athena 3D Printer)	Camera tripod, camera hood
	4. 10–20 citations, R7 [43]	Tools and Equipment	E-waste ABS	Recycled ABS	FFF (Lulzbot Mini)	Pipe Connectors
	5. <10 citations, R2–R7 [44]	Naval sector	Wood flour	PLA filled with wood flour and lignocellulosic fibers	FFF (Cincinnati Big Area Additive Manufacturing)	Tooling mold for boat roof
	6. 20–50 citations, R3–R7 [45]	Furniture	Low/medium density fiberboard scraps, melamine, paper	PLA filled with shredded wood scrapes	FFF (RE:3D Gigabot)	Desk cable feedthrough parts, drawer knobs
	7. 20–50 citations, R6–R7 [46]	Gardening	Mussel shells	Calcium carbonate composite with mussel shells	DIW (Custom from Makerbot. Water allows reprints.)	Fertilizer flowerpot
2019	1. 20–50 citations, R3–R7 [47]	Household appliances, Tools and Equipment	PC from EoL products	Recycled PC	FFF (Gigabot X)	Elastomer tooling molds, Household part replacement, car ice scraper
	2. 20–50 citations, R7 [48]	Sport	Bamboo and flax fibers	PLA filled with bamboo or flax fibers	FFF	Biking brake levers
	3. 20–50 citations, R7 [49]	Sport	ABS and PP waste	Recycled ABS or PP	FFF (Gigabot X)	Skateboard, Kayak paddle, Snowshoe
	4. < 10 citations, R7 [50]	Ecology	Oyster shells	Concrete composite (sand, rocks, vermiculite) filled with oyster shells.	FFF	Marine bio-shelters for seawalls
	5. 10–20 citations, R7 [51]	Urban Furniture, Scenery	Fibrillated fibers from poplars	PLA filled with poplar fibers	FFF (Cincinnati Big Area Additive Manufacturing)	Podium structure
	6. <10 citations, R7 [52]	Scenery	Glass Fiber Reinforced Polymer from Constructions	Acrilic-based thermoset resin filled with shredded rGFRP	DIW (UV-assisted, Custom)	Amusement park arc

Table A1. *Cont.*

Year	Reference	Application Fields	Waste and/or Scrap	Recycled Material	Extrusion-Based AM Technology	Product
2020	1. 20–50 citations, R2–R7 [53]	Medical	Waste from rigid and flexible windshield wiper blades	Waste-based polymer composite	FFF (Deltabot RepRap, Lulzbot TAZ 6)	Fingertip grips for hand prostheses, molds for fingertips
	2. <10 citations, R7 [54]	Medical	Scraps from hemp shives.	PLA filled with hemp shives	FFF (Printer D300)	Customized Neck orthosis, Laryngoscope blades
	3. <10 citations, R7 [55]	Military, Medical	Plastic waste (PET)	Recycled PET	FFF (Gigabot X)	Air Force training aid, Face shield frames
	4. <10 citations, R7 [56]	Tools and Equipment	PET from bottles	Recycled PET	FFF (Lulzbot Taz 5)	Quadricopter airframe
	5. <10 citations, R7 [57]	Education	Plastic waste (PET)	Recycled PET	FFF	Learning tool For recycling processes
	6. <10 citations, R7 [58]	Gardening	Pozzolan powder waste	PLA filled with Pozzolan powder waste	FFF (Ultimaker 3)	Irrigation system module
	7. 10–20 citations, R7 [59]	Buildings	Concrete shredded waste	Concrete filled with concrete waste	DIW (Custom)	Room module (partial)
	8. <10 citations, R7 [60]	Furniture	Plastic waste from 3D-printed models and single-use tableware	Recycled PLA	FFF	Ornamental customized brick wall
	9. <10 citations, R2–R7 [61]	Urban Furniture	ABS shredded waste	Recycled ABS mixed with virgin ABS	FFF (Ultimaker 3)	Joints for shading modules
	10. <10 citations, R7 [62]	Urban furniture, Scenery	Glass Fiber Reinforced Polymers from Wind blades	Acrylic-based thermoset resin filled with shredded rGFRP	DIW (UV-assisted, Custom)	Amusement park Arc, freeform fountain
	11. <10 citations, R7 [63]	Furniture, Fashion	Mussel shells	Sodium Alginate composite filled with shredded mussel shells	DIW (Custom from Makerbot. Ion cross-linking allows reprints.)	Lamp, Hairpin
2021	1. <10 citations, R7 [64]	Ecology	Seashells from canning industry and glass from smashed car windows	Geopolymer formulation with recycled binders	DIW (Delta Wasp)	Artificial reefs
	2. <10 citations, R7 [65]	Tools and Equipment	Glass Fiber Reinforced Polymers from Wind blades	Acrylic-based thermoset resin filled with shredded rGFRP	DIW (UV-assisted, Custom)	3D printer extrusion head support
	3. <10 citations, R7 [66]	Medical	Potato starch	PLA with thermoplastic potato starch	FFF (Prusa i3 MK3S)	Personalized Anatomical models

Appendix B. List of the Selected Case Studies from the Practice-Based Context

Table A2. List of the projects from the practice-based context analyzed according to the year, the field of application, the R-imperatives, the secondary material (waste and/or scrap), the new recycled material, the extrusion-based AM (Additive Manufacturing) process, and the produced artifacts. (R2 = Reuse; R3 = Repair; R6 = Repurpose; R7 = Recycling; FFF = Fused Filament Fabrication; DIW = Direct Ink Writing; LDPE = low-density polyethylene; PET = polyethylene terephthalate; ABS = acrylonitrile butadiene styrene; PLA = polylactic acid; PC = polycarbonate; PP = polypropylene; EoL = End-of-Life).

Year	Project	Application Fields	Waste and/or Scrap	Recycled Material	Extrusion-Based AM Technology	Product
2015	1. "Project Seafood", R7 [67]	Fashion	Plastic waste from beaches	Waste-based Thermoplastic (mainly PET)	FFF (Ultimaker Original)	Sunglasses
2016	1. HiveHaven honeycombs, R7 [68]	Ecology	Plastic waste (Bottles)	Recycled HDPE	FFF	Honeycombs
	2. "Print Your City", R7 [69]	Urban Furniture	Plastic waste from citizen	Waste-based Thermoplastic	FFF Robotic Arm (Kuka)	Benches
2017	1. "Dolphin Board of Awesome", R7 [70]	Sport	Algae and plastic waste (Bottles)	Recycled PET And PLA filled with algae	FFF	Surfboards
	2. Concrete 3D Tiles, R2–R7 [71]	Building	Glass and construction rubble	Concrete with 40% glass and rubble	FFF	Molds for 3D Tiles
	3. Adaptable 3D Design Façade, R7 [72]	Building	Plastic waste (mainly bottles)	Waste-based Thermoplastic (mainly PET)	FFF	Customized Building façades
	4. "Algae Lab", R7 [73]	Exhibition, Furnishing Accessories.	Algae and starch	Algae-based Thermoplastic	FFF	Utensils for Museum exhibitions
2018	1. "Million Waves Project", R7 [74]	Medical	Plastic waste from ocean	Waste-based Thermoplastic (mainly PET)	FFF	Upper limbs prosthesis
	2. On-demand spare parts, R3–R7 [75]	Tools and Equipment, Aerospace	Plastic waste from astronauts	Waste-based Thermoplastic	FFF (Custom)	Spare parts
	3. "Living Seawall", R2–R7 [76]	Ecology	Plastic waste	Concrete filled With recycled plastic fibers	FFF	Molds for 3D Tiles for marine habitat walls
	4. "Cabin of 3D Printed Curiosities", R7 [77]	Buildings	Ceramic waste	Waste-based ceramic	DIW (Custom)	3D tiles for roof and lateral walls
	5. 100 m^2 House, R7 [78]	Buildings	Concrete debris from demolition sites	Concrete filled with demolition debris	DIW Robotic arm (Cybe Construction)	100 m^2 house
	6. "Gaia", R7 [79]	Buildings	Vegetable fibers (rice—industrial scraps)	Concrete composite (25% soil, 40% straw chopped rice, 25% rice husk, 10% lime)	FFF (BigDelta WASP 12MT)	Zero environmental impact house module

Table A2. *Cont.*

Year	Project	Application Fields	Waste and/or Scrap	Recycled Material	Extrusion-Based AM Technology	Product
	7. "The Robotic Playground", R7 [80]	Urban Furniture, Toys	Plastic waste (PLA)	Recycled PLA	FFF Robotic Arm (Caracol)	Co-designed tables, chairs, outdoor toys
	8. "Print Your City", R7 [81]	Urban Furniture	Plastic waste from citizen	Waste-based Thermoplastic	FFF Robotic Arm (Kuka)	Multifunctional Benches
	9. Paper Pulp 3D Printer, R7 [82]	Furniture	Paper waste	Recycled paper pulp	DIW (Custom)	Lamps
	10. "Not Only Hollow", R7 [83]	Furniture	Reclaimed polycarbonate (CDs, food molds)	Waste-based Thermoplastic (mainly PC)	FFF Robotic Arm (Custom)	Cabinet
	11. "Botella light", R7 [84]	Furniture	Plastic waste (Bottles)	Waste-based Thermoplastic (PET)	FFF	Lamps
	12. "Second Nature" R7 [85]	Furnishing accessories	Plastic waste from ocean, nets	Waste-based Thermoplastic	FFF (Custom)	Tableware
2019	1. "Tera", R7 [86]	Buildings	Building waste from industries	Biopolymer Filled with basalt	FFF Robotic Arm (Autodesk)	House module
	2. "GENESIS Eco Screen", R6–R7 [87]	Urban Furniture, Ecology	Plastic waste (Bottles)	Recycled PET	FFF (BigRep)	Ecowalls for urban biodiversity habitats
	3. "The 3D Bar", R7 [88]	Furniture, Exhibition	Coffee cups waste (PLA)	Recycled PLA	FFF Robotic Arm (Caracol)	Bar, stools, tables
	4. "Deciduous" R7 [89]	Exhibition	Plastic waste (Bottles)	Recycled PETG	FFF Robotic Arm	Pavilion
	5. "Conifera" R6–R7 [90]	Exhibition	Wood waste	PLA filled with wood waste	FFF (Delta WASP 3M Industrial 4.0)	Architectural installation
	6. "Strats", R7 [91]	Urban Furniture	Plastic waste	Waste-based Thermoplastic	FFF	Stools, lounge chairs, tables
	7. "Beyond Digital", R7 [92]	Furniture	Industrial Plastic waste (PP)	Recycled PP	FFF Robotic Arm (Caracol)	Office desk
	8. Plumen and Batch works lamps, R7 [93]	Furniture	Plastic waste (Bottles, household appliances)	Waste-based Thermoplastic (mainly PET)	FFF	Lamps
	9. "Ice-Dream", R7 [94]	Furniture	Industrial scraps from thermoforming	Recycled PLA	FFF (Delta WASP 3M Industrial 4.0)	Chairs, tables
	10. AVR Tables and Stools, R7 [95]	Furniture	Plastic waste (Bottles)	Waste-based Thermoplastic (PET)	FFF	Tables, stands, stools, desks
	11. "Feel The Peel", R7 [96]	Furnishing Accessories	PP waste, Orange peels	Recycled PP filled with orange peels	FFF (Delta WASP 2040 Industrial 4.0)	Cups, tableware

Table A2. *Cont.*

Year	Project	Application Fields	Waste and/or Scrap	Recycled Material	Extrusion-Based AM Technology	Product
2020	1. "Second Nature", R7 [97]	Urban Furniture	Ropes from fishing and shipping	Waste-based Thermoplastic	FFF Robotic Arm (Kuka)	Benches
	2. "Let the waste be the hero", R7 [98]	Furniture	Plastic waste (Toys)	Waste-based Thermoplastic	FFF	Stools, tables, lamps, plant pots
	3. Oil palm fibers chairs, R7 [99]	Furniture	Oil palm waste fibers	PLA filled with oil palm fibers	FFF	Chairs
	4. Model No. Furniture, R7 [100]	Furniture	Agricultural waste	Waste-based Thermoplastic	FFF	Tables, Benches
	5. "Volta", R7 [101]	Furnishing accessories	Plastic waste (Bottles)	Recycled PETG	FFF Robotic Arm (Kuka)	Vases, tableware, home elements
	6. "Reprint Ceramics", R7 [102]	Furniture, Furnishing accessories	Ceramic waste	Clay from ceramic waste	DIW (Deltabot)	Lamps, vases
	7. "Co.ffee Era", R7 [103]	Furnishing accessories	Coffee waste	Thermoplastic filled with coffee waste	FFF (Ultimaker)	Furnishings
	8. "Was orange", R7 [104]	Furnishing accessories	Orange peels	Thermoplastic filled with orange peels	FFF (Ultimaker)	Furnishings
2021	1. "Tecla", R7 [105]	Buildings	Vegetable fibers (rice—industrial scraps)	Vegetable fibers scraps with local soil and raw earth	DIW (Crane WASP)	Eco-sustainable 3D-printed habitat
	2. "R-IGLO", R2–R7 [106]	Exhibition	Plastic waste(PET)	Recycled PET	FFF Robotic Arm	Self-sustainable exhibition structure
	3. Recycled 3D-Printed Chair, R7 [107]	Furniture	Post-consumer plastic waste (PET)	Recycled PET	FFF	Chair
	4. "91–92", R7 [108]	Furniture, Furnishing accessories	Plastic waste (PET)	Recycled PET or PETG	FFF	Stools, Vases
	5. "Aectual", R7 [109]	Furniture	Plastic waste	Waste-based and bio-based Thermoplastic	FFF	Customized room dividers

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