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THE RELATIONSHIP BETWEEN 3D TECHNOLOGIES AND CIRCULAR MANUFACTURING USING THE 10R TOOLBOX

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Abstract: In this article, we are looking for a possible connection between the 10R toolkit, which represents the basic concept of the Circular Economy, and 3D technologies (scanning, printing, additive manufacturing, CAxx systems). We will examine each of the 10R tools one-by-one and with the help of examples, suggestions and our own experiments, we will point out opportunities that may even predict a general trend in the future. We criticise the participants in society (population, industry, government). Pointing out that any positive change is only possible with the joint action and change of attitude of the participants.

Keywords: *10R, Circular Economy, 3D scanning, 3D printing, CAD*

1. INTRODUCTION, CONCEPT OF THE CIRCULAR MANUFACTURING

Today, the world economy is on the verge of a very significant change. The change is taking place both technologically and philosophically. The population of our planet is getting bigger, it has already exceeded eight billion, which is approaching the limit of the planet's carrying capacity. The Earth's climate is getting warmer, which gradually reduces the areas suitable for cultivation and habitation. In other words, there are processes taking place in the climate that have fatal effects for the existence of our civilisation. In order to avoid this tragical vision, we must seize every opportunity to reduce the narrowing of living space and the environmental harm. The Circular Economy does not encourage one-time use (linear economy), but aims to recycle goods that have already been, or have not been used yet, or are classified as waste. A significant part of the European Union decided that the economy should transform today’s linear economy to circular as quickly as possible. In this article, we are looking for answers to where and how 3D technologies can be integrated into the Circular Economy and Circular Manufacturing.

2. Elements of the 10R toolbox

The 10R as a toolkit is an action plan gathered in 10 points, which is about how we can re-incorporate used parts, equipment and products into the production of new products. The term 10R originates from the initials of the English equivalent of 10 points. 10R itself is an extension of 3R, 4R, 6R (Breteler, 2022). The 10 points are listed in Figure 1 according to the decreasing priority level from the point of view of the circular economy (Cramer, 2022). A more detailed explanation of the 10R toolbox will be expanded and linked to 3D technologies in the next points.

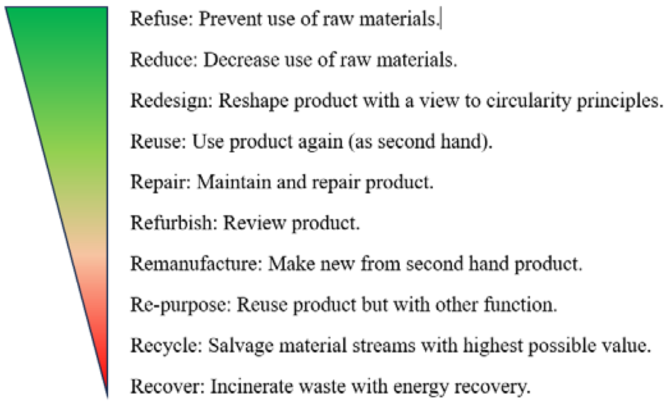

Figure 1. *Levels of circularity (Cramer, 2022)*

3. Connection of certain 3D technologies to 10R

First, let us clarify what we mean by 3D technologies. This includes 3D scanning and 3D printing, but in many cases also various CAxx procedures and computer simulation methods (FEM, CFD). The development of computer capabilities and artificial intelligence (e.g. ChatGPT, Gencraft, Microsoft Copilot) makes it essential to study and integrate the above-mentioned technologies more and more closely into the design, production and recycling processes. In the following subsections, the relationship of the 10R toolkit to 3D technologies will be presented one by one.

3.1. Refuse

Refuse means to deny using raw materials. The goal is to produce a more durable, longer-lasting product. According to former experiences, we can say that the more materials are there in a product, the more durable it is. This kind of thinking needs to be erased from people's mind; the attitude should be changed. Extending the life of products can be achieved through careful design and testing. This requires well-educated, thoughtful, broad-minded engineers. In addition, companies must be interested in ensuring their products have a long service life. This should even be supported by economic and legal incentives (such as tax relief). On 24 04 2024, the European Union adopted the directive that guides companies in the direction of the Circular Economy. The member states have 2 years to enforce the directive in the national legal system. Furthermore, to legislation, it is also important to influence people's way of thinking: previous cell phones or smart watches (iPhone, Samsung, etc.) must be immediately changed when it appears on the market.

What can we do at this point with 3D technologies? In particular, CAxx and simulation technologies can help us in the matter of increasing the service life. An R&D assignment completed in 2006 by the Authors, is given as an example (Sarka, 2008). The clients were the Mátrai Erőmű Ltd. and the Jászberényi Aprítógépgyár (which is no longer in operation). Our task was to strengthen the gear drive of a bucketwheel excavator (dimensions of the gear drive: length: 7 m, height: 3 m, width: 1.6 m). The companies simply wanted to increase the rigidity of the gear drive housing by thickening the side walls. The "let us add more material" principle is clearly visible. Working together with a colleague from the institute, the gear housing based on the existing drawing documentation in a CAD system was reconstructed and then examined the model using FEM software. Modifications were made only there where large deformations were developed (Figure 2). With this, a stronger, more rigid housing was created, while the mass increase of the gear drive amounted to a few 10 kilograms compared to the several 100 kilograms of the original idea.

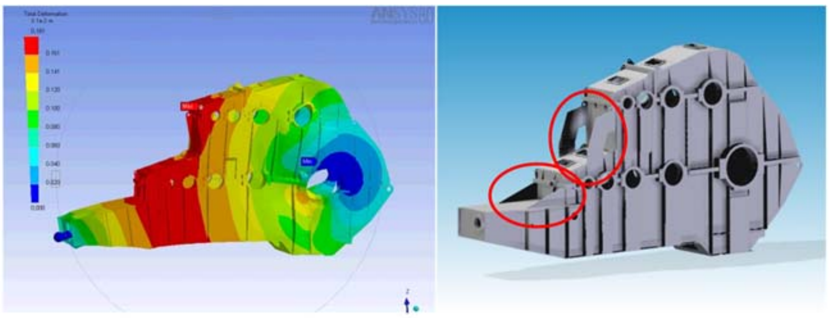

Figure 2. *Re-engineering of the gear drive of a bucketwheel excavator*
Left: total displacement value, right: the stiffened gearbox housing
(stiffeners circled in red)

Thanks to the strengthening, the load capacity of the gear drive has increased, thereby increasing the productivity of the excavator. As a result of greater stiffness, the service life of the bearings has also increased. The example clearly shows the importance of careful planning and high added value work.

3.2. Reduce

Reducing the amount of raw material used. If we are already producing a new product, we should make it with as few materials as possible. The European Union can be said to be an economy with a shortage of raw materials. It needs a lot of imports, so it is in the basic interest of European companies to be able to manufacture their products using as few raw materials as possible.
With the help of various additive technologies, we can make products and pre-manufactures that require a minimal amount of material remove for post-processing. Simulation and testing software are also very important in this case, since unnecessary material parts can be removed from the component designs, even before the first prototype is produced. Various optimisation procedures are of great importance in this planning phase (Szabó & Szarka, 2019). If we consider 3D printing itself as a production process, then when designing the manufactured part, we can proceed in such a way that we use as little material as possible, and if possible, we do not have to print a large amount of supports (Figure 3).

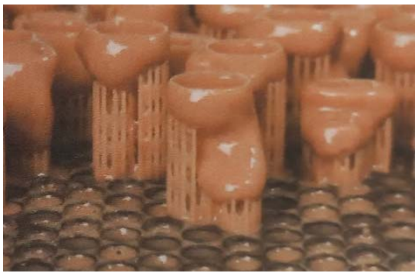

Figure 3. *3D printing with a large amount of support (hearing implant) (Gibson, Rosen, Stucker, & Khorasani, 2021)*

One of the development possibilities of the software of 3D printers would be if a series of pre-programmed supports that could be selected from a set were available. Of course, the supports would also exist in physical reality, and by placing them on the printing table, the amount of newly printing of the supports can be reduced, as well as the amount of raw material used. The prefabricated supports could of course be used several times. During printing, in many cases the supports also play a role in regulating heat conduction (increase or decrease). By changing the material quality and geometric design of prefabricated supports, this role can also be intervened, thus producing a better-quality product.

3.3. Renew (Rethink)

Renewal, rethinking. In other words, the modification of an existing product in such a way that its service life increases, or the replacement spare parts used during the repair contain less material. This kind of engineering work has been present at car manufacturers for decades, when they do a model update on the slightly aging (it has been produced for 3-4 years) (Dömötör & Péter, 2012) type, with this they want to create the appearance of novelty. In other words, the main reason for reformulation is not to improve the product, but to boost sales, and often it is also the change of problematic components.

During the rethinking, CAxx technologies and simulations can be used as described in the points above. 3D printing as a technology can be important when manufacturing prototypes of renewed parts. Especially if the new parts have undergone some kind of optimisation procedure (Seregi & Ficzere, 2021) as it can be seen in the case of Figure 4. We can then obtain geometries that cannot be produced by any other technologies but additive technology, or even if there is an alternative manufacturing procedure, implementing these geometries would be hard.

Figure 4. *Car seat-belt bracket*
(traditional and generative design, 40% lighter and 20% stiffer)
https://www.autodesk.com

The renewal can also be point at making the product easier to repair, even by the user. By facilitating the acquisition and replacement of parts that are expected to fail during use, the repair of products can be prioritised over replacement. It can be a fundamental design aspect that the repair does not require special tools or expertise.

It can be replaced with detailed, step-by-step tutorials (repair guide) and video content. The use of CAD and CAE in such cases greatly speeds up the redesign, but the available 3D models also make it easier to create repair descriptions and animations. Such an aspiration is realised by the business model represented by the iFixit company, which provides a uniform set of tools, spare parts and model-specific repair instructions for repairing mobile devices at home.

3.4. Re-use

Reuse has a little different meaning in 10R than it has in the system of 3R or 4R. It should be taken literally here, that it is: looking for a new owner for the used but still functional product, who will continue to use it. Among the 3D technologies, 3D scanning can be effectively used in this field, with its tool system, the geometry of a used product can be accurately assessed, and it can be quickly checked whether it can really be used any longer. In the case of a larger series of products, an additional advantage is that frequent failures can be recognised, based on this set of information, the original geometry can be further optimised by CAD and FEM, taking into account the deformations resulting from real use. By uploading the geometries to a database created for this purpose (e.g. databases similar to Grabcad or Traceparts), it may be easier to find new users for the product. Knowing the geometry, it is possible that the component will not be integrated into the original product unchanged or with minor modifications. A little distant from technical life, this has already gained significant ground in the field of used clothes, furniture, and cars, thanks to easy and safe internet interfaces (second-hand).

3.5. Repair

Repair means fixing broken devices. 3D technologies may offer one of the biggest opportunities for progress in this field. In the case of an older product, we often encounter the phenomenon that a small part breaks, but unfortunately, there is no longer exist spare parts for it. The product would still be perfectly usable if there were a spare part (Dömötör, 2023). If the CAD model of spare parts that are no longer produced were available from a cloud storage (not necessarily for free, but for an acceptable or symbolic amount of money) for users, it would be easy to print a new part for the product. It is possible that some aesthetic disadvantages would develop in the case of a new part, but in the case of a 10-year-old toaster, for example, this no longer matters. Figure 5. shows the reconstruction of a part that cannot be purchased, since the device (timer switch) containing the element is not an expensive product, so spare parts are not provided. However, after recognising the cause of the failure, by making a 3D model of the failed part and using 3D printing, it is possible to replace the switching arm quickly and cheaply, which requires little raw materials, and thereby extends the life of the entire structure. The broken arm with a small cross-section was given maximum thickness, taking into account the available space. A further change is that a hole of the same diameter was placed in place of the injection-moulded rotation shaft. The original shaft was made of the same material. After printing a steel rod was later into the hole, thus increasing the life of the element. The timer switch has been working flawlessly ever since.

Figure 5. *Reconstruction of switching arm (Dömötör, 2023)*

An opportunity for further development of 3D printing in this area would be if we could solve the problem of adding printing to a broken product. This can be achieved with a properly prepared connection surface, even coated with an adhesion-promoting layer. An alternative solution to the same is to print the broken or worn part and then fix it with some kind of binding element or adhesive. In the case of a larger part, a lot of raw materials could be saved if only a small broken part has to be replaced, because the rest of the product is intact.

A new market segment can even be developed for this. Companies that offer spare parts for old products. Here, 3D scanning can be considered as a completely ordinary service. The user sends in the remnants of the broken part by post, the company digitises it, corrects it, then prints the new one and sends it back to the customer by post. Unfortunately, the manufacturing companies are not interested in the repair/repairability of the products but force the purchase of a new product. Not even the automotive industry is an exception to this. Step-by-step, we are getting to the point where even cars will be beyond repair. Even if a replacement part is available, at such a price that the owner wonders whether it is worth investing money in it, he continues to use it at a lower quality level (e.g. without air conditioning). This situation can be improved by changing people's worldview and changing the legal environment.

3.6.Refurbish

When refurbish a product companies actually renovate them. More and more such initiatives are being launched, which is commendable. In most cases, it is just a sudden flare-up for the given company to advertise itself. Here we can think of either clothes (shoes) or furniture (IKEA - the second life of furniture). In this point, 3D technologies can appear in the re-production of defective parts as described in the previous point.

Approached from a design point of view, it may also arise that the product is not defective, only the cover represents an outdated design, or it may simply be worn, faded, or in the worst case, discoloured or cracked. In this case, taking into account the aspects of easy exchangeability, a designed cover can be printed in place of a cover that corresponds to the current fashion, i.e. a cover with a shape that may be different from the original, or a unique colour and pattern. Designed according to this philosophy, the life cycle of the given product can be significantly extended. Of course, replacing the cover can only be a solution if the internal parts of the product can still be used flawlessly, even for the life expectancy of a new product. In a welfare society, there is apparently a real need for this uniqueness. Just think of the replaceable covers of mobile phones or the wide variety of patterns and shapes.

3.7.Remanufacture

Production of a new product from a material that has already been used once means remanufacture. For example, building material taken from buildings condemned for demolition, or similar products. We distinguish between two types of remanufacture, one is direct, and the other is indirect. If the material needs to be refurbished or repaired, we are talking about indirect remanufacturing. This is also an area of the 10R where 3D technologies cannot really gain ground.

3.8.Repurpose

Repurpose happens when the product is used for a new task, not for what it was originally designed for. In such cases, the form of the waste and the original technology often change during the preparation for use. (Dömötör, 2015) A typical example of this was in Hungary in the 1970s, when milk in plastic bags appeared. People were used to the fact that practically no waste was generated, the materials used were all made of natural materials, so they could be burned in solid fuel stoves or disposed of in compost. However, they did not know what to do with the milk bag. It was not good to burn it, because it had heavily poisonous smoke. That is why they started making different products out of it. We know that this is only a constraint, we are looking for a new task for the waste (e.g. artificial grass covering). However, there are also cases where the situation described above is not the case. A material is waste from the point of view of one technology, and raw material from the point of view of another technology. We see an example of such a case in (Pintér & Sarka, 2020), in connection with sandblasting waste. The authors researched several possible uses for sandblasting waste. Unfortunately, 3D technologies cannot appear in this area either.

3.9. Recycle

During the recycling of raw materials, waste turns into raw material again. Glass and metal are melted down, plastics are made into granules again, and paper is made into paper again. 3D technologies can appear here as users, albeit indirectly. In the production of prototypes, we often encounter the fact that the printing did not turn out well, or the geometry still needs to be modified, or something went wrong with the printer, the body was torn from the table. In such cases, many raw materials become waste. It would be great if this waste could be turned into raw material again, made into wire or powder again. Thinking further about the issue of printing waste, it would be great if the user could create the recycled raw material in his own home. Probing tests (Kmetz & Takács, 2021), (Takács & Kmetz, 2020) have already been carried out on this, in an attempt to introduce circular production into 3D printing.

3.10. Recover

By the word recover, we must understand that a part of the energy contained in the waste material is recovered in some way, instead of going to the landfill. Waste incinerators play a significant role in the hot water supply and heating of large cities, as well as in several chemical industry processes (e.g. Százhalombatta, oil refinery). It is easy to see that this is not a perfect choice in the Circular Economy since the circularity ceases after one round will be finished. What was burned, cannot be burned again. The material content of the waste must return to its raw material state so that a product can be made from it again. Unfortunately, 3D technologies cannot take a forward step in this area either.

4. SUMMARY AND CONCLUSION

We must conclude that 3D technologies can appear as a solution in several places in the 10R area, but not everywhere. Where they appear, however, they can all be research areas. At the place of their appearance, trained, thinking, well-informed and experienced professionals are needed to be able to achieve meaningful results. For the success of circular economy, the entire human society must change. The governments of the countries must support with incentives those companies that would open in the direction of the Circular Economy (not just in words, greenwashing). Companies will not switch to the Circular Economy as long as the linear economy can be operated even one euro cent cheaper, produces more profit, and causes enormous environmental damage. From the list above and looking at Figure 1 it can be seen that a significant impact in the upper parts of the 10R hierarchy can be achieved. These areas are precisely those ones, where the various 3D technologies have a right to exist. In other words, it is our job, as university teachers-researchers, to graduate highly qualified, creatively thinking engineers from the university, thus creating more opportunities for newer and newer ideas that move the current linear economic model in the direction of the Circular Economy. The circular economic system requires more invested human work from the individual (user, consumer, engineer, producer) by being an active part of the process. Unfortunately, this is the biggest restraining force in allowing the economic transition to take place more quickly.

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