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Gerdi Papa

THE WASTE AND THE DIGITAL: End-of-life materials and digital procedures as an opportunity for architectural sustainable development

IDAUP XXXII Cycle

Università degli Studi di Ferrara
DA Dipartimento Architettura Ferrara
UNIVERSITETI POLIS

THE WASTE AND THE DIGITAL:
End-of-life materials and digital procedures as an opportunity for architectural sustainable development

Candidate: Gerdi Papa
POLIS Supervisor: Dr. Antonino di Raimo
DA Supervisor: Prof. Roberti Di Giulio

Cycle XXXII

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Cycle XXXII

IDAUP Coordinator Prof. Roberto Di Giulio

THE WASTE AND THE DIGITAL:
End-of-life materials and digital procedures as an opportunity for architectural sustainable development

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To my real-life superhero who still inspires me every day

My father

ABSTRACT

Globally, almost all economic systems rely on the consumption of natural resources to produce economic output and fabricate large amounts of waste as a result. While the system itself seems effective, it causes deep environmental burdens to our habitat, and, most importantly, disrupts social integrity and sustainability. The by-product of our system in this case waste has been a resource that has largely been disregarded. Digital tools on the other hand have shown great presented and equipped architects and designers with methods of design and fabrication which greatly expand on their capabilities. The shift in architectural design of designing the process instead of the final product opens implications for other fields as well. The ability to share these processes and directly translate designs to physical products greatly enhances the means of architectural production beyond what was capable of before. Digital tools in this sense, through a meticulously designed process, have the means to direct and create methods that transform products at the end-of-life into valuable resources for design and building. The main aim of this thesis is exactly exploring and understanding procedures based on digital tools that are able to activate and transform products at the end of their life cycle into valuable, cheap, and available resources for sustainable construction methods.

Aside from just the problem of how to transform waste, this thesis also deals with issues of fabrication and open-source design, and the implications they can have on a process of design and production that is based on waste as a resource. The practice-based approach used by the thesis is represented by a series of experiments, workshops, and design class works that each inform parts of the procedure. The final outcome of the thesis is represented as a set of procedures that designing with materials at the end-of-life can have, where processes need to part of a feedback loop of material, where the outcome of one design can become the input for the next one.

Keywords: waste, digital fabrication, digital design, end-of-life materials

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1. INTRODUCTION

1.1 Reasons for this research

1.1.1 The problem of waste

Figure 1 Typical image of a landfill nowadays in poorer countries but not only. Photo: Bay Ismoyo

The last decades saw our society completely change the way we think and act in relation to our environment and how our way of life is damaging it. Our way of life that is based on production and consumptions is proving to be catastrophic to our environment, with our oceans contaminated with plastic, landfills full of waste, and extremely dangerous levels of CO_2 released into our atmosphere. Faced with a problem of these proportions we have tried to set up policies and change the way we dispose of waste, with recycling at the storefront as the most sustainable way to deal with waste. In e report published in 1999 called *Cutting the Waste of Stream in half*, recycling was defined as stated below: "the series of activities by which discarded materials are collected, sorted, processed, and converted into raw materials and used in the production of new products" (EPA, 1999).

In this context, recycling becomes a way in which we can transform or repurpose what we define as useless waste into useful products. The process involves not only changing the geometry and form of the waste material into a new one but first of all changing its initial or current purpose into something useful. Other definitions found around the internet of waste bring us to a few results. The most interesting for us is certainly the one where waste is defined as: “of a material, substance, or by-product, eliminated or discarded as no longer useful or required after the completion of a process”. In this sense, waste can be defined as something that has lost its initial purpose and recycling as a way to repurpose these materials into new functions and uses.

1.1.2 New tools

Figure 2 Created from programmable water-based biocomposites by Neri Oxman and MIT Media Lab (2018). Photo: MIT Media Lab

The main aims of architects and architecture are those of designing and making. These two processes have always interlinked and informed each other both during design but have remained divided. In his book “Translations from drawing to building” (1997) Robin Evans discussed the unavoidable gap that remains in architecture between the drawing and building processes. He especially highlights how great inventions can be found in that gap. The digital practice especially has shown to have the capabilities of narrowing the gap between drawing and physical product while showing abilities to evolve more than ever before. The ability to seamlessly transition from the process of designing to making is enhanced more than ever through digital tools.

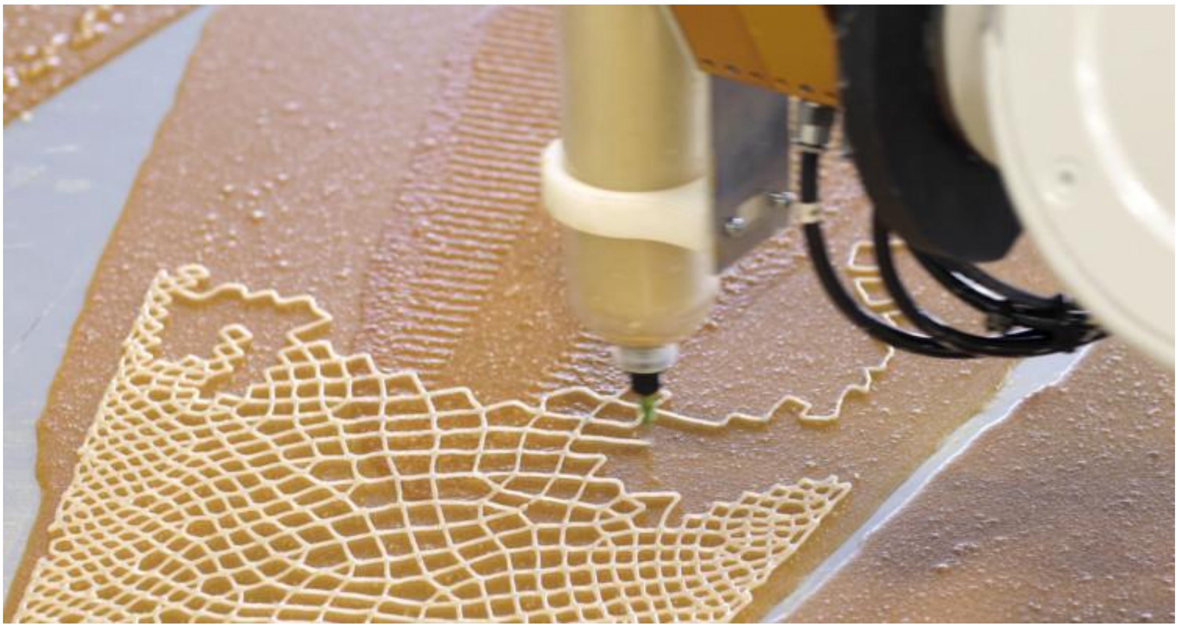

Figure 3 Custom robotic arm 3-D Printing bio-composite material (2018). Photo: MIT Media Lab

As hard as we try, it is inconceivable today to think of architecture and design without the use of computers. CAD/CAM has been a centerpiece of many fields such as industrial, aerospace, and automotive design industries changing both the design and manufacturing process. As professionals have been using CAD software for nearly thirty years, and have transitioned to more efficient and easy to edit 2D drawings. Although these advancements from analog to digital did not reflect in the design of buildings themselves. It wasn't until three-dimensional modeling software and digital fabrication became widely used that the design thinking expanded into new types of architectural form and construction.

New technologies allow for fast prototyping machines that can produce fast and accurate physical models directly taken from the computer. Data is transferred from the computer to computer-controlled machines that are able to fabricate parts at a real scale from materials such as plastic, steel, or wood. This process greatly benefits in streamlining the production of the product and blends together processes that are usually compartmentalized, often narrowing or eliminating steps from design to production. This newfound possibility to narrow the gap between designing and making has piqued the interest of architects during recent years. As Branko Kolarevic puts it "This newfound ability to generate construction information directly from design information, and not the complex curving forms, is what defines the most profound aspect of much of the contemporary architecture*”* (2003)*.* Therefore if we can define design information, we have the possibility to use that directly as construction information, seamlessly exchanging information between one process and the other allowing for construction to happen in a continuous self-informed process.

These processes open up a lot of area for discussion on the materials which these machines can use to manipulate them into new objects. While it is true that they allow for great precision and speed, they also often require materials to be pre-manufactured into a standard design that fits the machine's precision expectations. If we were to expand the capabilities of these machines we would have to understand how other materials can benefit from the production of these production processes. How can design help to expand the usage and life cycle of materials that have otherwise lost their intended purpose? New design and production tools can contribute to activating an almost untapped material resource that holds great potential.

1.2 Waste

1.2.1 Waste and it's potential

Globally, almost all economic systems rely on the consumption of natural resources to produce economic output and fabricate large amounts of waste as a result (Hebbel, et al., 2015). While the system itself seems effective, it causes deep environmental burdens to our habitat, and, most importantly, disrupts social integrity and sustainability. An example par-excellence of this phenomena are the images we are offered of the poor living in urban areas, which search for materials among large piles of waste. This symbolizes the clash between two worlds: the overproduction and overconsumption economy we are thriving in, on one part, and the deep social segregation of vulnerable groups on the other, which is made of the ones who cannot access ‘the city’, be it housing, jobs, services and market in general. These images coincide with the largest urban agglomerations, where most of the waste is produced, especially non-organic waste. Unfortunately, waste is still majorly treated linearly, by being disposed of in unsanitary landfills, or burnt in incinerators, and is not included in a circular flow of transformation from product to resource.

If we consider the output of these processes in a more general term, we can conclude that it is a ‘waste of waste’. Cities produce 1.3 billion tons of solid waste per year, which is expected to grow to 2.2 billion by 2025 (The Economist, 2012). It comes as no surprise that the countries that produce more waste are the 34 OECD countries[1]: indeed, more than the other 164 countries together. China is about to become an outlier in this regard, with statistics estimating that it will produce more than 50% of all global solid waste in the next 5 years[2]. There are two approaches which can address these countries that produce the most waste: either consider them biggest pollutants and an environmental problem, as the traditional point of view; or to look at them under new light: countries with full potential for recycling. This optimistic standpoint asks for a paradigmatic shift in the way we consider garbage and waste.

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[1] Organization for Economic Cooperation and Development

[2] *The Economist online*, last accessed 29/07/2020

Figure 4 Representation of the amount of waste produced in NYC in an hour, Rapid Re[F]use source: Terraform One (2010)

Although many believe that waste should be valued as a resource. “Waste and its meticulous handling are valued as gifts, offered by society to itself. Where we turn the parable’s missed opportunity to our advantage, a modified economy would be set into motion. Perhaps then we would come full circle in being sustained by the constant transformation of matter and energy at hand, without beginning and without end.” (Angélil & Siress, 2010)
They emphasize that waste needs to be considered a gift, rather than a ‘negative output’. In the end, it is understandable that waste is considered an investment, which needs to give back value and profit. “So far, this investment is deadlocked and we seem to have lost the key to how to open its potential and benefit from it as a life-long revenue” (Hebbel, et al., 2015).

When the waste is disposed, as the final output of a production or consumption system, societies need to have access to it through different forms and make revenues from it. But in our economies, the profit from the use of waste once it is disposed of, is captured by another subsector of economy. They are other by-products.

Problems in our current waste management system have been highlighted by Leonard in several contributions, such as "*The Story of Stuff*" and "Take, Make, Waste" (2010). She argues that the current system in which we manage waste is not environmentally unsustainable, because still waste is included in another economic system. The problem is that it is considered as secluded from the initial input system. "In fact, we follow a linear process where the outcome of our consumption is not valued as a resource, but seen as a product excluded from the cycle of our economic system belonging neither to the natural resources nor to the desired products" (Hebbel, et al., 2015).

There is a hint of nonsense in the governing process of waste: municipalities are paid by citizens to collect and dispose of their waste, thus considering it not as a resource, but rather as a negative by-product. In the US, out of 250 million tons of solid waste produced each year, only about 90 million tons are recycled, while the rest is incinerated or disposed of in landfills (United States Enviromental Protection Agency, 2018). This ratio in a country like Albania is even lower (but more on Albania later).

This can be considered a 'waste of waste', and influences negatively the whole production cycle: the water consumption, energy, wood, or other materials needed to produce the original products, which will turn to waste subsequently. According to Timechange.org, during the production of a plastic bag oil is needed as a base material, and also, in the same amount, as energy during production techniques. Even more troublesome is the fact that for each plastic bag that is produced, 250 grams of CO2 are released into the air[3]. This is a very alarming situation, which can be rapidly improved if plastic is recycled appropriately. Indeed, almost half of this amount of CO2 can be contained. This example takes into consideration one industry, but in other industries, the situation is even more problematic in terms of CO2 emissions and other toxic gases. For example, recycling steel would save 75% in energy. "And to produce 1 ton of paper, 98 tons of natural resources are needed" (Hebbel, et al., 2015). In this context, recycling becomes also the perfect way to efficiently get raw materials that can continuously be reintroduced into the production chain.

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[3] 'Plastic bags and plastic bottles – CO2 emissions during their lifetime', Timeforchange.org, last accessed on 27/04/2020, http://timeforchange.org/plastic bags-and-plastic-bottles-CO2-emissions.

1.2.2 Circular Economy

Today, circular economy, or urban metabolism, has become a buzzword, because of its newly gained support in the era of overconsumption. Nevertheless, these approaches have been present since decades in economic debate, and surprisingly, in architecture and urban development as well. In the late ‘70s, a theoretical model was created by landscape architect J.T.Lyle and his students of Cal Poly Pomona University, where communities are perceived to contain their activities within the boundaries of renewable resources, as opposed to causing environmental damage. This theory was further developed by the work of W. R. Stahel, co-founder of the “Product-Life” Institute in Switzerland. He became the pioneer in the field of sustainability, by emphasizing the “service-life extension of goods”, thus laying the ground to the formulation of the famous concept of the three R’s in product cycle: “Reuse, Repair, and Remanufacture” (Hebbel, et al., 2015). In his work “The Product Life Factor” (1982), the author promoted new strategies and economic policies to achieve sustainability in waste recycling. Indeed, his work is relevant today, as a background in the model that is known as ‘circular economy’. It comes as no surprise that many companies worldwide have embraced these concepts of reuse and life extension, with a positive impact on natural resources.

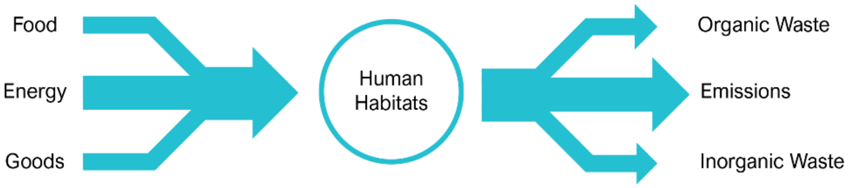

Figure 5 Linear Model – High rate of consumption and pollution
“Cities for a small planet”, source: Richard Rogers (1996)

The well-known term “cradle to cradle” was also first introduced by Walter R. Stahel, to be later turned into a theoretical principle by one of Lyle’s followers and scholar, William McDonough, together with Michael Braungar, a chemist. The “Cradle-to-Cradle” model aimed to promote the idea that all products that come from a system of industrial or commercial processing should be considered part of the same cycle, in a circular way, like a true natural cycle. The authors introduced a framework of the metabolism-like flowing of materials. “The key idea is very obvious: products should be designed in such a way that they can become part of a continuous recovery and reutilization process" (Hebbel, et al., 2015). In this viewpoint, products are none other than nutrition for a global metabolism and are not disregarded after their life-cycle is completed.

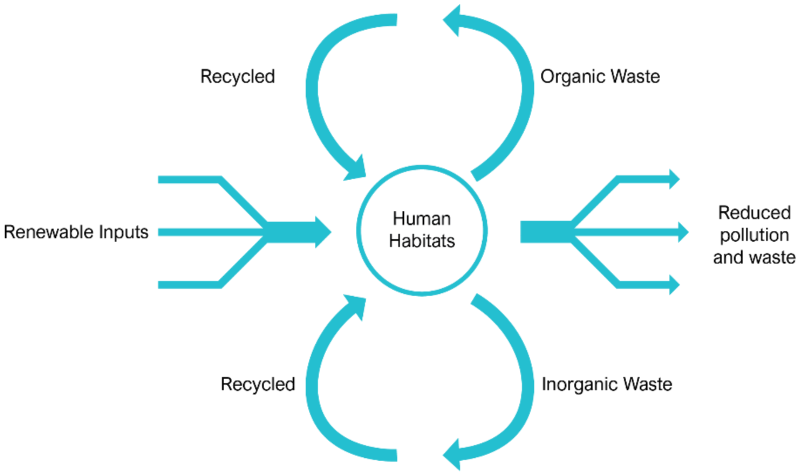

Figure 6 Circular Model – Less new inputs, more recycling "Cities for a small planet", source: Richard Rogers (1996)

Of course, this change of thinking towards waste, as McDonough and Braungart argue (2002), cannot be achieved without some systematic changes in mindset and policymaking. This should be accompanied by new systems, which are based on the 'recovery' principle rather than 'new production'. Secondly, awareness should be raised at the social level in this new system. The "Cradle-to-Cradle" model mimics natural cycles and embodies some principles that are applicable in biomimicry, where nature is referred to as a 'standard' by which all actions in the economic sectors are measured. "Biomimicry means that we do not ask what we can extract from our natural surroundings but instead seek to find out how we can learn from nature to turn the abundance of renewable energies into a circular metabolism of growth and economic surplus without wasting or polluting a single element inside this system" (Hebbel, et al., 2015).

Clift and Allwood (2011), claim that the existing failure to improve in a real way energy efficiency in industrial processes has been the use of unsustainable indicators. "Instead of the energy input, what should be targeted and reduced are the materials circulating in the industrial realm" (Clint & Allwood, 2011). Subsequently, they argue that niche, closed processes need to be created, which have waste as the main input. This would bring down the 'stigma' against 'the unwanted substance' and turn a page towards "industrial ecology". In parallel to this shift in production techniques, efforts should be mobilized in natural rehabilitation, and the disconnection between ‘production of new products’ to the ‘exploitation of natural resources’. This decoupling is crucial for the long term success of the cradle-to-cradle method.

“A change to a circular economy model would save materials, i.e. natural resources, in the value of over one trillion US Dollars” (Ellen McArthur Foundation, 2014). Following this line of thinking, the EU has recently promoted a method that aims at answering the question: “Who is responsible for the waste we produce, and who needs to take care of it? Producers or consumers?” The system is called “extended producer responsibility” and its goal is to highlight the producer’s responsibility in the process. Ultimately, the producers decide the product design, hence the responsibility of the management of the first-life cycle falls to them.
“The EU’s directive on ‘end-of-life vehicles’ not only obliges manufacturers to accept vehicles that are no longer wanted, but also requires them to recycle or reuse 80% of the parts by weight, a proportion that will rise to 85% by 2015. The manufacturers can farm out the job, but only to authorized firms” (The Economist Online, 2018). “Examples from other industries show that this political tool can force designers and engineers to think way ahead of the first death of their product, constructing it in such a way that it can become the resource for yet another life cycle” (Hebbel, et al., 2015).

Designing the items at the source for a circular economy, in this case, becomes as much of a corporate responsibility as well as an ethical responsibility of every designer. And while regulations can certainly provide a guideline to be followed future designs we still need to account for all the products that do not find themselves into the circular economy model. Such products can and should be a part of the discourse on how to integrate them into this model, especially when most countries do not have clear guidelines and an efficient recycling system.

1.2.3 Albania: an overview of the waste management

Up until now, the discussion has been based on concepts of waste production, recycling, and circular economy, based on data and cases from developed Western countries. And while those countries are the most responsible for the worldwide waste crisis, they are also the most equipped to deal with it. Years of policies and regulations have somewhat created a base for governments as well as companies to implement strategies and work on recycling as a real way to prevent it. This cannot be said however for smaller and less developed countries where waste and litter have become a real problem and the country is not equipped or does not have sufficient knowledge and policies set up to efficiently face the waste crisis. And while many third world countries have already seen the catastrophe that waste can bring to the environment, there are some, like Albania, who are dangerously close to it.

In 2018, Albania, a country of roughly 2.8 million people, managed and disposed of 1.32 tons of urban waste according to the report on Urban Solid Waste released by INSTAT[4] (2019). That is the equivalent of 383 kg/person. Organic waste makes 61.2% of the disposed waste. That is not a bad number if you take into consideration that Albania is mostly a rural country, with few high-density metropolitan areas, and where most of the population is based on the Tirana-Durres area. “In smaller communities collection of waste is not possible so individuals are responsible for the disposal of their waste” (Komisioni i Komunitetit Evropian, 2010, p. 9). This has caused littering of most of rural landscapes in Albanian villages, and contamination of surface waters, such as streams, rivers, etc.

It is also worth noting that “In 2018, 18.5% of all solid waste was recycled compared to 17.4% in 2017” (INSTAT, 2019). This shows a small growth in recycled goods, but not enough to become a factor. In the National plan for waste management (2010) it was a clear intention to help the market grow, the market never took off enough mostly due to an uneducated general public and no policies for recycling. And this again you can see that in 2015 Albania “recycled 25.2% of its waste” (INSTAT, 2016). There is a rise in waste that goes through the incinerator with “2.8% of all waste being burned in the incinerator” (INSTAT, 2019). The numbers when compared to a country across the border like Kosovo, who in 2018 “recycled only 5% of its solid waste” (INDEP, 2018)[5] which does not show a big rise when compared to 2016 where “62.461 tons were accepted by recycling companies and

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[4] *INSTAT stands to the Albanian Institute of Statistics* http://www.instat.gov.al/ *[last accessed on-line 20.09.2020]*

[5] INDEP stands for Institute of Development Policy of Kosovo

10.871 tons where are exported to other recycling industries abroad,” (Ministria e Mjedisit dhe Planifikimit Hapësinor - Agjencioni për Mbrojtjen e Mjedisit të Kosovës në bashkëpunim me Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), 2018, p. 51) which amounted to 15% and 2% respectively. Macedonia in comparison has lower numbers with “Recycling and composting of MSW covers a minor 0.26 %, according to data provided by the Ministry of Environment and Physical Planning for 2012” (European Enviromental Agency, 2013) as cited in Ministry of Environment and Physical Planning, 2012) All these numbers seem very low when taking into account that all three countries have presented plans and strategies for recycling and waste management. “Approximately one-third of all waste produced in Albania can potentially be recycled” (Ministria e Infrastruktures dhe Energjitikes, 2020). Indeed, this prioritization of recycling processes comes not only as a stance towards more sustainable development but also as part of the commitment of the Government of Albania to fulfill the minimal EU Standards, as stipulated by the National Strategy for Development and Integration[6] (2013) and other National Strategies to date.

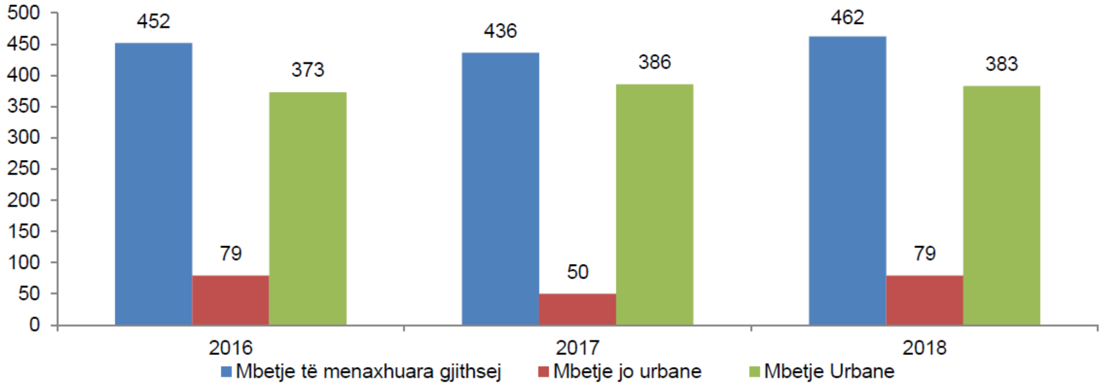
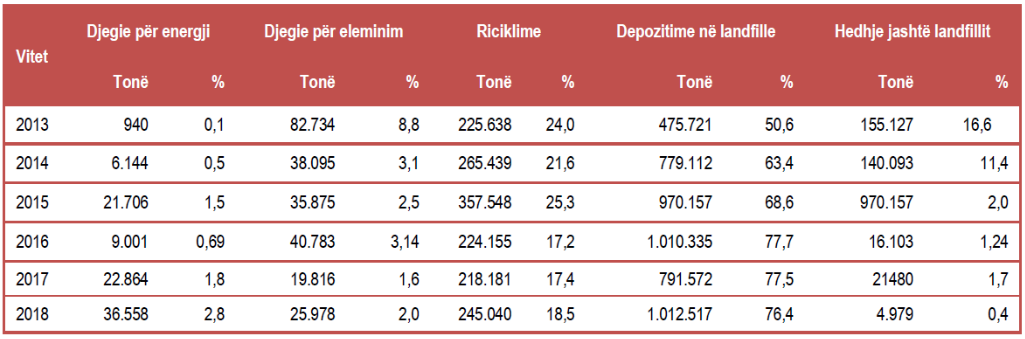


Figure 7 Urban Solid Waste managed in 2018 in kg/person. Source: INSTAT (2019)



Vitet	Djegie për energji		Djegie për eleminim		Riciklime		Depozitime në landfille		Hedhje jashtë landfillit	
	Tonë	%	Tonë	%	Tonë	%	Tonë	%	Tonë	%
2013	940	0,1	82.734	8,8	225.638	24,0	475.721	50,6	155.127	16,6
2014	6.144	0,5	38.095	3,1	265.439	21,6	779.112	63,4	140.093	11,4
2015	21.706	1,5	35.875	2,5	357.548	25,3	970.157	68,6	970.157	2,0
2016	9.001	0,69	40.783	3,14	224.155	17,2	1.010.335	77,7	16.103	1,24
2017	22.864	1,8	19.816	1,6	218.181	17,4	791.572	77,5	21480	1,7
2018	36.558	2,8	25.978	2,0	245.040	18,5	1.012.517	76,4	4.979	0,4

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[6] This refers to the second NSDI for the period 2014-2020, approved by the Council of Ministers (2013), which follows and is coordinated with the first NSDI (2007-2013) and the Stabilization and Association Agreement (dated February 2009)

Figure 8 Waste distribution through the years. Source: INSTAT (2019)

The NSDI gives an overview of the strategic goals of the government in the programming period (6 years), which is lined up to the programming period of cohesion policy in the EU. Among other sectors, the NSDI underlines important goals related to environmental protection, i.e.:

- "Integration of environmental concerns into all Albanian development policies and actions."
- "Effective enforcement of legislation to protect forest, land, and water resources."
- "Establishing sewerage and wastewater treatment infrastructure for the entire coastal and lake areas and establishing a comprehensive multiple-use system for effective coastal management."
- "Encouraging public participation in environmental protection and preservation through environmental education and raising of environmental awareness among the population."
- "Supporting the sustainable development of the natural environment for both recreation purposes and to promote ecotourism" (Council of Ministers, 2013).

In more practical terms, this strategy indicates that by 2020 waste in Albania should be reduced 55% while also making sure that the remaining 45% are properly disposed of. This indicator, while promising, failed to encompass the overall situation of waste management in Albania in the last 3 decades. Therefore, it comes as no surprise that this target was never reached.

On paper, Albania is performing quite well in terms of policy frameworks and legislation adaptation. Recently, the National Integrated Waste Management Strategy[7] was revised, for the period 2020-2032. This strategy states that the regulatory framework is in line with EU policies in the management sector waste. However, implementation at the regional or local level is poor, especially in terms of infrastructure and related services. The main reason for this discrepancy is the lack

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[7] The Strategy was drafted by the Ministry of Infrastructure and Energy, and supported by KfW German Development Bank, through the consultancy of INFRASTRUKTUR & UMWELT, in cooperation with *COWI* and *FLAG*. The strategy was approved by the Decision of the National Territorial Council No 1, dated 13.01.2020

of funding dedicated so far to landfills and waste management, and even less to recycling programs. The service is entirely provided at the local level, from waste collection to end-disposal in landfills. Therefore, the financial capacity of each local government is in proportion to their population size, the ratio between urban and rural populations, and other local priorities.

The National Integrated Waste Management Strategy proposes to take considerate steps towards improving waste management, by:

- Defining the appropriate methodology and technology for future investments in the sector;
- Determining realistic costs and fees;
- Providing an objective, transparent and verifiable system for determining priorities for investments in waste management infrastructure;
- Providing an investment plan for local and regional infrastructure of shared waste management according to the stages in the short, medium and long term, in relation to the collection and waste transportation, reduction and recycling, as well as treatment plants and / or waste disposal;
- Proposing the necessary legal and institutional changes to be adapted (Kfv, Ministry of Infrastructure and Energy, 2020).

The objective to set up a unifying methodology for cost calculations in the waste management service provision offers a green light for the recycling and reuse components of the circular economy. It allows for policymakers to understand and better predict future costs, service provision rate, and the weight of recycling in the overall scenario.

To date, in Albania, there are only 3 sanitary landfills (Sharra – in Tirana, Bushat in Shkodra and Maliq in Korca). The rest of the waste is disposed of in 88 non-sanitary dumpsites and more than 340 illegal dumpsites all over the country (Env.Net, 2018). In the previous years, waste segregation was piloted in Tirana and other municipalities. Nevertheless, the lack of integration to the operating system for waste management made the effort invalid, because the recycled waste was then collected in joint waste disposal machines, with all the rest, and sent to the landfill to be treated accordingly. The operations were also small in scale because they only targeted waste collection in public space and not the waste generated in residential areas, which remains unsegregated to date.

Waste disposal in Albania remains highly non-compliant to European environmental protection standards. Industrial waste makes for a wide percentage of water pollution, due to no strict law enforcement. Moreover, during 2017 there were exposed cases where waste was burnt deliberately to reduce the quantity disposed of in the dumpsites of Kamza and Porto Romano (Env.Net, 2018).

1.3 Digital Tools

1.3.1 Creating new tools

Regardless of the content, new technologies induce shifts in thinking and perception. They have the ability to develop innovative realities or as Marshall McLuhan states: “We shape our tools and then our tools shape us” (1970). For McLuhan, advances in the technology of media are driving social reform. The spaces which we inhabit, pictures we look at, or sounds we hear are all shaped through visual material. Our perspective and understanding are expanded through this method. Profound transformation to our environment has been a result of these changes which have also expanded and created a new framework in which architects design and build.

Digital technologies have many consequences for the various stages of the design process. Computational modeling techniques, automated manufacturing processes, and virtual applications “contribute to a major acceleration in the generation, development, and presentation of architecture” (Cocchierella, 2018). The careers of architects, designers, and engineers have already been largely impacted and have evolved through technology. Le Corbusier claimed during his manifesto "Towards Architecture," that technology had changed the architectural process in its entirety and not that it has not only been a formal or visual inspiration for a new style (Le Corbusier, 1927). Today, emerging technologies are again radically shaping our careers. Computer-aided-design tools have significantly changed how architecture is produced, from the design process to new understandings of space and structure.

Software now extends what architects are capable of and can be used to produce designs in ways that have barely been feasible, both in technicality and formality, until now. Computer technology, to a large degree, liberates the design process in architecture from conventional standards of development: “Dependencies are shifting, both in the design and the production process, from analog to digital processes” (Cocchierella, 2018). Computers widened the reach of the imagination and permitted the development of forms that would have collapsed time constraints and technological resources. The implications of this obsession of ‘the digital’ possibilities, however, often go little further than experimenting with shape, which is worryingly one-dimensional considering the complexities of their geometries. Greg Lynn, one a supporter of the open interactive field of forms, provided a critical evaluation of this institutional dependency: “There is a language of design that the computer brings with it, and mainly, you do what the software does well” (Novak, 2002). The promise of computer-aided design and development is much more optimistic than this quotation indicates. It needs, however, an understanding of the principles of the information technologies that computers use. The consequence of the architectural development method is accompanied by other criteria and restrictions.

Subsequently, to the design practice receiving improvements coming from modern aspects of architecture layout, more application of the architect's expertise in design can be found in the media and information technology while not forgetting construction. Digital media’s influence on architectural design and performance can be interpreted from two sources. The implementation of architectural ideas is promoted by the computer through digital methods. Spatial relationships and the understanding of it are greatly enhanced through the availability of an interactive three-dimensional model simulated into a virtual space. In this way, computer-generated images mean that spatial principles can be interpreted, analyzed, and shared in the preliminary phases of the design process. From the first architectural drawing and model simulation last 3-D model data set, the entire design and planning process is now being measured (Hemmerling & Tiggemann, 2011). However, virtual environments, such as those used in video games, are now used as autonomous architecture fields that are mostly unavailable to architects. Especially the ability to simulate a building room in real-time through a first-person perspective brings significant advantages during the assessment phases. “The goal of the use of virtual reality in practice, therefore, is to approach an architecture whose effect, and as many of its consequences as possible are known and experienced before its execution” (Cocchierella, 2018).

On the other hand, some processes of computer-aided manufacturing using CAD-CAM interfaces and fast prototyping processes have risen dramatically in recent years. Through this technology, the fabrication of a diverse range of shapes can be achieved without the need to change the manufacturing process. As the process is completely automated the price does not increase or change. What is special about this technology is that different shapes can be produced using the same manufacturing process. In theory, as this process is completely automated, the price of production is the same. The result of this new flexibility of design for architectural development is that the consideration for costs is eliminated from the regular product. The manufacture of individual goods using industrial manufacturing processes facilitates the design and customer-specific mass customization in architecture, as has already been identified in other areas of development. Looking at the key fields of use for digital tools, it is evident how advanced approaches of computer-aided-design can also impact the formal expression of architecture.

1.3.2 Digital Design

The open attitude that distinguishes the architectural design process seems impossible to be replicated by computers. Few architects use a computer specifically to produce their projects. However, especially between students and young architects, in the early design process, we can see that the pen is replaced by computer software. “But the potential of digital design is not in the simulation of operations that were formerly analog, but on the harnessing of processes inherent to the computer to capture, link, process, and evaluate complex interrelationships” (Cocchierella, 2018). Here we notice a significant distinction from the conventional CAD implementations, which may have helped the process of drawing but failed to have an impact on the modeling system itself.

New digital technologies now allow spatial principles to be built and modeled using processes various parameters are considered. The background now is defined far before the initial geometry in the simple parametric model. Mathematical instructions that can change and shape the structure or other parts of the model are presented now in the algorithm. Software applications in architecture today have been equipped with plug-ins that allow users to code their own algorithms that are useful in individually defining boundaries of the project as well as production methods of design. Architects become the creators of their own tools. The entire structure can be manipulated through this process-oriented approach without missing any connections between each individual component. To a large degree, the design process is assisted by information technologies in this style of architectural development. Programmed parametric models in this way reflect a modern modeling approach that concurrently involves information that is relevant to both architecture and computers.

For particular architectural problems, adaptable systems based on parametric models can be built that respond to external factors such as daylight or wind. According to Luiggi Cocchierella: "The form of the design arises through the definition of linkages and prioritization of individual parameters" (2018). Production is shifting from a structured and graphical method to a conceptual and evolutionary phase. The architect becomes the designer of the process rather than that of the result of the process. The benefit of this method, aside from the accessibility of the interaction during the design process, is the ability to make design changes and test various solutions without any loss of information or work, thus allowing for a virtually infinite number of iterations of the design process.

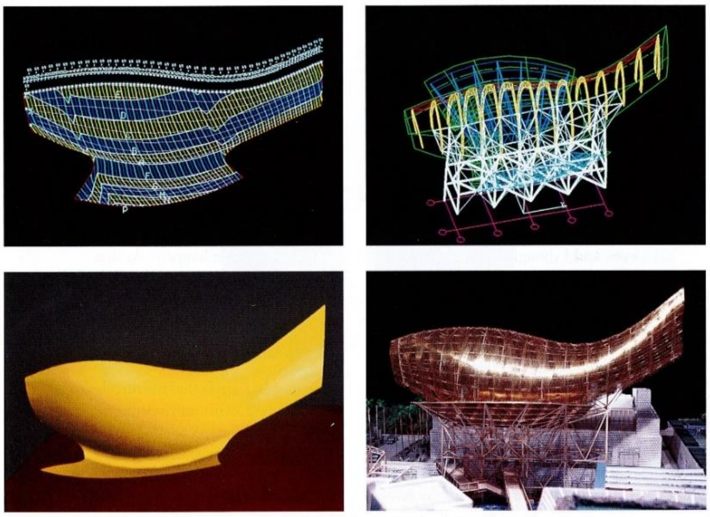

Figure 9 Computer built models of Gehry's fish sculpture in Barcelona[8]. Credits. Frank O. Gehry (1992)

The principles of parametric design (Woodbury, 2010) also form the basis for Building Information Modelling (BIM). This term refers to a digital planning methodology in which all processes around the design, planning, execution, and management of a building are connected together in a network. In addition to graphical information on construction geometry, this provides non-graphical

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[8] *Gehry office presented for the Olympic village of Barcelona in 1989 a new design system that created a large sculpture. The same technique was used as Frederick R.Weisman Art and Teaching Museum (1992), the Guggenheim of Bilbao (1997), Los Angeles Disney Concert (2003).*

information such as information on quantities and materials, environmental and economic principles, description of functional areas, and usage profiles. The changes that are made to these stages explicitly impact other places, regardless of whether the 3-D model, the floor plan, or the list of building components was modified. In addition to a detailed link across all construction knowledge related to architectural design, BIM also describes interfaces to other areas of planning such as structural engineering, construction technology, or facilities management.

1.3.3 Digital Fabrication

Computer-aided manufacturing processes make it possible to convert these interactive 3-D data directly into actual objects or items. More commonly known today just as digital fabrication, components that have been digitally fabricated and mechanically manufactured extend the constructive capabilities and incorporate choices of material and its parameters into the design process itself. (Cocchierella, 2018). However, these methods of processing do not always contribute to a systematic transition in architecture but they do help in the improvements of the systems. The outcome in this case is independent of the process itself. The expansion of digital technologies can’t be attributed only to buildings of complex nature as compared to other areas of production, architecture has always adopted new tools at a slower pace. Modern manufacturing systems can create cutting-edge goods (i.e. automotive industry) although this cannot be said for architecture, where virtually every constructed building is a prototype built on traditional methods. Although high-tech goods occur in modern manufacturing systems, such as computer construction or the automobile industry, virtually any building that is constructed is a prototype developed using traditional methods. The building method in this case proves to be an expensive and time-consuming process that fails to utilise the creative freedom offered by digital design tools. Material research in construction is certainly seeing interesting developments. In Digital Fabrication machine-aided processes are further developed and connected to digital design methods. A masonry wall is autonomously constructed by industrial robots controlled by an algorithm allowing for a production process that can present a multitude of variations (Gramazio & Kohler, 2008). Development process inputs then flow back into the design process as programming parameters and thus inform the digital and physical architecture.

Digital architecture fabrication is a comparatively new development that has arisen over the last 30 years as a significant feature of critical discourse, technical practice, and specialization education. Essentially, it is a subcategory of Computer-Aided Design and Computer-Aided Manufacturing (CAD / CAM) because it uses computer-controlled machines as tools to cut or make parts. While still relatively recent in architecture, these processes have been part of the engineering and industrial design for more than 50 years in the production and manufacture of vehicles, aircraft, and smaller consumer products. Components are usually designed and produced using 3-D modeling software, and then scale models are developed using a rapid prototyping process that transforms digital information into a physical structure. Since this type of object contains all details from the conceptual model, it is also very detailed and thus gives a thorough overview of the architecture. This stage may be reiterated to revise the design until such a point is reached that full-size prototypes are made, either as parts in themselves or to form molds from which components are subsequently made; in either scenario, a variety of materials may be used depending on the intended purpose (Dunn, 2012).

More specifically, this model has allowed more fluidity between concept production, creation, and fabrication than in conventional methods, which required a more linear and orchestrated process. The potential to make things directly from design information has precipitated a transformation in design disciplines, as it allows the designer to engage with the entire process from concept to final product in an unprecedented manner (Dunn, 2012). Lisa Iwamoto described this shift in her book Digital Fabrication: Architectural and Material Techniques:

“For many years, as the process of making drawings steadily shifted from being analog to digital, the design of buildings did not reflect the change. CAD replaced drawings with a parallel rule and lead pointer, but buildings looked pretty much the same. This is perhaps not so surprising—one form of two-dimensional representation simply replaced another. It took three-dimensional computer modeling and digital fabrication to energize design thinking and expand the boundaries of architectural form and construction.” (Iwamoto, 2009, p. 5)

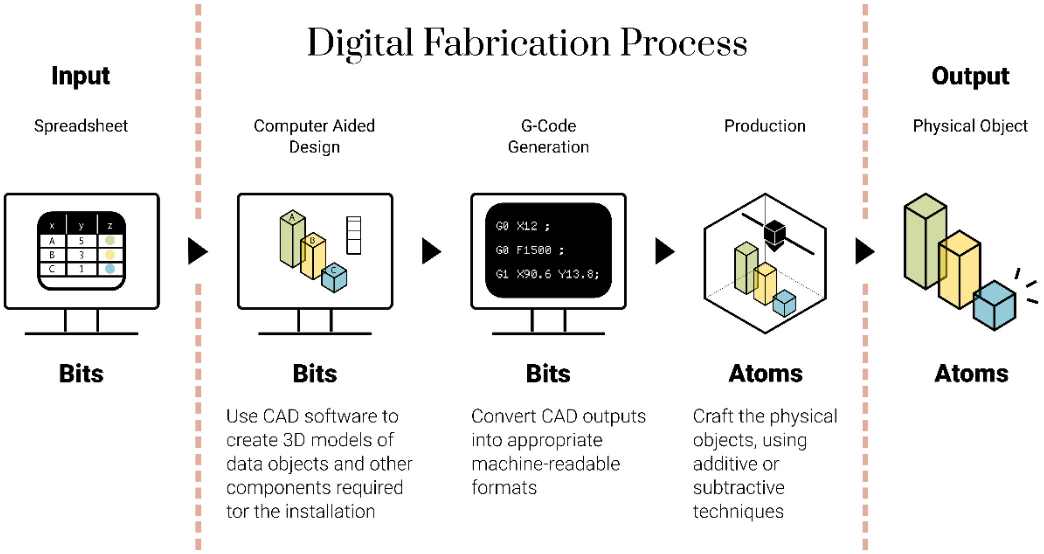

Figure 10 Diagram of the main steps of a data-driven parametric and digital fabrication process Source: https://batjo.eu/it/digital-fabrication/ [last accessed on-line 12/08/2020]

1.3.4 Makers

The current construction industry has largely shaped our living environments over the last century, trying to offer a solution that was largely driven by profit and deeply rooted in well-established economic methods. Referring to what was stated above about the waste that the construction industry is causing, this model becomes unsustainable. The construction industry for the average person has needed to reinvent itself for quite a while, and digital tools could be the solutions to exploring new methods of designing as wells as models of fast and easy-to-build.

Last but not least we have to take into consideration not only the advancements in that our society is going through. Firstly, and especially a huge part of what we produce now is digitized first. This digitalization and the ability to share designs as files over the World Wide Web has fundamentally changed the making process as well as the economics of making in general. The construction and manufacturing market has been largely shaped by two industrial revolutions and finally the automation industry. Breaking down complex processes into smaller singular tasks that, it made possible the creation of assembly lines as well as the creation of factories (Anderson, 2012).

The idea of a "factory" is transforming. As the computers and the World Wide Web democratized creativity in bits, this new movement based on prototyping is growing exponentially. From 3-D Printers to laser cutters and CNC machines the new democratization is allowing for bits to be turned into atoms. Accessibility to those machines has increased at a steady rate over the past years with companies, entrepreneurs, research laboratories or even artisans have been implementing these tools in their daily jobs. Today anyone with a good design can send their files to those companies and have their design be prototyped, in small batches or large, or even make it themselves if they own a 3-D printing machine. Would-be entrepreneurs, designers, architects, makers would no longer be at the mercy of large companies to manufacture their ideas.

To summarize this new movement and involvement of digital tools, there are three main characteristics that this movement follows:

1) People using their digital desktop tools to create new designs ready to prototype

2) A common habit and desire to share new concepts and to involve and work with a broader community of creators.

3) The use of universal design file specifications that allow anybody, if they choose, to submit their designs to commercial manufacturing services to be manufactured in any quantity, just as easily as they would manufacture them on their desktop. This dramatically shortens the road to the notion of making.

“The new abilities that this model offers are to be both small and global at the same time. Both artisanal and innovative. Both high-tech and low-cost. And most importantly creating the type of products that this world wants but doesn’t know it yet, because these products don’t fit neatly into the mass economics of the old model“ (Anderson, 2012). And while production can be made local and design international, the material of the product is still tied to location and place. These processes have made it possible to unleash a creative surge among creators now able to manufacture their ideas from anywhere. How can these new abilities involve also a material solution to all the new possibilities of designs available?

2. RESEARCH METHODOLOGY

2.1 Problem Statement

One of the main challenges that our society phases in the next 20 to 30 years will be waste or to put it more boldly, how we think, and deal with it. Not only in managing it but most importantly in the terms of design and construction. The current economic model based on consumption or the "Take, make, waste" (Leonard, 2010) has proven largely inefficient. We are passing on using a resource that we create because of the pejorative stigma associated with it. Yet what is a waste to one person is not waste to another, which makes the definition of the term highly complex. It requires a careful and differentiated recognition of the enormous differences in various cultures and social perceptions. In his book "Design for the real world", Victor Pathanek (1971), refers to Frances Fitzgerald, an American journalist who wrote about the cultural differences concerning the theme of waste between American troops and the native population in South-East Asia during the Vietnam War: "... while they (the Americans) saw themselves as building world order, many Vietnamese saw them merely as the producers of garbage from which they could build houses" (Fitzgerald, 1973). And it is exactly this ability and way of thinking that defines waste as a valuable resource to be tapped into, used, and reused, which defines one of the starting points of this thesis. "The future city makes no distinction between waste and supply" (Joachim, 2013).

There is a worldwide call and need that waste should and must be seen as a potential resource. Hebbel, Wisnieska, and Heisel, in their book 'Building from Waste' (2015), state that one of the key factors for sustainable building concepts could be the investigation of refuse products as a key factor and resource. Keeping this in mind, we must understand the waste that can be used for new construction processes and that it can also be recycled. Taking the definition of recycling or re-using from Hebbel again, "recycling takes given objects in their context and re-applies them in different contexts and with different functions with little or no physical modifications" (2015).

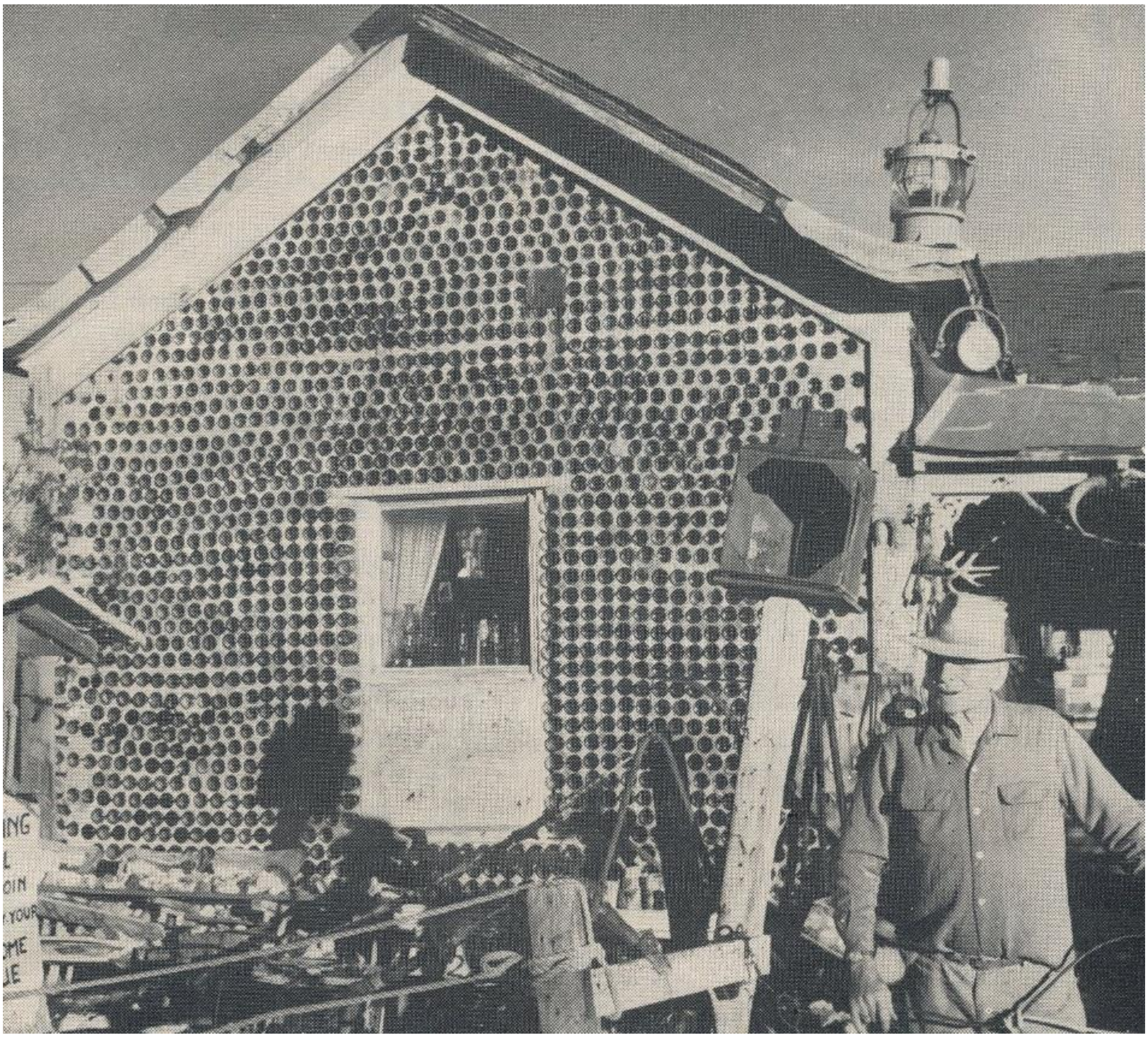

Figure 11 The Rhyolite house, Death Valley, NV, USA, has been built out of 50,000 discarded glass bottles, a cheap construction resource in the desert. There is no distinction here between waste and supply. Source: Published in The Antiques Journal (1969)

Reusing waste for new construction processes is not new, in the contrary, it is something that has been done consciously out of necessity. Slums are just some of the simplest examples of finding the use of urban waste in today’s context. The need to survive and shelter has pushed one of the poorest communities in Albania for example to build out of everything they could find. Flat aluminum sheets used for construction site fencing change into roof or wall panels, old doors and windows get reused or repurposed and anything that can’t be filled in completely gets covered with whatever advertisement banner they could find. These are all actions taken out of necessity that result in the very poor quality of shelters as well as health hazards that come from working with unselected waste materials. These factors can and should be addressed by future architects, designers, and engineers (Hebbel, et al., 2015) now more than ever who need to adapt their way of thinking and designing to incorporate one of the most untapped resources of our generations.

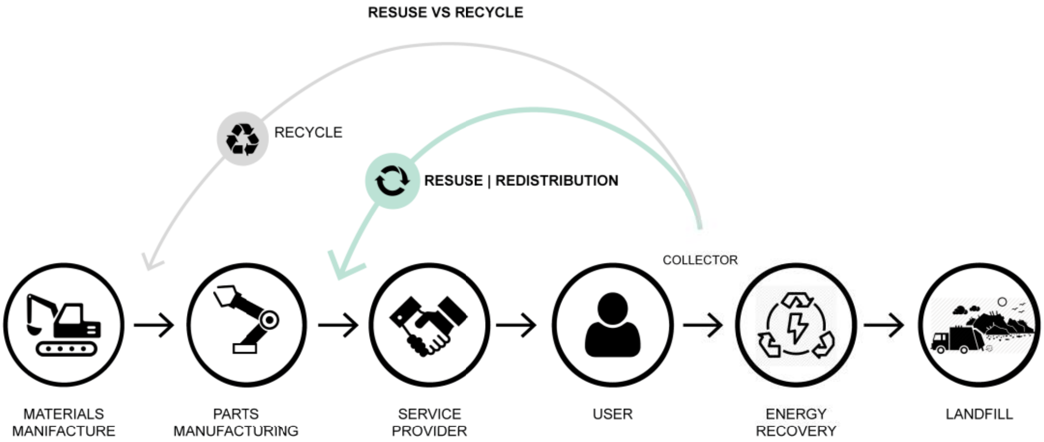

Figure 12 Reuse vs Recycle. Source: Author based on Mine the Scrap Project (2017)

As stated above, the architecture profession has profoundly changed in the last years. Designs pertaining to the circular economy model have become staples of what architecture and design can do for the environment. Technology has obviously proven integral in this, not only in recycling but as mentioned above, in manufacturing. We can argue that one of the main advantages of building with salvaged materials is that they also benefit from the technology used in their creation in order to re-introduce them to the product lifecycle chain. While recycling remains as one of the main ways to do this, we can argue that re-using saves even more energy as it avoids the costs of re-manufacturing the material. This approach requires an inversion of the design process (Bavarel, et al., 2014), where we design from an available database of materials already identified thus re-using waste and extending the life cycle of the product.

There has also been a large number of research projects which will be discussed in this thesis that have investigated the use of raw or recovered materials in the context of digital design and fabrication workflows, for example, the arrangement and positioning of irregular wood components through algorithmic methods (Monier, et al., 2013). Digital Design and parametric tools have the means to deal with complex or irregular material geometry that would normally be expected of waste. Further studies show the opportunity of scanning and data processing natural wood branches, (Schindler, et al., 2014) and connect them by optimizing their form placement in respect to the global geometry. Mine the Scrap Project[9] uses scanning and a stream from any webcam to identify and classify scrap or waste according to its geometry. Thus the final design can be dynamically adapted and changed based on available material. Digital fabrication techniques for the material of unknown geometry considers the above-mentioned workflows with the purpose of producing a double-story timber structure with wood plates of different dimensions (Eversmann, 2017). These new design processes add to the design processes by directly increasing the possible available material stock. A material stock that becomes more complex than the standardized alternatives available now, but that offers a reduction in energy costs related to recycling. Greater complexity in the geometry of materials can be addressed with the help of computational parametric tools as well as produced by digital fabrication tools. These new design processes allow for greater complexity in the material stock which namely recovering materials out of waste would show, reducing the energy costs associated with recycling. Greater complexity in material stock can be tackled with far more ease with the help of the computational tools and data that are at our disposal.

Taking into account all of the discussed topics above, it becomes clear that waste should be considered a resource of the future to be used. There are many cases of building with recycled materials that this thesis will discuss in order to create a broader understanding of the topic and its applications. On the other hand, the digital processes involved in re-using waste raise questions of their own. The normal design process is usually based on designing and then manufacturing the product according to the design itself. Technology has gotten progressively better at building precisely what we design on the computer screen but still relies heavily on manufactured and precise materials. While we can certainly transform waste to fit certain standards and criteria, still designing with waste asks the designer to think of a finite material available at a certain moment. Overcoming these problems and creating seamless processes and practices of designing and construction with waste can greatly benefit a circular economy by extending the life cycle of products and cutting costs. This solution could become a staple on how we think and design in the future if we can introduce waste to normal processes. As waste is found

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[9] The project transforms irregular, non-uniform stocks of construction scrap into new forms, using pattern recognition to find beauty and intricacy in neglected waste. Mine the Scrap finds the unique best use of each piece in a new structure through a sophisticated process of scanning and classification. https://www.certainmeasures.com/__mts_software.html

almost always in our surroundings (as urban centers are creating more waste than ever), it cuts transportation, manufacturing, or even recycling costs. The creation of practical, easy to build construction processes can become very important in societies where the waste management is a problem far from being solved. As we now have much better tools to design and build it becomes clear that new approaches to waste must be explored. We can clearly see new uses for certain materials in the architecture world. Shigeru Ban emergency shelters with paper tubes are a great example but new ways to reuse and design with materials have become possible.

2.2 Research aim

As stated above, the possibility of reusing waste materials in new ways with digital tools opens a lot of interesting directions. As waste and future uses of it have been continuously topics of discussion, there is still room to discover in the possibilities that digital tools offer when dealing with it. Waste is a resource that our cities produce continuously and in great quantity. Architecture and the building industry are some of the main culprits at its production need to find an answer on how this resource can be useful. As all resources mined from the earth, waste can be 'mined' from the city. And once mined like any resource it needs to be fed to a procedure s that can make use of it. Through recent advancements in the recycling industry, waste material has been put to use in creating new products that can be applied to construction processes. From experimental solutions to industrial products, these new materials often require specialized industries or machinery or become one-off experiments. If a country does not have the means to deal with waste in any other way, this becomes a problem.

Material life-cycles can be extended to serve further purposes. The emergence and application of computer-aided-design and computer-aided-manufacturing can open discussions on how waste can be transformed into a useful material through design. Digital tools in this sense become integral in enabling the link of the transformation of material from waste into a 'resource'. Through these tools, waste that is very local can be seen as a resource as long as the individual is equipped with the right tools and strategy. Therefore the main aim of the research is to: ***Find digital design and fabrication procedures that can extend the end-of-life cycle of materials.***

Reusing waste as a resource has always been a go-to solution for the poor. That along with the stigma that accompanies waste has kept our society from fully developing new processes that take advantage of this growing untapped resource. Digital tools have the power to elevate the quality, aesthetics, and functionality of these materials by creating processes previously unavailable to them. If we pair this with the ongoing growth and democratization of digital fabrication tools it becomes clear why this research is relevant in today's context.

2.3 Research Questions

As the thesis brings together two concepts that are not usually brought together, investigations into the topics and finding relevance is important. Waste regarded as human refuse, something we don't want to see or smell, needs to be understood in all its potential. Digital tools, on the other hand, have become integral in today's practices, expanding the design and manufacturing capabilities, and creating new design processes. It becomes logical to connect waste and digital tools as a way to transform, design, and build with waste materials. As stated in the previous chapter, anything that is unwanted can be defined as waste. Waste in this case will be dealing with materials at the end of their life cycle. This opens up an enormous amount of possible materials to be used as almost everything we produce is designed to have end-of-life. Digital tools in this case become imperative in the processes of transforming waste materials into usable resources through design. New designs can be generated and explored through parametric tools, evaluated and optimized before fabrication starts. As the collection and transformation of waste do not happen only through design, but they need a range of procedures, this thesis will aim to investigate the range of procedures that can create a set of operations that transform waste through digital tools for architectural design.

Therefore the main research question that this thesis asks is:
How can end-of-life materials be given new life-cycles through the use of digital tools?

Therefore some of the sub-questions that this thesis will deal with are:
Q1 - What are the most common practices and examples in transforming waste into a desirable material? What are the applications of these materials in building processes?

Q2 - What is the relevance of digital tools in today's practice? What are the implications and advantages that these tools offer? What are the benefits of using digital tools when dealing with waste?

Q3 - What are the important aspects of designing with end-of-life and reuse? How can the process of designing with waste become more efficient through the use of digital tools?

2.4 Research Methodology

The research focuses on a practice-led[10] and practice-based[11] research methodology as a strategy to gain new knowledge in practice and to directly expand on that knowledge through the practice itself. The thesis aims to advance the knowledge and practice of designing and building with waste materials through digital tools. The thesis is based on two main topics: that of waste and digital tools. The first part of the research is based on a qualitative study of current literature of processes and methods regarding the application and transformation of waste into

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[10] **“**Practice-led Research is concerned with the nature of practice and leads to new knowledge that has operational significance for that practice. In a doctoral thesis, the results of practice led research may be fully described in text form without the inclusion of a creative work. The primary focus of the research is to advance knowledge about practice, or to advance knowledge within practice. Such research includes practice as an integral part of its method and often falls within the general area of action research.” (Candy, 2006)

[11] “Practice-based Research is an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice. In a doctoral thesis, claims of originality and contribution to knowledge may be demonstrated through creative outcomes in the form of designs, music, digital media, performances and exhibitions. Whilst the significance and context of the claims are described in words, a full understanding can only be obtained with direct reference to the outcomes.” (Candy, 2006)

a resource for building. Key concepts as well as a historical overview of the problem of waste in building processes are explored mainly through a literature review and qualitative study method. An overview of existing applications of waste in building processes is the main of this part of the research. This is followed by a literature and desk study review of digital tools and their impact on today's practice. The goal here is to create an understanding of the implications and applications that digital tools have had in contemporary practice and how those can be used in dealing with waste materials. The three main concepts explored involve parametric design, digital fabrication as well as the resulting movement of the democratization of fabrication tools, also known as the Maker's movement (Anderson, 2012).

This is followed by a selection of case studies and a qualitative evaluation of their results towards processes that involve digital tools and waste. The case studies presented in this part are selected by the following criteria:

- Involve waste in one form or another
- Involve digital processes either during the design or fabrication phase (or both)
- Must have a physical result derived from either a waste or a digital product.

The cases presented during this phase will serve as the bases for the practice led part of the research. In order to apply outcomes and create a broader understanding of the practice, this part will focus on practice conducted by the author during his research period, in the form of building workshops and classes. Each practice builds upon the previous ones by introducing new digital methods in dealing with waste materials. New understandings of practice are achieved through the application of digital tools during the design and building phases of structures that use 'waste' materials. Their aim is to apply ideas and concepts studied during the first chapters into situations where dealing with waste through digital tools takes center focus. Qualitative evaluation and analysis of the results are then presented and used as a way to create a new understanding of the practice and a new understanding of processes that involve waste and digital tools.

3. WHAT A WASTE

3.1 Waste as an opportunity

During this thesis, waste is seen as an opportunity for new architectural applications of waste materials. To perceive it as such it becomes necessary to reconsider its definition and to introduce an understanding of it in line with our investigation and explain how this approach helps the practice conducted throughout this research. This chapter does not deal with or discuss liquid and hazardous waste as the applicability and discussions fall outside of the scope of the thesis.

Waste or commonly called garbage in everyday life (although that is a term we are trying to avoid) is defined as materials that are undesired or unwanted. These can range from manmade materials and objects to natural matter as well. During this thesis whenever the term waste is used we refer to solid waste rather than liquid or waste that is produced by energy production and that gets released in the air or soil. The definition of waste may very well vary, what is categorizes as waste it only depends on the perspective, which complicates the definition of the term. In-depth the term essentially requires a level of differentiation from cultural and social perception. During communist Albania, as in many third world countries, waste was mostly organic and solid objects, even after their intended initial use was usually stored until a new use could be found.

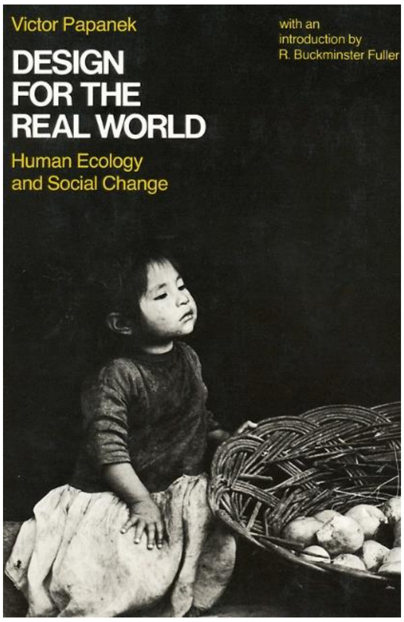

Figure 13 Cover of Design for the real world. Credits: Victor Papanek (1971)

As Victor Papanek refers to his book: "*Design for the real world* "(1971), describing cultural differences underlined by journalist Frances Fitzgerald as concerning in regards to the waste between American troops and the native population in South-East Asia during the Vietnam War. The troop, states Victor, "see themselves as builders of new world order, however, the Vietnamese saw them merely as the producers of garbage, which they could use to build houses".

The word “Desire”, is associated with a sense of longing for something. In contrast, items that we deem as useless and therefore don’t want around us anymore, seem to have an absence of this concept. Therefore, the concept of waste involves emotions and feelings which must not be evaluated in rational terms. There is a role of importance that aesthetics and other senses play. The single thought of something being made out of waste can trigger negative emotions in the observer, with a feeling of it being dirty or unwanted. This is one of the barriers that stop waste from being considered largely as a future building material.

3.1.1 Waste through time

Human beings have generated waste from the earliest days of mankind, through their mere existence on earth, through their production of culture and goods. It is documented that in North America, the Mayan Indians collected waste and arranged it in a monthly cycle, which consisted of using soil for covering or burning solid waste, resulting in an overall increase in the level in their settlements. Indeed, “the development of solid waste is strongly connected to the evolution of human settlements into urban conglomerates” (Hebbel, et al., 2015). In a first attempt at creating a system that would be able to manage waste, ancient Greek civilizations implemented dumpsites at the outskirts of their cities, making sure they were dislocated from the city walls, in order to prevent enemies from entering the city. The same dilemma triggered similar reactions in Rome as well, where various regulations were introduced in order to implement the very first waste collection and management system (Barbalace, 2003). The ancient Romans methodically stacked up broken terracotta amphoras, or oil pots, for more than 250 years, forming Monte Testaccio. Excavations in the 90s indicate that it was produced over time and not necessarily as a dumb location, but carefully and deliberately thought. Throughout the years the hill become a famous spot and park with interventions from the architect, Raffaele de Vico in 1931. Abandoned now due to maintenance and budget issues, it looks like a grassy hill until you take a closer look at it and notice the stacked layers of terracotta pieces.

Figure 14 Monte Testaccio in Rome composed of broken terracotta pieces. Source: OliveTimes.com

By the 19th century, the way waste was dealt with had changed very little. Waste was typically essentially thrown out of the window in the Middle Ages, often justified by the assumption that stray dogs and other animals would eat the waste (including human feces. The filth attracted rodents, even though this was simply the case, who produced diseases that also affected human beings. The European populations were dramatically impacted by the bubonic plague, cholera or typhus, and altered political environments (Worrell & Vesilind, 2011).

“The ‘Great Sanitary Awakening’ in the 1840s was spearheaded by a lawyer, Edwin Chadwick (1800–1890), who argued that there was a connection between disease and filth. The germ theory was not, however, widely accepted until the famous incident with the pump handle on Broad Street in London. The public health physician, John Snow (1813–1858), suspected that the water supply from the Broad Street pump was contaminated and was the cause of the cholera epidemic. He removed the handle and prevented people from drinking the contaminated water, thus stopping the cholera epidemic and ushering in the public health revolution” (Worrell & Vesilind, 2011).

Many of the former waste products were biodegradable in origin. With the rise of the industrial revolution, everything was about to change. During the 19th and 20th centuries, the composition of solid urban waste altered drastically. Product waste replaced the organic, which faced a major decrease. Chemically hazardous waste, from manure to urine, which mainly came from horses as the main mean of transportation for the time, transformed into a prime danger for the health of people. During the 20th century then, waste was considered to be the main and biggest issue in almost all the cities and urban settlements (Hebbel, et al., 2015). As a result, using machinery that collected waste from the streets and treated it, were seen as a common solution. “Dectructor”, an incineration facility in Nottingham, England, to mention an example. In the meantime, in the USA “sorting machines” were being introduced, together with some pioneering recycling initiatives, for metal and other materials that were of use. Nevertheless, throughout Europe and the USA, landfills were the most-commonly implemented facilities, to co-dispose industrial waste, together with other municipal waste. However, measures to protect sites and groundwater from the seepage of hazardous chemicals were almost inexistent. During the 1970s and 1980s, a major shift in public opinion took place, affecting all structures regarding the management of waste (bacterial and nuclear waste together). Communities started pressuring local authorities to either take measures or shut landfills down, so as to prevent pollution of the environment and water sources. This also coincided with President Lyndon B. Johnson's call for "better solutions to the disposal of solid waste" (Melosi, 1981) that elevated solid waste to the level of federal attention. "In the lexicon, it has defined the phrase" solid waste "as a substitute for the word" refuse. Soon after, a Solid Waste Disposal Act of 1965 (Public Law 89-272) as Title II of the 1965 amendments to the Clean Air Act, was introduced and passed by the Congress.

Recycling programs began to emerge in the developed world during the 1980s and 1990s. Waste was no longer seen as a material that was unnecessary or useless, but instead as a resource to produce new materials, such as reclaiming land from the sea by using landfill remained materials. Private recycling firms, drawn by the enormous potential of the accumulation of solid waste materials to recycle them for a circular industrial production process, have begun to reach the markets of most developed countries. Hebbel, Wisniewska, and Heisel (2015) In their book ‘Building from waste’, note that most developed nations have structured recycling principles in their societies today, even though waste reuse rates have stagnated since the late 1990s. “Throwaway society” and “take-make-waste” (Leonard, 2000) were both phenomena rising during this period of time, as due to the convenience that came from the collection processes. Nowadays we've noticed an increase in consumption patterns, accompanied by a general lack of attention for re-inventing or promoting further recycling processes. The majority of goods being produced are rather produced as mere consumption material, with little to no consideration on their quality and durability, and even less for their possible recycling (Leonard, 2000). From this very statement we understand the importance that design can have in the range of products that are not designed to be recycled and reused, and as such, become waste or unwanted the moment they cannot complete their primary intended function.

3.1.2 Modern Architecture and Waste

The absence of proper waste management systems in Europe during the 20th century encouraged fields like architecture to come up with dedicated terminology, which addressed the polluted and unhygienic city conditions. Le Corbusier, Bauhaus figures from Weimar and Dessau, and the Dutch De Stijl Party, just some to mention among the few that became part of the movement, suggesting that the built environment should function like a "healing machine". In this framework architects considered themselves to be the main agents of social hygiene, with the aim to create a method that would tackle the issue of pollution emotionally, physically, and aesthetically. This movement to strategically partner architects, with engineers, doctors, and politicians, soon led public health to be a crucial topic of several urban reforms. Between 1920-1950, the Congres International d'Architecture Moderne (CIAM) introduced a new greener, safer, lighter, and more accessible image of the European city, as opposed to the notorious gloomy and dirty city (Mumford, 2000). For decades, the architectural and urban discourse of the Modern Movement dominated the resistance of the "sick" and the "healthy" city. Nevertheless, this view was rather one-dimensional, given that it considered changing the image and the conditions of the city from "sick" to "healthy", only based on design matters. The function of a prosthesis for a human body that lives in an ideal state, a kind of spatial and visual care, was assigned to architecture and urbanism.

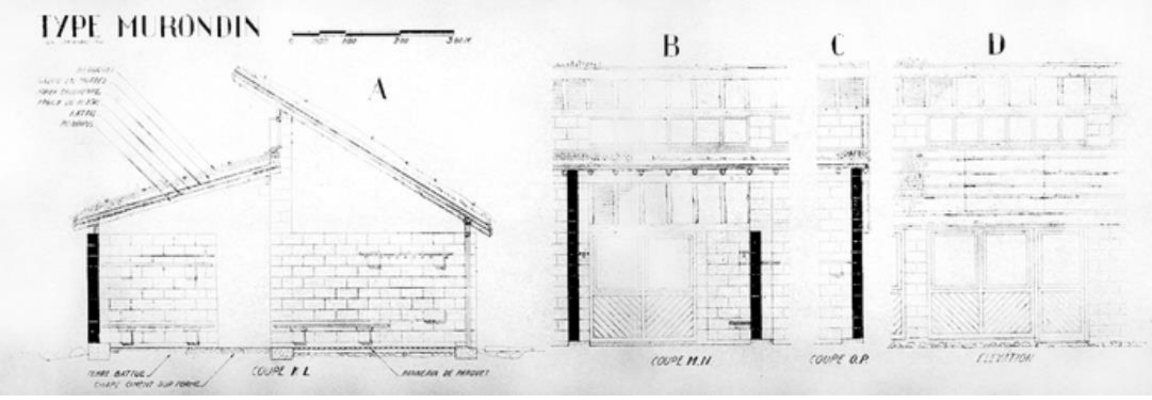

Figure 15 Le Corbusier and Pierre Jeanneret, working drawing of a "Murondin" house, 1940, from Le Corbusier, Les Constructions "Murondins" Paris and Clermont-Ferrand: Chiron, (1942)

Following this claim, for cities like Paris or Zurich, Le Corbusier created imaginative scenarios, replacing current inner-city structures with high-rise (Fondation Le Corbusier, 2006). The new models of design aimed at avoiding contact with the ground, of both humans and the structures themselves as much as possible. Hence, columns became the only element of contact, ornaments were stripped off of all facades and rooftops, and the color white became a symbol of the clean state that was being promoted as the cleanness or healthiness of architecture. This made architecture to be considered as a profession mandated to bring order in the midst of a hygiene crisis. It is important to note also another proposal by Le Corbusier during World War II, Les Maisons Murodins (Fig. 11) (McLeod, 2015). As refugees were fleeing to France in large numbers, shelters could not be built fast enough to accommodate them all. Therefore, Le Corbusier proposed the practical idea of the shelter being built by the users themselves and with readily available materials like wood, logs, dirt which were found in the immediate surrounding. Different types of units are presented during this proposal, with ‘the house for 6 dwellers’ being the most important. The proposal was never accepted and remained just an idea but Le Corbusier’s view on a clean architecture is contradicted by an architecture that uses ‘waste’ as a primary resource. Both waste and the history of architecture grew to become more and more tied to each other (Hebbel, et al., 2015). Up to this moment, that very mindset and design models that followed it can be seen around the world, adopting a policy, where architecture facilitates design models that separate people from their own waste that they produce.

Considering the replacement of the conception of the ideal body, from it being safe only when free of various illnesses, to it being a self-regulating organism, waste still remains considered as valueless and undesirable. The body constantly oscillates between the extremes of healthy and sick, as a self-regulating organism, so that illness is recognized as the essential and integral precondition for defining with health. Therefore, being sick becomes a push for regeneration and development for our organism, by undergoing and overcoming the state of crisis, in order to draw new and more dynamic conditions of a balanced status-quo. Quoting George Canguilhem: “The healthy man does not flee from the problems posed by sometimes sudden disruptions of his habits, even physiologically; he measures his health in terms of his capacity to overcome organic crises to establish a new order” (1991). In reality, might a disease be the real motivation for constructive adaptation and thus the precondition for human development? Can waste, similarly, be considered an integral part of the philosophy of our architectural design models, instead of just removing it from the creative process?

Part of the inspiration of this thesis comes also from these questions, as tapping into the potential that waste brings could be the answer to the crisis that it or we have caused. If waste can be translated from its status quo of ‘not needed’ to its full potential as a resource and commodity, we might find ourselves with a completely new way of designing and building. Architecture and design hold a responsibility, in a way, to find the proper use of waste, both aesthetically and structurally and functionally.

3.1.3 Waste in today’s Society

Garbology is “the science that studies the phenomenon of trash composition”. The definition of garbology was defined by in 1971, after the first study of the wastebasket trash material of the renowned musician, Bob Dylan (Webermann, 1980). In certain cases, when it comes to deciding the routes of social change, the use of various materials and methods, spiritual preferences, and dietary compositions, it overlaps with the discipline of archaeology, all of which can be traced through the study of the waste that a given culture created at a certain moment in time. (Hebbel, et al., 2015). Today, the very young discipline of garbology is used to analyze solid waste and to define new concepts for waste management, fundamentally changing the formation of waste. The type of waste produced tends to decide the urbanization and financial status of diverse societies. The percentage of inorganic substances in their waste rises as people grow wealthier and migrate into urban conglomerates, while organic substances account for only a decreasing share. By comparison, the biological and compostable components of waste also reach up to 85 percent in rural areas (Baker, 2012).

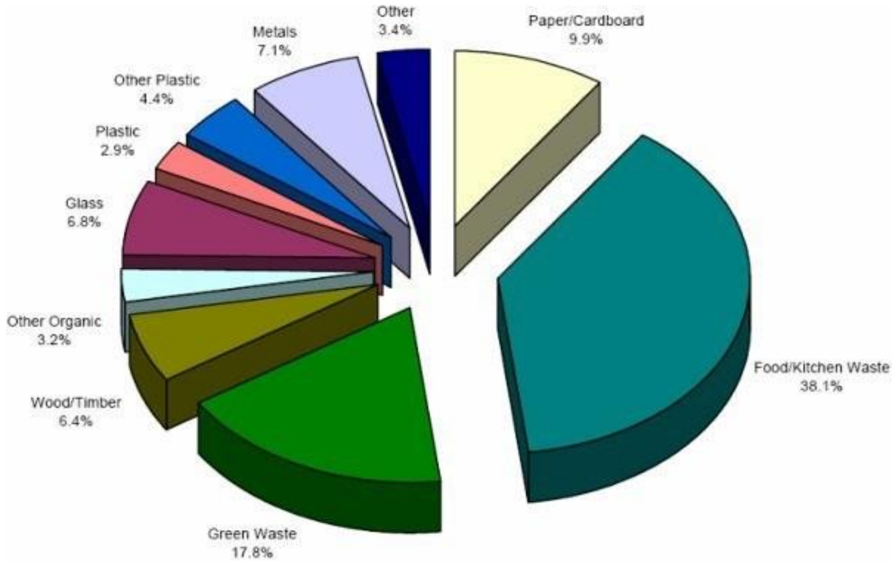

Figure 16 Typical components of Municipal Solid Waste in an urban location Source: www.see.murdoch.edu.au

Increasingly the problem for our society is how to minimize our production of inorganic waste, and how to turn into a resource those inorganic substances in our waste that are maybe inevitable. This is the basis of the four R's: Minimize, Reuse, Recycle, and Recover, as we speak of a minimal or even zero-waste society (Saeed, et al., 2007). In order to prevent any disposal at all, this hierarchy of waste management, as it is also called, strives for complete circular metabolism. This thinking has changed the behavior of the younger generations of our culture over the past two decades (Hebbel, et al., 2015). Buying accessories made from reused truck canvases or other throw-outs, for instance, has become trendy. Although this movement is primarily directed at the reuse of materials and goods, it could easily be extended to refer to the other three R's as well, leading to a waste-free society.

The Zero Waste International Alliance in 2004 established a concept of such a zero-waste philosophy: “Zero Waste is a goal that is ethical, economical, efficient and visionary, to guide people in changing their lifestyles and practices to emulate sustainable natural cycles, where all discarded materials are designed to become resources for others to use. Zero Waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them. Implementing Zero Waste will eliminate all discharges to land, water, or air that are a threat to planetary, human, animal, or plant health" (ZWIA - Zero Waste International Alliance, 2009).

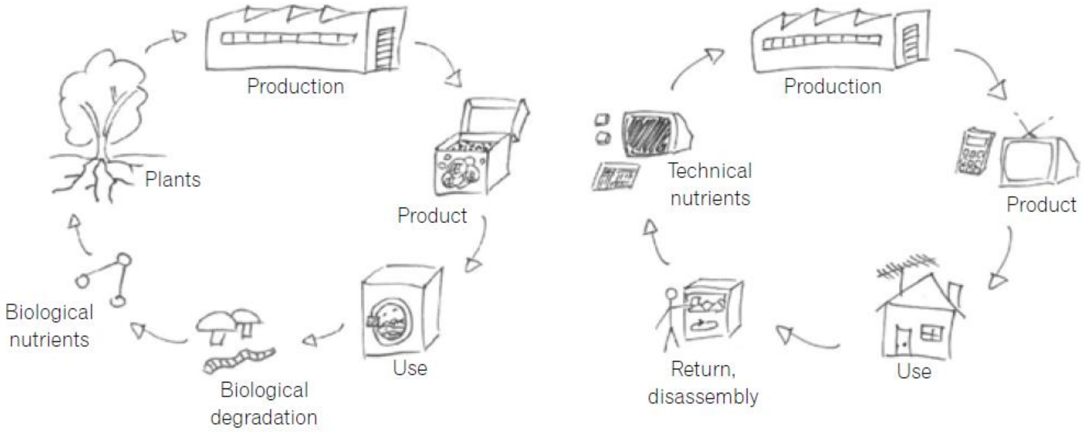

Figure 17 Biological Cycle for Product Consumption vs Technical Cycle for Product Service. Credits: McDonough Braungart Design Design (2002)

This concept provides a socially conscious alternative to the existing paradigm of "take-make-throw" (Hebbel, et al., 2015). It positions not only the manufacturer but also the customer in the ethically active position of reusing waste goods as a resource and preventing the creation of waste based on an unhealthy lifestyle. The Cradle-to-Cradle idea aims in the same direction, as discussed above, and will be discussed further below. In their Cradle to Cradle book (McDonough & Braungart, 2002). Things William McDonough and Michael Braungart say, in comparison to a Cradle-to-Grave philosophy that has so far been the dominant system in our societies, a development logic based on a fully closed resource loop. They expanded the four R's to a list of seven to stress their argument: Reduction, Reuse, Recycle, Recovery, Rethinking, Restoration, and Regulation. In particular, the last word in this enumeration extends the obligation of suppliers and customers to political decision-makers as well. In introducing new legislation, new thinkers and designers will join the stage by introducing the hope of the writers, who will begin to see waste as what it should be: an amazing opportunity for new product production.

The goal of this holistic paradigm, which integrates ecological, industrial, social, and economic values, is to build productive processes that ideally contribute to a community that accepts waste since more waste means more opportunities.

All of these models, whether effective or not at the present level, recognize waste as a sustainable resource for continuous doing and making, not as a final and definite product of a society that needs to be done away with. The question at stake is: can we use this information to improve the quality, design, structure, or character of goods so that after their first life cycle they are not seen as waste?

3.1.4 Urban Mining

Urban mining is a relatively new approach, promoting recycling of materials and components from waste goods or, more extensively, from buildings containing high amounts of useful materials, or at least undesired goods. Ilka and Andreas Ruby explain the current shifting knowledge in their text "Mine the City", stating that base materials in raw form cannot be found in nature, but rather in more ‘cultural’ milieus, i.e. buildings. “At the sight of their natural roots, the material resources of construction are being rapidly depleted thus accumulating inversely inside buildings. Today, for example, more copper can be found in buildings than on Earth. Our buildings become mines in themselves as mines become increasingly dry” (2010). The city, in their opinion, must be viewed as a grouping of buildings and mines, much required for its reproduction.

Urban Mining studies and issues of the number of resources that can be recovered in landfills or buildings are blended in Thomas Graedel’s studies. As Gradael puts it, buildings store not just the resources to be recycled, but a huge amount of energy that could be reactivated along with them. He claims that only 5 percent of the energy originally used for its manufacture is required for the reuse of aluminum that could be recycled from buildings. “Aluminium is extensively employed in buildings, but it does not remain permanently in place. Buildings are remodeled periodically and even deconstructed, thereby freeing the aluminum for recycling. Therefore, it is not inaccurate to regard this aluminum as ‘urban ore’ and cities as ‘urban mines’” (Graedel, n.d.).

Figure 18 Plastic Bottle Bus station built near Polis University during the first edition of Tirana Architecture Weeks. (2012)

Urban mining illustrates the ability and possibility of resourcing waste materials by being transformed, reshaped, remodeled, or reconfigured at the end of their first life cycle as they join a second. Dirk E. Hebel in his book Building from waste states that “it also opens up the question of whether the consideration of the waste state of a product should not become the starting point of its design proper” (2015). This clearly shows a different approach from the traditional design process where materiality and its source are introduced through later stages of the design.

Open urban landfills, which in most developed nations have been declared illegal during the early 2000s or even before, have been converted to recreational, green space upon their closure. Interestingly, they are experiencing a ‘comeback’ as important suppliers of metals and rare earth, rather than being considered merely waste disposal sites. In 2009, 8.4 billion euro was saved in Germany alone by recycling useful materials from waste goods. It is understated, however, that putting into function former dumpsites has a deep impact on the urban environment. Moreover, it is understandable that many citizens are reluctant to use them, due to possible health hazards caused by a toxic compound, which were isolated previously in many earth layers. It comes as no surprise, therefore, that focus has shifted to buildings, because they serve as a real mine for the recovery of materials, especially high-value ones, like copper or aluminum. Indeed, the cost of recycling these materials is lower than the cost needed to demolish these types of buildings.

Concrete, currently the world's most used construction material (Crow, 2010), will play a crucial role in this game. Francesco di Maio states that “we can use local buildings as a source for aggregates instead of shipping aggregates from far away” (2013). He discusses the possibility of recovering aggregates, like different-sized stones, rocks, or sand, as well as cement, and underlines their environmental potential in reducing unnecessary CO2 emissions and energy consumption in general, which is associated with concrete production. Not only this, but technical analysis suggests that concrete produced from recycled materials has better performance in strength and endurance from normal concrete. (Hebbel, et al., 2015). Urban mining illustrates the ability and possibility of resourcing waste materials by being transformed, reshaped, remodeled, or reconfigured at the end of their first life cycle as they join a second. It also lays down the question if the state of the waste product should become the starting line for each new design.

3.1.5 Waste from construction

Under a report from Transparency Market Research, the amount of construction waste produced globally every year will increase to 2.2. Billion tons by the year 2025. Such a conclusion was also later stated by Construction & Demolition Recycling. A focus on the economic performance of construction has meant the widespread adoption of non-reusable and complex materials (Curtis, 2015). These materials – although adjustable, long-lasting, easily installable, and cost-efficient – have no reuse value as they are either irreversibly consumed on the removal or are not permitted by building codes for reuse (Storey, et al., 2005). “Products such as plasterboard (drywall), treated framing timber and reinforced plaster monolithic claddings are all single-use materials that are found in 90% of residential structures built in New Zealand, and represent 85% of all demolition waste” (Curtis, 2015, p. 6). These ‘engineered’ materials are built in a way that makes it nearly impossible to them remove without any damage and difficult to recycle or reprocess without losing value (Chini, et al., 2001). At the end of a building's useful life, the effort (cost) required to separate these materials exceeds the possible return for selling the recovered product.

Figure 19 some of the possible materials that can be recognized as construction waste after a disassembly. Source: https://blog.allplan.com/en/construction-waste-and-materials-efficiency, [last accessed on-line 29.05.2020]

Modern construction methods have also resulted in the dumping of increasingly toxic waste materials. Consumer and regulatory demand for long life and weathertight homes have led to the widespread adoption of composite and petrochemical-based materials. These materials are usually used with chemical stabilizers to avoid the ingress of water, for example, chromate copper arsenate (CCA) treated timber. When landfilled, these chemicals will delay the decomposition process, harm surrounding ecosystems, and potentially pollute groundwater. "The arsenic in CCA treated timber is readily leached into the environment in amounts which are 500 times higher than harmless background levels (Parisio, 2006, p. 8). Based on present construction trends, the progressive dumping of toxic waste should continue to be expected (Keene & Smythe, 2009). Furthermore, to achieve the stipulated performance of modern construction standards, silicone, adhesivebacked tapes, and expanding foams are commonly employed. “Subsequent alterations to the envelope result in huge quantities of waste, as uncontaminated separation of materials is all but impossible at the source” (Finch, 2019).

Construction stands in a very delicate position as it is one of the main culprits for urban waste but also one of the industries that can and should do significantly more to reduce it.

3.2 Circular Economy Model

The pre-eminent solution to the waste problem is to eliminate the potential for the production of waste in all stages of a product’s life cycle at the time of design. This approach is called ‘cradle-to-cradle’ or ‘Circular Economy’. Circular Economy promotes a design that takes into account all cycles of the product's life. While this sounds a perfect approach on paper, the implementation requires time and changing the way we have been doing things for a long time.

3.2.1 Introduction to Circular Economy

Attempts at the ‘design-level’ to address the management of artificial, chemically bonded, and composite, hybrid waste materials were first implemented by Dutch Politician Adrianus Lansink in 1979. Lansink introduced what became known as ‘Lansink’s Ladder’: “a simple schematic presentation of the order of preference for waste management options, with disposal at the bottom and prevention at the top” (Watson, 2013).

Lansink’s 1979 proposal evolved into today’s (2018) internationally recognized waste hierarchy (Fig 20). While Lansink’s ranking highlighted the importance of managing waste streams at the highest possible level that of prevention through design – these ideas failed to significantly influence manufacturers or consumers. Worldwide municipal solid and construction and demolition waste levels have both continued to trend upwards from 1980 levels, with any significant reductions being a result of economic fluctuations rather than changing product design.

The Waste Hierarchy concept proposed by Lansink – although largely inconsequential on its own – helped to fuel a growing belief that designers should be doing more to prevent waste. In 2002, chemist Michael Braungart and architect The publication of William McDonough titled ‘Cradle to Cradle: Remaking The Way We Make Things’ highlighted the need for designers to pre-emptively consider how their products will transition into valuable raw materials for other designers/needs.

In opposition to the linear ‘cradle-to-grave’ cycle that continues to dominate manufacturing, ‘cradle-to-cradle’ represents the all-inclusive management of materials and by-products of manufacture from extraction through to their integration into another product or life cycle. Braungart and McDonough are outwardly critical of the established principles of sustainability. It is argued that sustainable practices simply ask us to “substitute” one material for another that is “less bad” (2002). Instead, the authors propose a ‘cradle-to-cradle’ approach that formalizes the long-held idea that we as humans need to emulate natural processes in the way we manage materials over their life span to eliminate waste material.

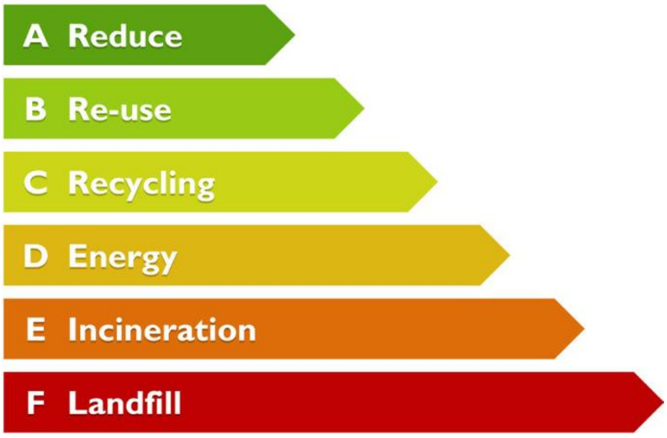

Figure 20 Lansik's Ladder, Recognized today as the Waste Hierarchy. Credits: Ad Lansik (1979)

‘Cradle-to-cradle’ ideas have inspired an entirely new agenda for sustainable designers and architects. Coined the ‘Circular Economy’, it represents a deliberate attempt to circumvent the ‘take–make–waste’ consumption sequence that dominates the manufacturing industry and is responsible for the vast quantities of waste we as a society produce.

The time and location of the idea of sustainability emerged are difficult to ascertain, however, the idea of sustainability was established as an action plan, a blueprint for steps toward a planning approach (Filho, 2000). The SD[12] paradigm provides conceptual tools to explore how to analyze the transition of the system from its present growth-oriented direction to a more growth-oriented sustainable one. As a logical metaphor, SD is suggested as a novel way of interpreting the development of the structure and stimulating the discussion on possible solutions. The first concept of waste management is that the volume of waste is decreased by one,

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[12] Sustainable development paradigm: https://sustainabledevelopment.un.org/partnerships/goal12/

generating less in the first place by consuming less. The imperative of "reduce" is not to interrupt all new development and related development. Innovation opportunities, but to reconsider the growth-oriented, market-like approach; consent to safeguard institutional opportunities. The Policy Statement, analogous to the argument for responsible use of the global regulatory space is the argument footprinting for carbon. The reduction of footprints and pollution offsetting will help for future generations, ensure a stable climate. The second concept of waste management is to "reuse" materials instead of throwing them away or moving such materials on to others in their original form, that will use them too. This is where sustainable development goals meet alternative concepts, new practices, and bold methods. (Papa, 2015) Recycling refers to putting old products that are unusable through a process that converts them into new products.

3.2.2 Material Categorization

A key aspect of the Circular Economy (CE) design is material categorization and selection. Although material categorization can be actively criticized as simply managing already compromised products; categorization at the design level ensures that any medium with the potential to generate waste is effectively eliminated.

In its most basic form, the CE asks designers to be more selective concerning the materials that they specify in design proposals. This means categorizing materials based on their whole life performance together with their environmental impact from fabrication and only selecting those that perform well in both categories. Materials sorted based on these measures will typically fall into one of three groups

- The Technical Metabolism – “refers to materials that are highly engineered and often energy-intensive to fabricate. Materials with such properties include aluminum, PET plastic, and steel” (McDonough & Braungart, 2002)
- The Biological Metabolism – “refers to materials that feed into a natural waste management process. Materials matching this description include untreated timber, lime-based plaster renders, and unbound stone” (McDonough & Braungart, 2002)

- Compromised or Monstrous Hybrids – “refers to materials that are either designed poorly or compromised in some way over their lifetime. Treated timber is a leading example of a material that has a compromised potential to be effectively and safely disposed of” (McDonough & Braungart, 2002).

Designers wishing to operate within the constraints of a CE would need to select materials from either the ‘biological’ or ‘technical’ categories. The designer would then need to ensure that no secondary material was added to the primary material in a way that restricted its long-term reusability or recyclability. A common example of this problem is the application of treatments to structural timber elements. Untreated timber sits in the ‘organic’ category ordinarily but then moves to the ‘compromised’ category when a treatment product is added. This transition is complicated by the fact that this treated timber product could be considered a technical material capable of reuse depending on the way it is fixed and assembled into a structure and its state after the end of its first use cycle.

3.2.3. Assembly and categorization

Material categorization does not guarantee effective waste management. If the product is not imagined as part of a greater system in which “materials and behaviors” are carefully considered, “there is very little point merely changing the design of a single product” through the selection of specific materials (Baker-Brown, 2017). This statement is in recognition that the cost and usefulness of the materials or components within a given product will dictate if end-of-life disassembly takes place. For buildings, this means using components that are geometrically, functionally, and aesthetically adaptable to a range of different uses across an extended time frame. Integrating components that meet these criteria (and that are also economically attractive throughout reuse cycles) is the key architectural challenge of designing for a Circular Economy. Although this depends also on the approach taken as salvaged material very rarely will come in a regular geometric shape.

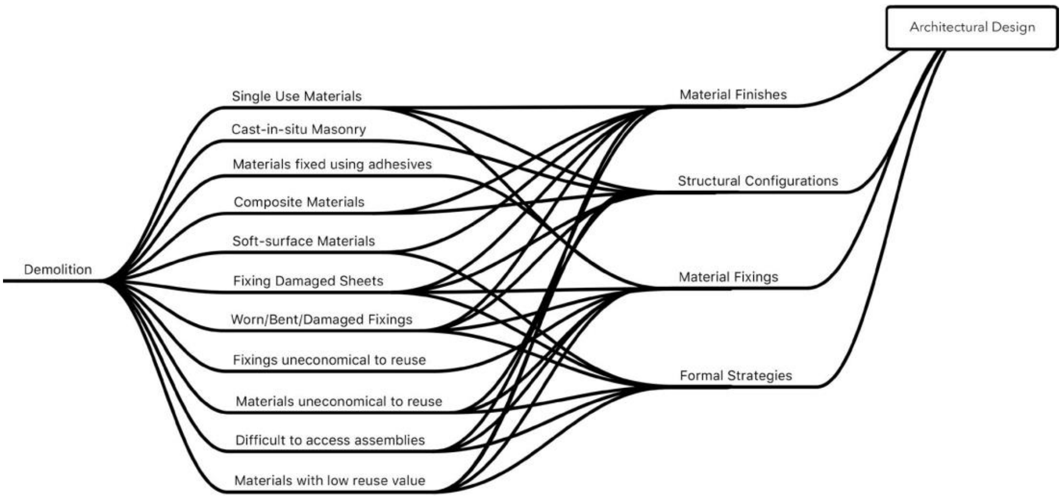

Figure 21 Relationship between architectural design and waste at the end of building a life. Credits: Finch (2019)

3.2.4 Implementation Challenges

The design requirements of adopting Circular Economy ideals are considered by many businesses to generate “labor-intensive” practices with “insufficient effective demand” and “financial arrangements (for circular revenue models) that cannot compete with linear revenue models” (SER, 2017). Contributing to this negative perception of the Circular Economy is a broad set of legislation that limits the potential value of upcycled and reused materials. Strict regulations of the building industry make it harder to just substitute chemically enhanced building materials with alternatives that are more natural or recycled. Today, however, these barriers to adopting a circular model are beginning to shift. For the first time, businesses are beginning to see the financial advantages of operating in a Circular Economy. An ever-decreasing abundance of quality virgin materials is driving up manufacturing costs and adding volatility to the supply chain (MacArthur, 2013). Another significant barrier to the implementation of Circular Economy building practices is the perception that buildings have an indefinite design life. There is little motivation for Circular Economy design, as the positive implications are seen as too distant to have any significant economic benefit to the individual funding the project at the outset. This assumption, however, that buildings last indefinitely, is largely flawed. Internationally it is reported that 44% of all C&D waste is from renovation (EPA, 1998). This figure suggests that there is significant remodeling activity that produces waste on an ongoing basis, regardless of the design life of the building itself.

Appropriate Circular Economy construction systems could largely eliminate this ‘mid-cycle’ waste by ensuring all extracted materials are in a state fit for reuse.

Additionally, ongoing legal action regarding the substandard performance of building materials, and international research indicating the general shortened expected life-spans for buildings built today, suggests that our perception of buildings lasting ‘forever’ is misplaced (Divich, 2016).

Keeping this in mind, we can think of two approaches to working for a circular economy

- Designing for with reuse in mind involves a process that starts at the design stage, where cooperation between designer, manufacturer, and the client is required.
- Re-using products for new purposes involves a complex problem of transforming the purpose of the product itself through design

Contrary to the first approach or even to standard design methods, this requires a bottom-up approach, where each piece of ‘waste’ is a design or puzzle piece, that needs to fit into a new process and system.

3.3 Transforming waste

This study incorporates two concepts that have been understood so far as to separate entities, one-the waste-usually created by the other-building-either through the act of manufacturing, development, implementation, housing, conversion, adaptation, or demolition. According to this argument, "waste is a product of any human contact and interaction" (Hebbel, et al., 2015, p. 18), by applying different types of skills and energy, taking natural raw materials, understood as our sole type of capital, from one stage of being into another. On these terms, for millennia, waste has been considered as unique, rather than as a natural resource, or as a finished good. It was seen as an after-product, which based on our interpretations of raw versus configured, could not be listed in any of the given categories.

This section aims to extend the ability to consider waste as an important part of what we describe as a resource. We will thus recognize its ability to classify a new product as the necessary material or matter, which can either create or configure, to then be used as a supply source for further artifacts, after its very first life cycle. Based on this metabolic thought, the constructed environment is considered as an intermediate process of material storage, or to quote Mitchell Joachim, "The future city makes no distinction between waste and supply" (2013).

If the Worldwatch Institute predicts that the increasing population and wealth of the world, will be able to produce twice as much of the urban solid waste by 2025 (Baker, 2012), its volume is likely to skyrocket from 1.3 billion tons per year today, to 2.6 billion tons per year. Can we allow this material to be enabled for construction in the urban environment? If the answer would be YES, then we could easily reach to the concept of the circular metabolism, given that cities themselves tend to systematically produce all the material they need for expansion, without necessarily having to exploit new materials and resources (Hebbel, et al., 2015). On these terms, architects and designers are required to develop future-cities concepts, which are holistic, consider a circular attitude, and are able to integrate ecological, industrial, social and economic concepts as well, in order to produce effective structures, in which materials can be resilient, and able to live through various life cycles, transitioning from one configuration or use to another, without ever being seen as waste material.

While numerous techniques and ideas about how to transform waste into desirable and profitable goods have been developed in recent decades, the majority of nowadays building materials are still very much tied with information, ideologies, technologies, and cultural understandings that derive from the industrialization era. From here, a viewpoint on the sustainability topic and resource availability, rises, on pretty much uncritical grounds. How do we categorize waste? We can of course go for the very first obvious hint, and sort the waste out, based on material characteristics, for instance: biological waste, plastic, glass, paper, etc. But while speaking of alternative construction materials, is this the best way? According to Hebbel et al, “it makes more sense to sort waste according to the types of processes that turn unwanted into something valuable” (2015).

Methods and processes have been classified into five groups according to these guidelines for how to process waste: densified, reconfigured, transformed, planned, and cultivated. (Hebbel, et al., 2015). At first glance, the latter two can sound odd, but they argue that they hold the greatest potential as it includes coping with a product's waste process from its creation onwards and following the belief that waste can indeed become so desirable, that it is very convenient to produce more of it. Their goal is to unveil the secret potential of waste materials for construction through this very unorthodox cataloging method.

Identity formation, acquiring of a local spirit, as well as producing resource quality, and making urban systems be resilient through the implementation of local value chains, their usage, continued reuse, and ability to substitute other materials could become crucial factors. The illustrated projects selected for each group for this research come all from applied cases with at least one prototype constructed.

3.3.1 Densified Material

“The most obvious and direct way to process waste materials into building construction elements is densification” (Hebbel, et al., 2015). The main purpose of the garbage press, a very well-known practice in England during the 19th century, is to reduce the amount of waste through the practice of pressing compacting it. The theory behind these devices consists of the fact that low bulk density in waste, produces a loose mix. Therefore, the management of this form of waste turns out to be difficult, which is why processing companies have come up with special methods, which transform solid waste materials, into easy to cope with units. One way of coping is to use specific molds for the materials, which are able to compact them into manageable bales, which can then be stripped, in order to not be dissolved. Alternatively, relative to the incoming material, the loose mix can be pressed into small pellets, with a higher bulk density and which are uniformly shaped.

Many sorted or unsorted plastic materials are usually used for densification, and after transformed into new products through an extrusion process. The original material remains unchanged in terms of chemical composition in both types of processing; it is also neither disintegrated nor tampered within its physical shape nor combined to form composites. The resulting volume reduction is not the primary objective, but rather an instrument for triggering a particular capacity within a particular waste product (Hebbel, et al., 2015). Most of the projects produced by densified materials have in common one very specific feature: they manifest exceptional thermal and acoustic insulation abilities, which derives from their very high levels of compactness, which very often result in relatively high resistance to fire due to the material's air removal. Nevertheless, apart from their labeling as “easily inflammable” and in a loose material configuration, both straw and paper illustrate this ability in compressed shape.

Negative pressure, or alternatively vacuum state, can be used to build construction elements similar to compression. In Zurich, a temporary pavilion structure uses PET bottles embedded in a preformed membrane[13]. As a result of the membrane pushing

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[13] The second prototype of a pavilion structure made of recycled PET bottles has been successfully built by CoReSing. The vacummized arches will be used as the exhibition concept in the forthcoming Zurich meets New York Exhibition. The architectural structure for the numerous activities and exhibits of this festival will be three pavilions built from 'waste'.(2014) https://nb.ieb.kit.edu/index.php/pavilion-prototype-construction-from-recycled-pet-bottles/

the bottles together in a vacuum, the induced additional friction between the bottles binds the PET components into a closed structural unit. We are all very familiar with this idea and technology application, take the peanut packaging as an example.

Figure 22 Airless, a pavilion built out of compressed PET bottles enclosed in a membrane, source: ETH Zurich (2014)

According to the German Pulp and Paper Association (VDP), Germany recycles almost two-thirds of its cardboard and pasteboard waste. This equals more than 16 million tons of material per year, which is mainly used in the packaging and newspaper industry for recycled paper products. This tremendous potential for the construction sector is enabled by the project PHZ[14]. The densified bales, bound by metal straps together, have an exceptionally high potential for compressive strength. The bales are simple to stack and can, without any additional support, shape wall elements up to 30 meters in height. Their mass of nearly 500kg per unit also provides them with an extraordinary insulation feature. The 1 m walls made of

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[14] PHZ2 - A multifunctional event hall, a pub, and small service rooms were housed in the paper house. It was disappointing that the designers and authorities opted against the extra fire safety that could have been done with special impregnations or sprinkler systems for the bales or the overall house. This absence was due to the building's temporary character, which was expected to be recycled at the end of 2011. The building was destroyed by fire in April of that year. (2011)

corrugated and flat cardboard reveal valued properties, taking into account thermal insulation as well.

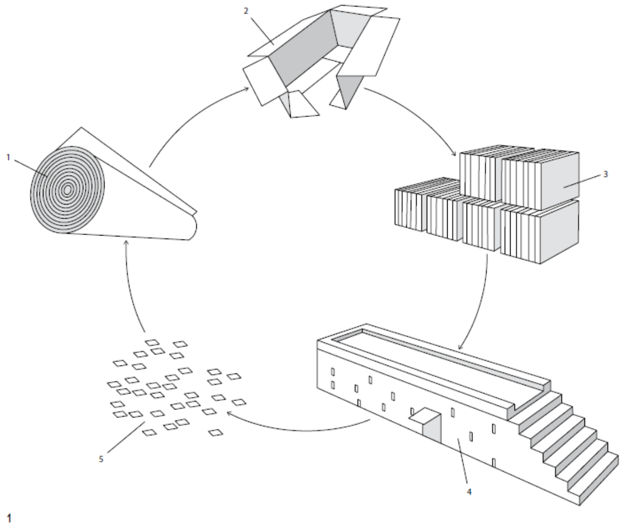

Figure 23 Discarded cardboard scrap recycling strategy: after use, the paper building blocks can be fed back into the process. Source: DRATZ&DRATZ ARCHITEKTEN (2010)

Figure 24 PHZ2 was a temporary structure to house start-up companies at the Zollverein World Heritage Site in Essen, Germany. Source: DRATZ&DRATZ ARCHITEKTEN (2010)

3.3.2 Reconfigured Materials

The arrangement of parts in a certain form, position, or combination is described as a configuration. The definition of reconfigured materials in Hebbel's book is described as "comprise all products where the components of raw waste have been rearranged before being processed into a new construction element" (Hebbel, et al., 2015). In order to change the original configuration of the material, mechanical forces such as sawing, shredding, or breaking are applied to the waste material.

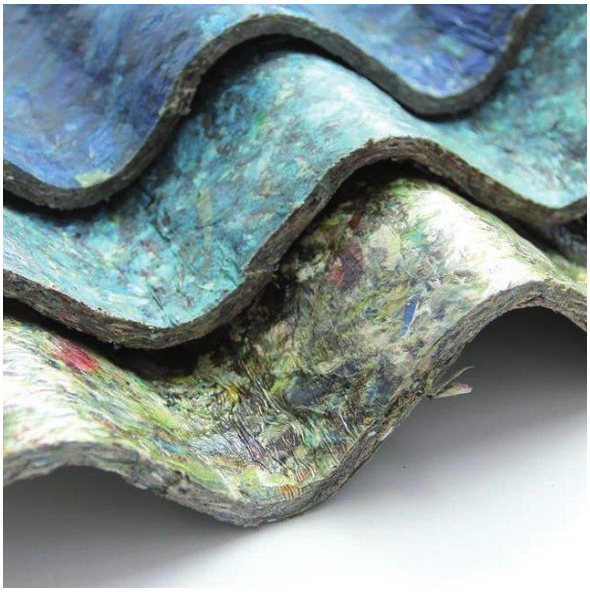

Figure 25 Tuff Roof - a corrugated roofing material made out of reclaimed Tetra Pak packaging. Source: Building from Waste (2015)

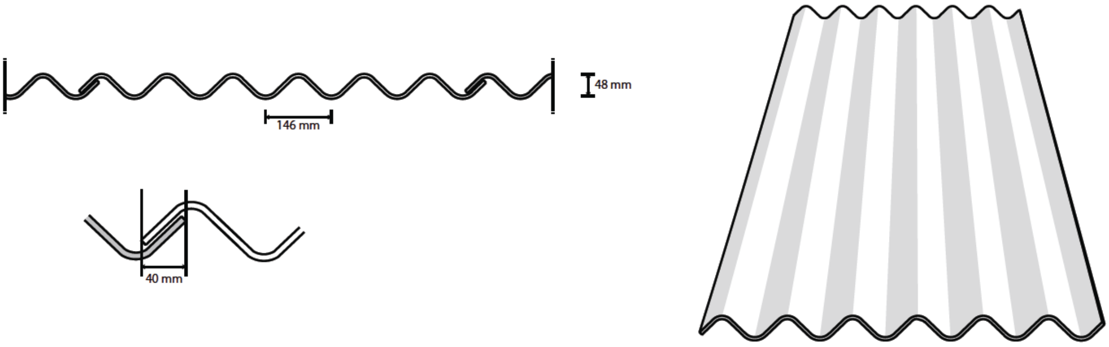

Figure 26 Turf Roof details by Daman Ganga Paper Mill, Gujarat, India. Source: Building from Waste (2015)

The reconfiguration and rearrangement can activate additional product traits not present before while also implying the possibility of changing form, although these traits might not be observed on the original waste material. Once an intended functionality is clear, the process has control over parameters such as weight, density, alignment, or aesthetic qualities.

3.3.3 Transformed Waste Material

Transformed waste intends products which have gone through a transformation of their molecular state. The process can change waste into a new almost unrecognizable product altogether that might have a new shape, form, composition, and function. “Transformation is an alteration of the material state by direct intake or incorporation of other materials or forms of energy from the surroundings – these are typically man-made and come in the shape of mixing chambers or pressure molds” (Hebbel, et al., 2015). Processes such as vitrification (transforming material under very high temperatures into a glass-like substance) the transformation of a substance into a glass-like condition under very high temperatures) can direct us to the answer on how future technology can convert waste products into functional and attractable building materials. New materials can come from hazardous waste without the risk of our health through this method.

Created by the team at ‘New-Territories.com’ The Olzweg project is an allusion to Martin Heidegger’s term “Holzweg” (meaning wrong track) which proposed waste glass as the main material to fabricate building components. Developed for a competition that required the transformation of an ex-military building in Orléans, Olzweg was to become the new Regional Contemporary Art Fund (FRAC).

The project is based on the idea of reusing discarded glass bottles as nearly 10,000 are discarded in the vicinity of the project neighborhood. The glass bottles are transformed into massive rectangular glass bar elements. A Robotic arm that would be specifically installed on-site would then autonomously place those bars to form a thick glass layer extending to the courtyard. The equal glass bars would be stacked on top of each other carefully alternating with 90° rotated bars in order to form a more robust structural configuration. By pulling and pushing through the robotic arms, the configuration of the glass lawyer can change by creating pockets of space. François Roche explains this process of the robot as almost ‘vomiting’ the glass back into the new configuration (Di Raimo, 2014). The reference to a process of the body that is strictly biological and intended for the body to be rid of waste is interesting. Even more interesting how this process creates something intentional and useful.

Figure 27 The Olzweg project proposes to use recycled glass bar elements as the main building material

Credits: new-territories.com (2006)

3.3.4 Designed Waste Material

The futuristic idea that goods that can be specifically designed to never go to waste are discussed during this section. This means that these products can spend their life-cycle continuously being in a constant state of reuse, re-adapting, and recycling, without the necessity to go through one of the processes mentioned above. The original form, traits, and chemical composition are retained during their life-cycle with the ability to adapt and change functions. After these designed objects have gone through their first life cycle their characteristics allow for more uses and life-cycles with different functions. The “take-make-waste” mentality or the linear way of thinking is still a big part of how we behave despite recent growth in environmental awareness. Future cities have long exhibited a zero-waste mentality with architects being called to work and think in a holistic style where future life cycles of the product are designed from the start. Seeing how every product we think of now will be part of the future, the design should always be a sustainable process. Yet this rarely goes beyond the completion or production of an artifact or the completion of a project. The designing of products and architecture can open up new possibilities if the final product is prematurely seen as a resource. This could generate a method where “one design effort generates several projects” (Hebbel, et al., 2015).

The proposal from United Bottles propose a design method the transforms plastic bottles into building elements. The usage of plastic bottles means giving value to a product easily discarded. Without ever limiting the first intended function the new design manages to be prepared for its secondary use (Hebbel, et al., 2015). The design includes an inward and an outward connection that fits perfectly into one another. This allows the bottles to be connected to four other bottles creating a plus like a shape. In theory, this design would allow for an endless constructed wall that does not need adhesive or mortar. In a similar fashion to a regular masonry wall, the bottles link up both vertically and horizontally.

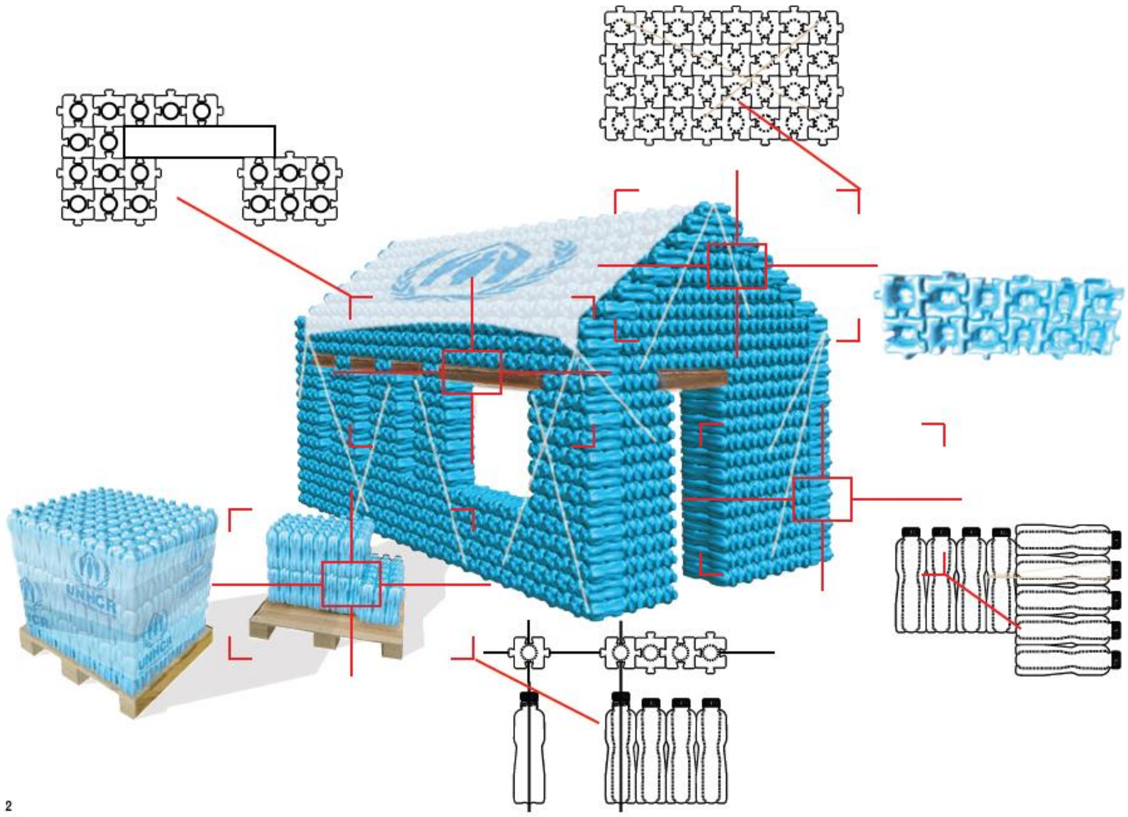

Figure 28 the special design concept of the United Bottle allows a second life cycle of this product as a building. Source: United Bottle group (2007)

Figure 29 United Bottles at the Design Annual Fair in Frankfurt (2007)

3.3.5 Cultivated waste material

“Grow your own house” is a quote that can encapsulate an avant-garde approach in the building industry. Grow in this case would refer to the process of changing the volume or multiplying the particles of a material in the attempt to create building elements. Microelements that were until now considered as hazardous, waste or just unappreciated have made this concept possible. “By contrast, in our understanding microelements belong to a rich resource of new building materials that are not to be categorized as renewable, but as self-growing– an important difference” (Hebbel, et al., 2015). While research has been ongoing for some time now, the building industry is just discovering the potential and value. Following the logic of metabolic thinking, these products can degrade and decompose after their original life cycle bringing important advantages. The second life-cycle sees these products becoming the resource for a new generation or even spanning multiple generations of the material being recycled and recreating itself. Because these materials can be grown in different environments transportation costs can be seriously cut. And since we are still discussing organic materials, it can absorb carbon dioxide during the growth process. Surprising products and transdisciplinary thinking would be the results of considering “Cultivated Waste Materials”. There is little knowledge documented on the usage of bacteria as an advantage during the design of construction materials. They can be adhesives and binding agents in substances that are compact and resilient. ”Here, a huge field of research is emerging, with an incredible potential for the future” (Hebbel, et al., 2015). Oil and gas may be replaced soon by biochemical processes as the primary resources in the chemical industry. Growing your material also introduces a concept that is fairly new to an industry that prioritizes efficiency, and that is growth time.

Hy-Fi, a MoMA Installation is composed of bricks that are made from corn starch and that grow in special daylight mirror filmworks in the shape of blocks. After the deconstruction, the bricks themselves are planned to be decomposed back by a company and utilized as fertilizer and compost further promoting the idea of a building that is fully grown and goes back to the earth through its life cycle.

Figure 30 A collaboration of New York-based architects Hy-Fi is a cluster of brick towers grown from mushroom at MoMA's PS1 venue, source: The Living (2014)

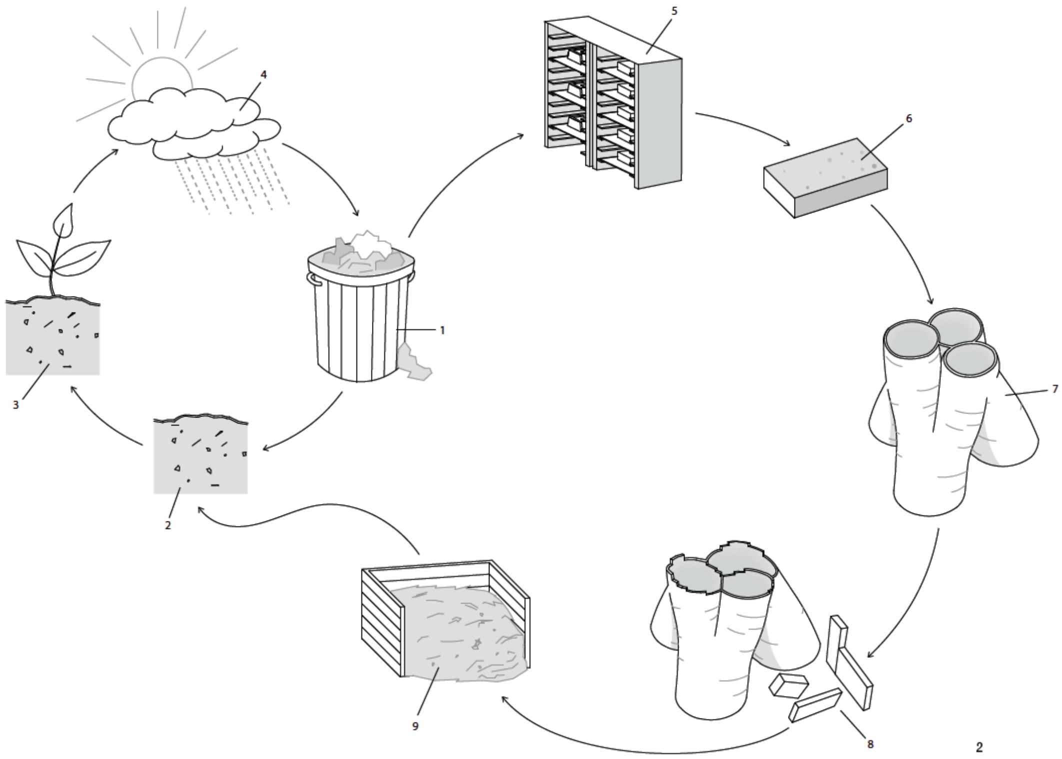

Figure 31 Transformation process from waste to building material and backc to waste. Source: Building from Waste (2015)

3.3.6 Observations

The discussion above was done to further understand the role and current practice in dealing with waste materials today. The bad stigma that comes with waste can be easily overlooked if we start to notice the advantages of costs and repercussions on the environment. By changing the configuration or form of waste, the connection between the user and the previous state of the matter is lost thus allowing for the material to be seen as any other material procured in any other way. Although the examples above show how to deal with collected waste of some sort or how to transform it completely, very few took into consideration the inherent ability of found materials to be reused in the found state. Arguably the best way to deal with future waste, as showed above is to design it out of the product's life cycle entirely when possible.

The methods mentioned above all pose some kind of process and implementation challenges. Most create new industry products altogether that utilize waste and are recycled but also that require long implementation times. Some also require specialized industries. The idea of designing products for multiple uses remains interesting but requires a long process of changing policies and industry shifting. Transformation and compression methods show the fastest approach without changing the products from a chemical standpoint. Production methods are fairly available worldwide also. Alternatively using waste in the found state could be a way to see waste as a resource no matter its condition, thus allowing for a quick process of transforming waste into something desirable. Tools that used to belong to specialized industries are becoming widely available that can aid in the transformation of waste. In this sense, it is important to explore possible ways of transforming recovered materials of waste in their found state as the possibility of quickly transforming it can open up new building processes while promoting concepts of a circular metabolism and extending the product life-cycles.

Table 1 Index of evaluation for some of the projects that use waste during building[15].

	Structural Component	Cover	Informed assembly	Disassembly	Reuse	SCORE (5)
Ubuntublox*	x	x				2
Strohhous*	x	x		x		3
Strawjet*	x	x				2
TuffRoof		x			x	2
Artec Pavilion	x	x	x	x		4
Vault201*	x		x			2
Stonecycling*		x				1
CRT Glass Tile*		x			x	2
Olzweg	x	x	x	x	x	5
United Bottle		x	x	x	x	4
Airless*	x	x			x	3
PHZ2*		x			x	2

Furthermore, analyzing and assessing the current examples can help in identifying weak points and spaces where current practices have been unable to innovate enough. In the book ‘Building from Waste’ a collection of projects (some of which are also shown here) has been created. These projects show the current state of the building industry in transforming waste into a desirable resource. Many of them have different purposes and solutions, such as turning waste into asphalt, but some of them have the potential in becoming building elements. In the table below the projects are assessed and given a score based on a set of diverse criteria. These criteria come from different requirements, from the ability of the new material to be a building element on its own, to its ability to be reused for other processes. The aim is to understand which methods have more applicability in different contexts. They are divided by the application or final result of the transformed waste rather than the method of the waste itself. Some of the projects mentioned below have been illustrated in this chapter. Designed waste products such as United Bottles also score high on this table due to. From the final score of the projects selected, Olzweg scored more than the others. The main difference from all the other projects is the presence of digital tools that drive the process.

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[15] Project with an asterisk have been referenced from (Hebbel, et al., 2015)

4. FROM ATOMS TO BITS

4.1 Introduction

Digital tools have become integral parts of today's architectural practice. One of the most important advances in this field is arguably digital fabrication. Digital fabrication is pretty much what the name implies: a method of making use of digital technology to control the manufacturing process. It uses a machine that computer-driven tools for constructing, transforming, or cutting objects. Digital production is currently often used to build designs as an explorative and feedback tool during the process of design titled Rapid Prototyping. The application of RP for the creation of end products that can function is called Rapid Manufacturing (RM).

Laser cutters already have a large reputation between digital fabrication tools such as 3-D printer and CNC milling machines. These new tools can be fully automated and fully controlled and operated by computers, they also offer a faster and more reliable solution than analog equivalents. As computer-driven machinery actually refers to a very broad concept in both terms used, function of machines (cut, bend, weld, mill, print, etc.) in relation to size and also in terms of price. "The state of the art of digital fabrication machines and their possibilities are discussed in chapter three". (Gershenfeld, 2007).

The general definition of digital production creates a wide variety of possibilities. The combination of a range of modern automated engineering techniques produces a fully operational plant – a Fabrication Laboratory (Fab Lab)[16] - for the typical price of the machine. The notion of integrating high-end industrial equipment to construct infinite possibilities originated from the famous MIT class "*How to do almost everything"* taught by Professor Neil Gershenfeld. The Laboratory breaks down walls between the physical and digital realms. Spreading FabLabs around the globe will empower average people to develop, optimize, manufacture, and test much of their own products. In this method, locals are the first responders to local issues. "As an experiment beginning in 2002, the first Fab Labs went to rural India, Costa Rica, northern Norway, Boston, and Ghana" (Gershenfeld, 2007). Since then, their

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[16] https://www.fablabs.io/ is just one of the many website that help you set up your own Digital Fabrication laboratory while also helping you connect with other labs around the world. A list of supported and suggested machines is available for everyone as well as support as needed.

number has grown exponentially, with more than one hundred licensed laboratories all over the world.[17]

Figure 32 a typical FabLab environment source: FabLab Foundation

Today's range of automated processing machines and their applications are in full growth. “We are now in the minicomputer era of digital fabrication.” (Gershenfeld, 2007). The same author proposes another class called MIT. “*How to make something that makes almost anything*”. The challenge of making better-automated production devices is open-source. “In twenty years we’ll make it so you can have it in the home”, (Gershenfeld, 2007). This evolution somewhat resembles the growth and emergence of personal computers and printers. Four decades ago room-sized computers were the only alternative on the market, with universities and companies being the only ones using them and their cost could go as high as a home. Desktop printers have the same history as they were introduced in 1985 by Steve Jobs with a prize of $7,000. Twenty years later the price of those machines was already 1/200th of what it used to be.

Basic means of development change every few centuries with innovations: “steam, energy, standardization, assembly line, lean manufacturing, and now robotics” (Anderson, 2012). Although these changes have a habit of coming from evolution in organizational methods, technology in this case is having a profound influence. Not only as a driver of the new factory but the computer is also offering the blueprint to make it. The influence in architecture that computer-aided design has had will now

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[17] While the network of digital fabrication laboratories is growing, https://fabfoundation.org/ provides an understanding on how widespread these are. [last accessed on-line 08.08.2020]

be coupled with the capabilities that computer-aided manufacturing can bring. Through digital fabrication, the digital and physical world are tied. Digital fabrication is a mechanism that ties the digital world to the real world. It is the convergence between these two realms that can improve each, generating tremendous opportunity. The next technological revolution is not only about new methods of producing tangible objects, but also about new ways of communicating, exchanging, selling, and funding.

There is no lack of far-reaching young writers and scientists when it comes to the next technological revolution. Research funded under the jurisdiction of the British Government: “Bridging the Digital and Physical worlds’ it was stated that long-accepted business models are being blown apart”, (Danveport, 2011). Chris Anderson writes in the closing chapter of his 2012 novel, *Makers*, that “the next industrial revolution creates a billion little entrepreneurial opportunities that can be discovered and exploited by smart, creative people”, this contributes to: “more innovation, in more places, from more people, focused on more narrow niches. Collectively all these new producers will reinvent the industrial economy” (2012).

Figure 33 Maker space at Westport Library in Connecticut. Source: Zdnet.com

4.2 Democratization of Production

4.2.1 Consumers before, producers now

Chris Anderson during an article in Wired Magazine entitled “In the Next Industrial Revolution Atoms are the New Bits” depicts the simplicity in which anyone can be an inventor and prototype or manufacture his own idea. “Here’s the history of two decades in one sentence: if the past 10 years have been about discovering post-institutional social models on the web, then the next 10 years will be about applying them to the real world”, (2010). Software and hardware are becoming more similar and grown more powerful by merging and enhancing each other. The potential of democratization is unleashed in our physical world from our digital world. “The Internet democratized publishing, broadcasting, and communications, and the consequence was a massive increase in the range of both participation and participants in everything digital — the long tail of bits. Now the same is happening to manufacture — the long tail of things” (Anderson, 2010).

Small factories have the capability of building components of design objects like bicycles or furniture that come in any shape or form. Financing and tooling are cut out from the process due to ideas moving directly to production. Web start-ups were originally composed of just a personal computer and two members and nowadays a hardware company can have the same composition. “When the cost of high-quality resources for design and prototyping becomes very low, these resources can be diffused vary widely, and the allocation problem diminishes insignificance. The net result is and will be to democratize the opportunity to create”, (Von Hippel, 2005). This prediction is quickly becoming a reality as the invention of some web-based tools and digital fabrication devices has made leaps forward.

In a similar fashion to how desktop printers made possible the ability to create entire pressrooms in our houses, new desktop versions of machines that can digitally fabricate goods open up previously exclusive high-tech methods available to everyone’s desktop. The open-source MakerBot is the first 3-D printer with an affordable price tag. It utilizes a fused deposition modeling (FDM) method which extrudes melted plastic wire. Although undergoing years of improvements the layers of Makerbot 2 still could only achieve a minimum layer height of 0.1 mm. This resolution can be acceptable for prototypes but falls short of standard product quality.

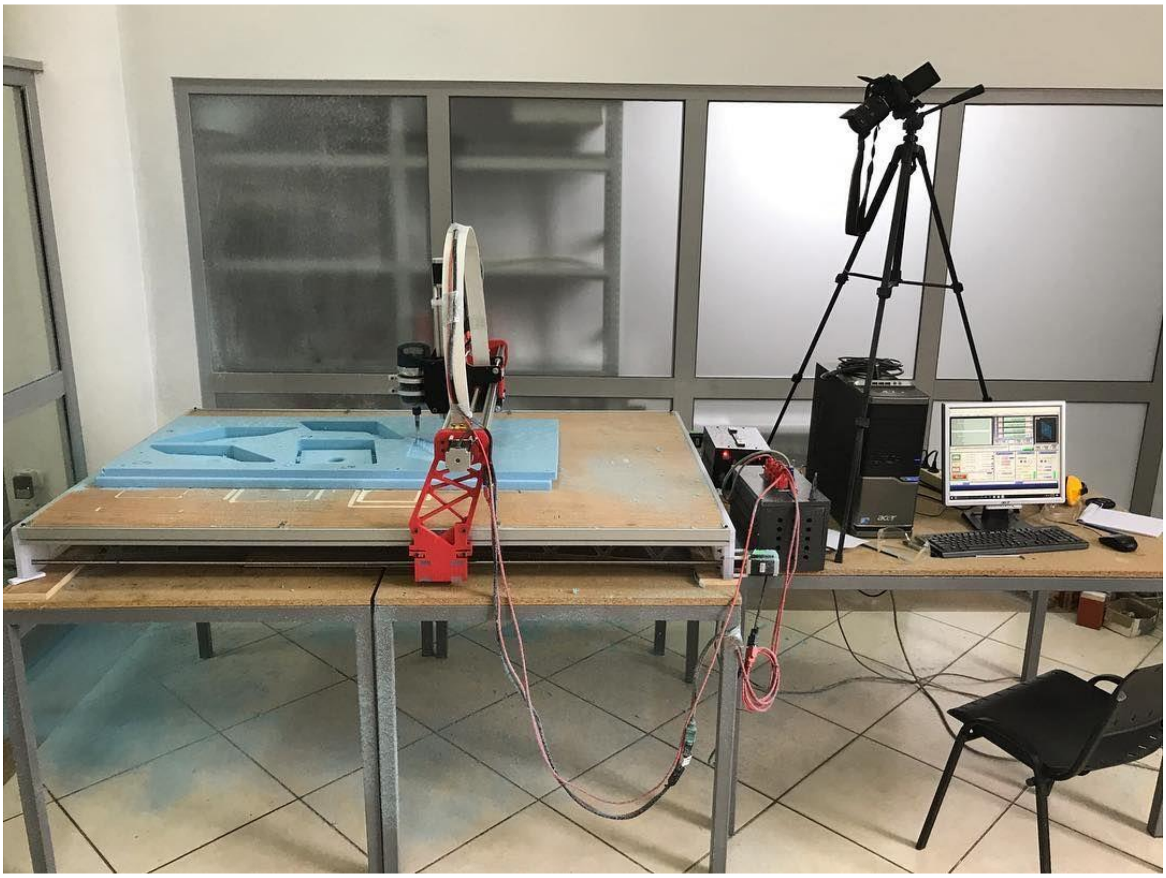

Figure 34 Open Source CNC Machine at Polis University. Photo: Author

Form 1 which is priced at $2500 was intended by design as a personal and small business printer. It uses a Laser Sintering (LS) method which is based on the usage of light to change the state of matter of a liquid into a solid-state. Some of the highest precision in the industry is achieved through this technique. The minimal layer height of Form 1 is 0.025mm. This means that factory quality is achievable from a desktop.

3-D printers are just the tip of the iceberg in a line of professional digital fabrication tools under development and research in order to allow non-professionals access to these tools. Their price point has been set to only a fraction of their predecessors attracting even more opportunities. In order to make it available for non-professional practitioners, the whole range of fabrication equipment is aiming at lowering the costs of the machines to attract a broader clientele[18]. They are priced at only a

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[18] *Some successful personal fabrication projects are Buildlog, LaserSaur, Build Your OwnLaser (all laser cutters), ShapeOko, DIYLCNC (small CNC routers), BlackFoot, Kikori (large CNC routers) and RedFrog (a pick and place machine) .*

portion of what their professional counterparts were priced before. More interesting these machines are often sold as DIY kits with parts 3D-printed themselves.

Figure 35 Makerbot Printer, Source: http://www.makerbot.com

Democratizing the opportunity to create through digital tools by putting these machines on every desktop is just one of the methods. FabLabs and Shared Maker Spaces around the globe is based on the idea of providing high-end fabrication tools virtually everywhere. This can lead to the creation of local focal points where fabrication spaces can be shared. The time of usage on the machine can be charged instead of large sums for the machine itself. Communities can be created naturally around maker spaces were sharing and evolving knowledge and inspiration becomes an added value.

Another method where the tools can be shared among the users is offering a service where the machine is ‘rented out’. Digital fabrication tools can be made available this way to users that do not have either the time or knowledge to operate this hardware. Users can directly send their files to the producers and have the product ready in just a few days. An internet connection is all that is required to be connected to these factories. A fair comparison would be online print services for photos where the quality and possibilities exceed that of a desktop printer. Examples such as Shapeways, Ponoko, or MFG.com who are not the owners of their production machinery but instead they lay out the software and connection between consumer and fabrication shops. Small scaled fabrication services are offered at Ponoko that has largely focused on the consumer portion of the market. MFG.com has been offering a similar service but targeting companies while offering a larger selection of fabrication tools, including analog tools. Although used mostly by small companies it is still considered as the world’s largest fabrication online marketplace. Emerging as a spinoff from the known company of Philips, Shapeways has opened 3-D printing factories boasting high-end machinery in New York. Smaller alternatives to these companies do exist and take a more local role while also extending these services to electronic and circuit boards production or ceramic 3D printing.

The democratization of fabrication tools has been accompanied by change also in traditional fabrication techniques. For example, not longer than a decade ago in the requirements of fabricating a product in China required social connection and a very large quantity of production. Access to China’s fabrication scene has been made widely available now by websites like Alibaba.com were buying any quantity of any component of the part that has been made easier than ever.

“Anybody with an idea and a little expertise can set assembly lines in China into motion with nothing more than some keystrokes on their laptop. A few days later, a prototype will be at their door, and once it all checks out, they can push a few more buttons and be in full production, making hundreds, thousands, or more. They can become a virtual micro-factory, able to design and sell goods without any infrastructure or even inventory; products can be assembled and drop-shipped by contractors who serve hundreds of such customers simultaneously” (Anderson, 2010).

Accessible and user-friendly digital tools are also part of the democratization of the production domain that is in no way only focused on the hardware. Sharing the same importance as the process of fabrication we also have to take into account the phases of design, optimization, sharing, marketing, and distribution of the product itself. The Kickstarter platform is an entrepreneur's dream come true. It allows people who have good ideas to seek out financial support from individual funders who share or believe in their idea also known as crowdfunding[19]. Accepted ideas by Kickstarter can range from artistic projects to entire new inventions and physical products. If the project fails at achieving its goal it is disqualified from receiving any of the pledge money. This model is presented as more than just a simple new

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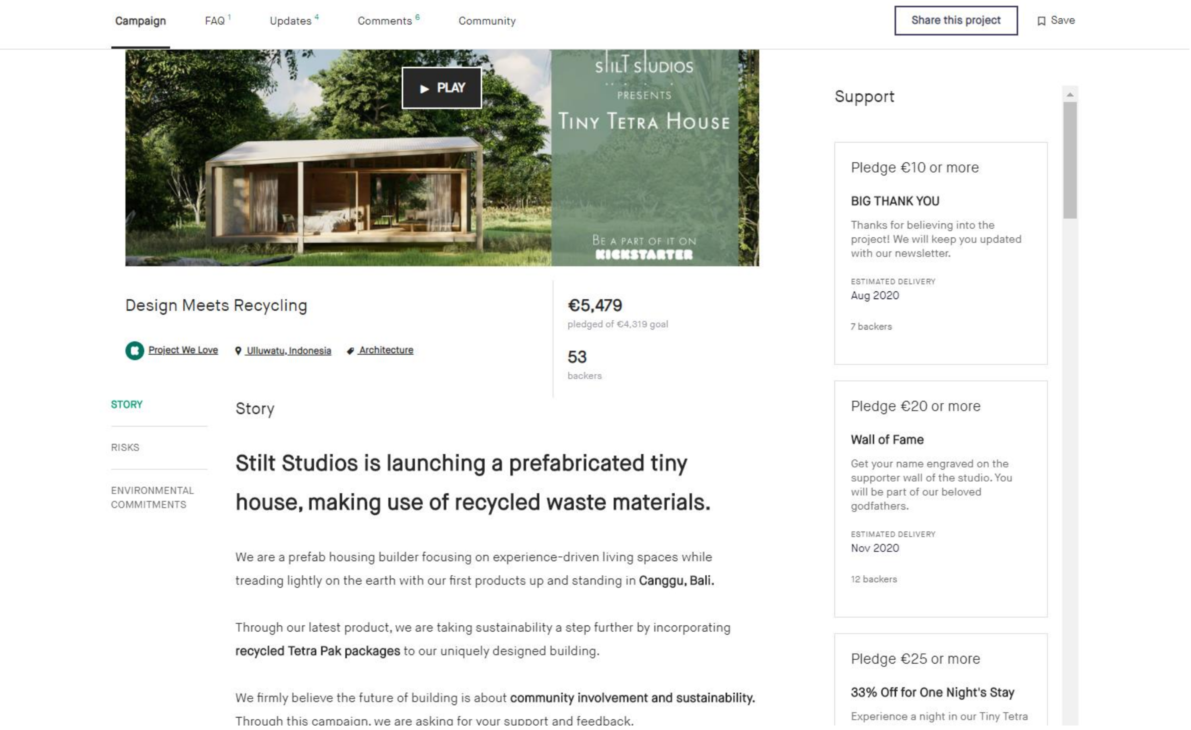
[19] *Crowdfunding - the practice of funding a project or venture by raising money from a large number of people who each contribute a relatively small amount, typically via the Internet.*

financial system but it allows users to purchase or commit to a project before even being made. Customers in this shift from being consumers to becoming a source of revenue, marketing, and even ideas.



Design Meets Recycling

€5,479
pledged of €4,319 goal

53
backers

Story

Stilt Studios is launching a prefabricated tiny house, making use of recycled waste materials.

We are a prefab housing builder focusing on experience-driven living spaces while treading lightly on the earth with our first products up and standing in **Canggu, Bali.**

Through our latest product, we are taking sustainability a step further by incorporating **recycled Tetra Pak packages** to our uniquely designed building.

We firmly believe the future of building is about **community involvement and sustainability.** Through this campaign, we are asking for your support and feedback.

Support

Pledge €10 or more

BIG THANK YOU

Thanks for believing into the project! We will keep you updated with our newsletter.

ESTIMATED DELIVERY
Aug 2020

7 backers

Pledge €20 or more

Wall of Fame

Get your name engraved on the supporter wall of the studio. You will be part of our beloved godfathers.

ESTIMATED DELIVERY
Nov 2020

12 backers

Pledge €25 or more

33% Off for One Night's Stay

Experience a night in our Tiny Tetra

Figure 36 Interface of Kickstarter project by Silt Studios, Tine Tetra House which uses recycled materials in the construction of their solution asking for crowdfunding. Source: Kickstarter [last accessed on-line 22.08.2020]

“So while the rest of us are having our heads turned by the latest buzzy social media thing, sites like MFG.com are quietly going about their work of turbocharging the world’s real economic engine, making stuff faster, cheaper and better”, (Anderson, 2012). So this new movement is not just about the tools of digital fabrication that have been available for decades (some) but also about the availability of these tools to the public. It presents itself as a new shift in the current practice and in the current consumer world where they are transformed into producers where the possibility of being anything from a producer of energy to a producer of products is enhanced further by a network of shared knowledge and devices. While consumption was democratized during the 20th century by the Fordian assembly line, in the 21st century we can finally democratize the production and information of physical goods. While the 20th century was characterized by an up-scaling and globalization trend, our century looks at doing the opposite. Sharing of knowledge and ideas on a global level will thrive with local mass customization and production of goods.

In 2000, 40% of global assets were under the ownership of the richest 1%. As a comparison, only 1% of global wealth was owned by 85% of the adult population (Davies, 2006). Economic power has been in the grasp of companies that have to lead the market for years. This new movement has an incredible potential of spreading this power and giving it back to the 7 billion people of the world. The nature of the economy can be fundamentally redefined. “Transformative change happens when industries democratize when they’re ripped from the sole domain of companies, governments, and other institutions and handed over to regular folks”, (Anderson, 2012)

4.2.2 Taping on the talent potential

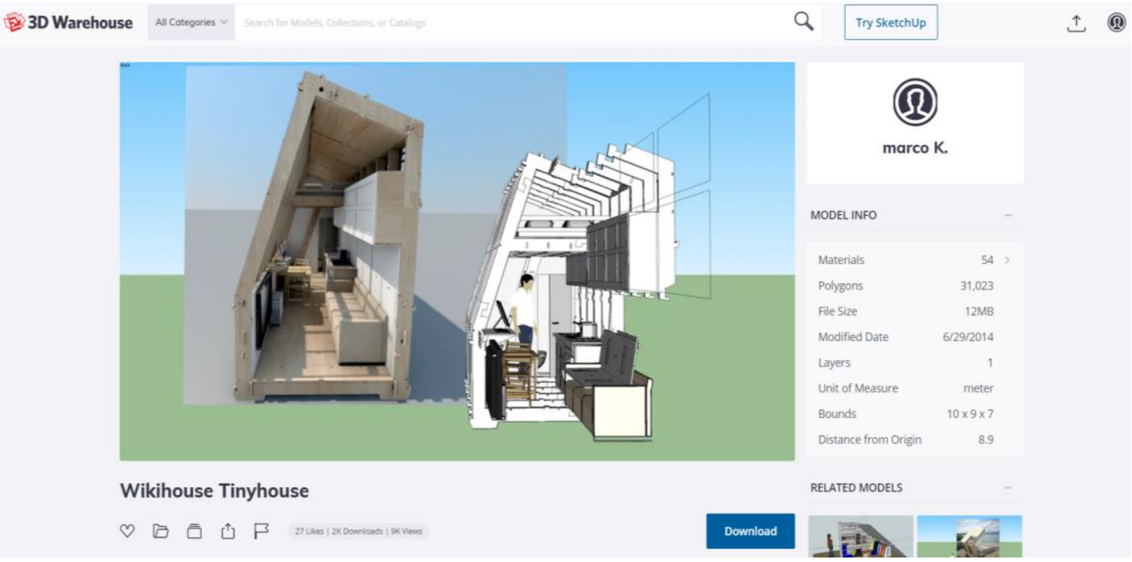
“Build a better mousetrap and the world is supposed to beat a path to your door. It’s a lovely thought, one that has inspired generations of American inventors. The reality, though, has fallen somewhat short of this promise: Build a better mousetrap and, if you’re extremely lucky, some corporation will take a look at it, send it through dozens of committees, tweak the design to make it cheaper to manufacture and let the marketing team decide whether it can be priced to return a profit. By the time your mousetrap makes it to the store shelves, it is likely to have been fine-tuned and compromised beyond recognition”, (Adler, 2011).

The social elite however is not the target of the next industrial revolution. Ideas can be shared by everyone that has enough talent to present innovations to the current scene. Whether or not the inventor holds a degree or is reputable, his ideas will be valued. This method can exploit more talent than ever before. Chris Anderson defines this hidden talent as “Long Tail of Talent” and says: “In many fields, there are a lot of people with skills, ideas, and time to help than there are people who have professional degrees and are otherwise credentialed. Exposing this latent potential, both of professionals looking to follow their passions rather than their bosses’ priorities and of amateurs with something to offer, is the real power of open innovation”, (2012).

4.2.3 Democratization of architectural innovations

It will not take long for amateur designers to be equipped and empowered by the same high-quality tools and hardware that professionals use in their designs. The role of architects will be changed from the influence of these new emerging technologies. This may sound threatening to professionals who have claimed ownership and control over these tools before. Although designers do have the potential to not only keep hold of their position but also enhance the process of design through the reformation of the design process altogether. While the design may not necessarily look different, the process behind it will inevitably see an overhaul. Studies have estimated that about 90% of the architecture around the world is built without the supervision of an architect through even the design process. Especially underdeveloped countries have shown that architects are an unaffordable luxury and decide to build without a design or consultancy from an architect. Even home renovation tasks are quite often done individually.

DIY production will receive improvements and enhancements from new tools that are web-based in combination with digital fabrication machinery. An empowering ability to directly affect the physical world around will catapult users forward and spark their creativity. Web-based tools such as the IKEA Kitchen builder could become the IKEA Office Builder as their ready-to-assemble products already are delivered as flat packages virtually everywhere. Sketchup, a free design software created by Google and later bought by Trimble can add plugins that can transform a rough 3-D model into the complete building information needed to fabricate and assemble. Wikihouse has already achieved this in away. Companies like WikiHouse offer an open-source solution that can inspire open-source hardware users in order to design, adjust, control, and print your own house. And while it may have started with just a few people printing novelty design items, it fully has the potential to empower everyone in the process of fabricating essential use items and even buildings.



Materials	54
Polygons	31,023
File Size	12MB
Modified Date	6/29/2014
Layers	1
Unit of Measure	meter
Bounds	10 x 9 x 7
Distance from Origin	8.9

Figure 37 Downloadable 3D model that also has the construction information available, allowing anyone to download and build their home. Source: 3D Warehouse and Wikihouse

Simultaneously, through these new tools, architects are given the possibility to claim agency over these tools but to also expand their influence to the 90% that currently overlooks architects in the design and creation process. A professional architect can still offer on average more knowledge and quality than amateur builders. Quality can be improved while empowering the innovation required in facing new challenges.

The typical role of the architect as well as the architect-client relation will be overhauled. As a one-off solution will not cut it anymore, architects will be available to design and propose a while new architectural solution range. Users will take a more important role in the design process. Fees for the service of the architect can change and finally be affordable for a wider range because they are able to propose multiple design solutions with less effort. A diminishing exclusivity of design will be noticed. The exclusivity of the act of designing will disappear. The skillset of architects must be expanded in the design of solution ranges while putting more effort into the process of the design rather than a single product. Clients will increase their centrality in the value chain as they shift from being just a simple source of revenue to a source for more solutions and investments.

Even architects who have been involved continuously up until now can see their role change in a multiplicity of ways. The role in the 10% fraction of architecture that architects have been involved in it can also change in various ways. Small scale projects such as housing and small offices will see the influence of architects decrease by the non-professionals as mentioned above. More complex building typologies that require far more expertise will most likely remain the domain of these architects as the complexity of these projects often proves a challenge even for experienced architects. The last decade has seen these projects increase in complexity and difficulty mostly due to demanding clients and stricter rules. Here it’s visible that the more specialized professionals gained control of these projects over amateur designers. Innovation in the 21st century will entail an innovation-focused instead on the process of design and making by incorporating new technologies and cultural changes and different challenges.

Figure 38 Gehry's Walt Disney Concert Hall (2003) demonstrates how buildings have become increasingly complex and non-standard. Photo: Khalid Salih

4.3 Mass Customization

Mass production and repetition do not have to be the norm for our industries anymore. Quantity does not guarantee cost-effectiveness when working with digital fabrication tools. While avoiding serial production, technologies such as CNC-milling or waterjet cutting can still achieve high quality while containing the costs of production. “It is just as easy and cost-effective for a CNC milling machine to produce 1000 unique objects as to produce 1000 identical ones” (Kolarevic, 2003). Production of singular and unique objects is made as efficient as the production of linear and identical ones through the support of digital design and a digital supply chain that is flexible and adaptable. While before we accepted repetition as the basis of the economy, this new flexibility empowers mass-customization.

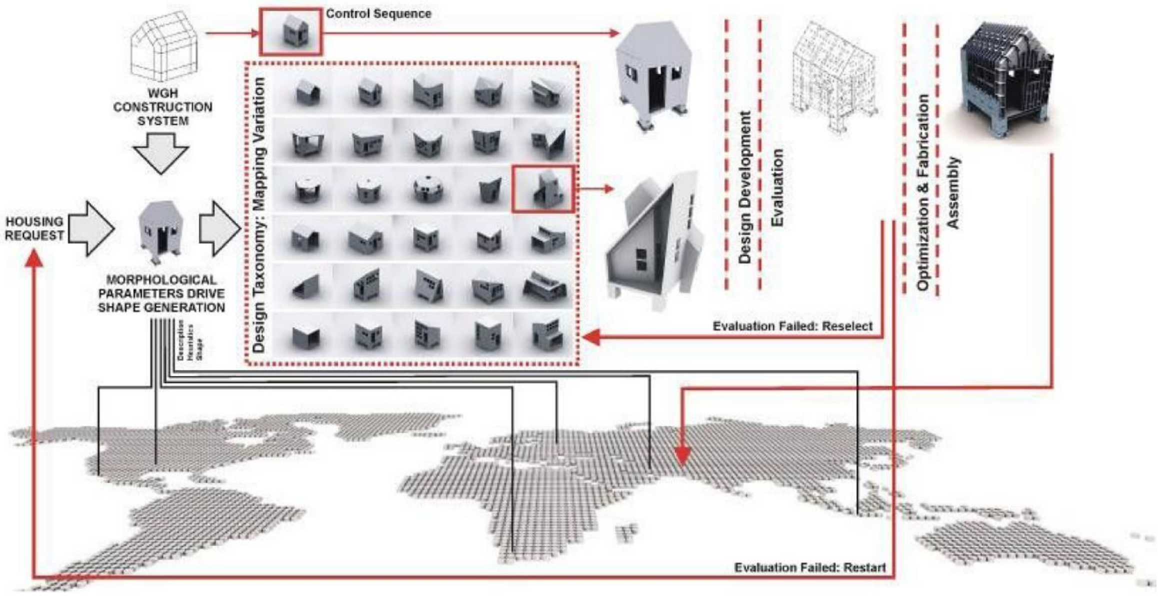


Figure 39 Mass customization of a house design, where each solution is buildable and can quickly generate drawing materials. Instant House by Marcel Botta (2005)

4.3.1 Possibilities of mass-customization

Principles of mass customization advertised and now found in the consumer product industry will expand to the construction and building industry too. As architecture has a clear relation and specificity to context and parameters such as climate, culture, site conditions, personal preferences influence the design, it is quite logical to want to apply mass-customization. Present discrepancies that vary in the macro or micro scales work naturally against the concepts of repetition. Good architecture and diversity go one with the other. Highly customized buildings, designed specifically to client needs and context are already found but until recently automated processes and this highly customized architecture was impossible to be linked in the same process. Mass customization as a system of production should be coupled with a process of design that allows similar differentiation. Terry Knight expanded by saying “there is a demand for that (digital frameworks for mass customization) now in architecture firms because we need to have designs that will be suitable for different contexts but are within the same general family. So we need to produce a Meta design that we can adapt to changing circumstances. I’m convinced that this is the wave of the future”, (2003).

The outcome could present itself as an architecture that completely fits the conditions of its context and accomplishes the preferences of the users. The shape of photovoltaic panels can be made in a manner that can harvest the energy of the sun at the highest efficiency. Personal preferences can shape the floor plans without adding any costs. Non-standard building shapes can have customized envelopes without the need for additional manufacturing and new cities could resemble more a natural forest, where every tree comes from a family but they are all unique.

When a small budget is an issue, clients will no longer be confined to catalog choices but can tap into the same flexibility that a client-architect process would allow them without the additional costs. High-quality architecture that is built to fit everyone’s requirements will become available for a larger audience. The Embryologic Houses that Greg Lynn’s (2013) designed to pose a great example of mass-customized individual housing units that are achieved through a parametric variation and produced through digital fabrication.

As the costs are shared between more individuals the quality that can be offered to clients is increased. The principle of sharing design costs between different industries has been applied since the first industrial revolution. If cars were produced in batches of just one, the costs would be extremely high. As the production is instead in series, customers actually share the quality price and innovation. We are finally looking at a new sector that embraces principles of sharing in a serial process by combining them with the capabilities of customizable single batches.

Figure 40 The Embryological Houses, generated from a parametric model of differentiation. Credits: Greg Lynn (1999)

There are also drawbacks that come from the possibility of customizable designs instead of opting for one time solutions. As more solutions will be adaptable from the get-go to different places, fewer architects will be able to design which can lead to an increase in unemployment. Designing a series of customizable solution can extend the role of architects to the 90% that currently does not need them. The question of whether the latter can make up for the first arises. Numbers show a story where the amount of work available for architecture is increasing and will increase: "By 2030, the population of the world living in cities will have increased from 3 to 5 billion, with 2 billion of these living below the poverty line. The problem the world needs to solve is to build a 1-million-inhabitant city per week for the next 20 years for $10,000 dollars per family" (Aravena, 2011). This new demand will require an incredible amount of resources in order to satisfy and while we can build faster thanks to new tools we also need to figure out how to build.

4.4 Local Production

During the first years, the application of digital fabrication in the industry proved profitable only for bigger companies that owned expensive machines for productions of large scale. That changed in recent years when CNC machines were designed and downscaled in order to allow more uses and to fit in more scenarios. One of those scenarios is the application of these machines that have become ideal for small-batch manufacturing lines able to fit into personal workshops or just controlled by individuals. Productions of small scale eliminate the need to have large factories where products are fabricated and shipped around the world. The shipping in this case happens at light speed and only in the form of information and digital data. Digital design can have a global agenda while physical production can remain local and rooted. “Flexible manufacturing has become the wave of the future. And better yet, networked, flexible manufacturing shows great promise for breaking through the walls of the old corporate system and becoming the basis of a fundamentally different kind of society” (Carter, 2010).

Pre-industrial era workshops were located close to their customers and these digital factories can do the same. Production through CNC cutting is more advantageous towards traditional craft due to its flexibility, reduced costs, and closeness to the client. Open-source or Semi-open-source design principles can be applied to these modern factories connecting them in a shared network with each other. Large scale factories will still be able to produce cheaper products when compared to local workshops or home printers. Costs of administration, interest, distribution, marketing, and so on are often left out of the large-scale process manufacturing. If we take those factors out then the costs can be comparable to each other.

Due to the size of buildings, the decentralized system of production is often more favored over the centralized production as costs of infrastructure and delivery systems which are usually high can be eliminated. On the other hand for small-sized buildings, that can be considered a one-off, digital fabrication can offer a flexible production strategy. Differentiations in the design can be obtained by introducing local parameters such as climate, surroundings, materials, and preferences. Local interventions in design can be made easier if design and fabrication are found in the same context as the client/user. This process is reminiscent of traditional construction methods where materials are transported on-site and workers use analog tools to transform the material into a building.

Figure 41 On-site fabrication CNC router created by FACIT homes. Credits: FACIT Homes

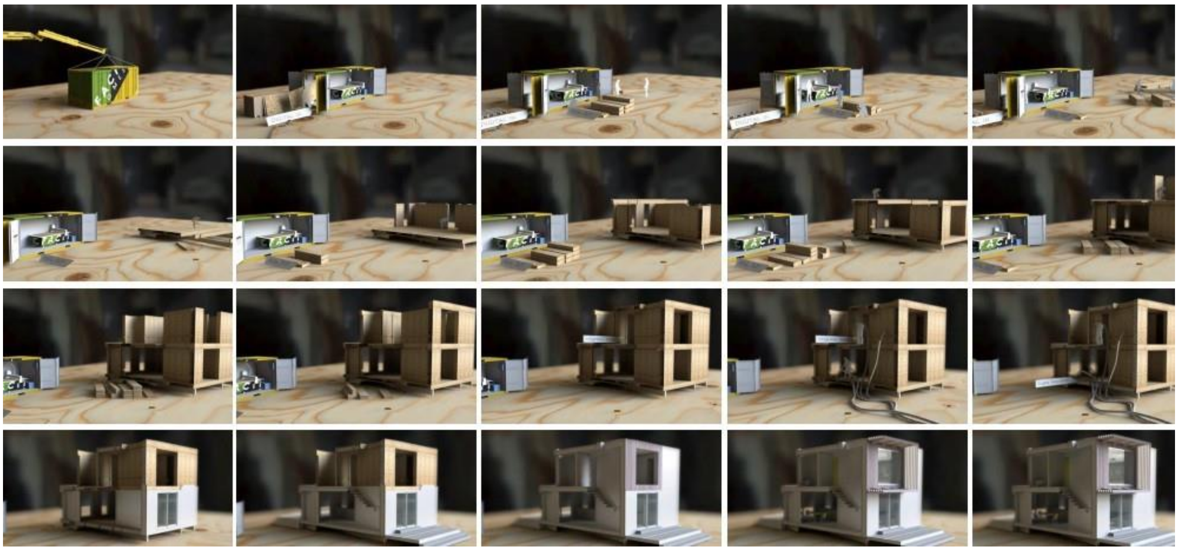


Figure 42 On-Site fabrication process where materials are collected and fabricated through a mobile unit containing a CNC-Router. Credits: FACIT Homes

4.5 Open-Source Collective intelligence

4.5.1 Open Source Hardware

“We’re just finding so many people with such interesting inventions and such great ideas, sharing that is where I see this going” (Gershenfeld, 2007). There is a direct link between atoms and bits that facilitates digital sharing. As digitally fabricated objects will have only digital information it can only be sent over the World Wide Web. While processes of fabrication can be local, on your computer, or in the digital workshops, the knowledge can be shared, developed, and improved as a global common. Design blueprints will become equivalent to sharing music files and PDFs. Successful software like Linux or Firefox was developed with the open-source principles in mind. By joining the physical and digital world through digital fabrication the opportunity to of hardware that can be defined as open-source is created. “Open source software projects are object lessons that teach us that users can create, produce, diffuse, provide user field support for, update, and use complex products by and for themselves in the context of user innovation communities”, (Hippel, 2005). The development of physical products is democratized through Open-source hardware. Benefits of open-source-hardware include the ability to utilize any form of design intelligence, either coming from professionals or amateurs.

If the innovation of knowledge is owned, then sharing faces that knowledge becomes impossible. Ideas that have been long outdated about intellectual properties serve to slow down the expansion of innovation. Some items can have lasting copyright of over 100 years and although this is a long time, some ideas need to be copyrighted in order to compensate the original creators. More vital innovations in the fields of medicine or clean energy however can be shared with people unable to afford it and sold to companies that can easily pay the price tag. An alternative to normal copyright laws could be to reserve the rights for a shorter amount of time or make only some right that can be reserved while others are freely shared. As an alternative, exclusiveness to only some rights can be given or the length of time could be shorter. Creative Commons (CC) licenses allow ideas to spread without added fees while also preventing others from drawing profit from ideas that have the CC licenses.

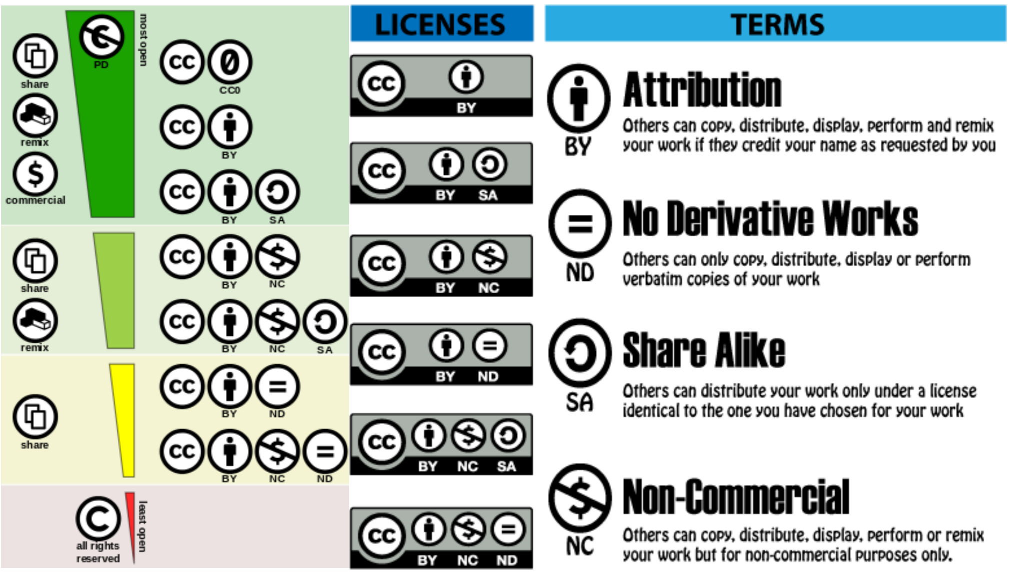


Figure 43 Creative Commons and how it works, Source: https://libguides.longwood.edu/copyright/creativecommons

4.5.2 The Open Source Business Model

While service industries seem to have gained from the new digital tools, our manufacturing industries look more unhinged by the changes. The potential that bits propose has been, in large part, ignored by businesses that create physical products. As Chris Anderson argues during his 2012 book, Makers, during the next industrial revolution we will see an even narrower gap between hardware and software companies:

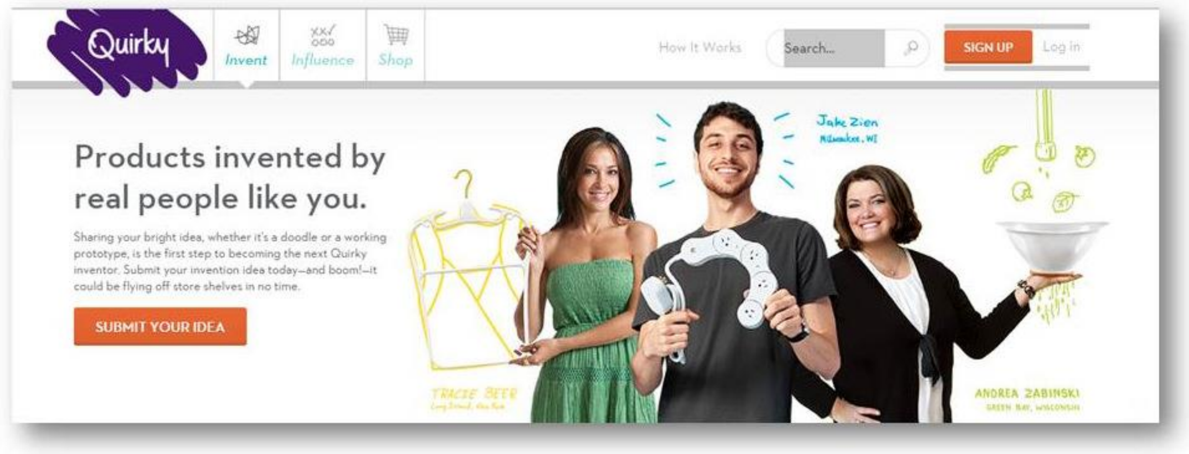
“At its core, the new manufacturing company has to incorporate all the skills and learning of traditional manufacturing companies – tight quality control, efficient inventory management, and supply-chain management – so that it can compete with them on a basic price and quality. But it also needs to incorporate many of the skills of Web companies in creating and harnessing a community around its products that allow it to design new goods faster, better, cheaper. In short, it must be like the best hardware companies *and* the best software companies. Atoms *and* bits”, (2012).

Three ways are presented by Erik von Hippel on the capacity of manufacturing industries to tap into the capacity of users in product development (2005):

1. Produce user-developed innovations for general commercial sale and/or offer custom manufacturing to specific users.
2. Sell kits of product design tools and/or “product platforms” to ease users’ innovation-related tasks.
3. Sell products or services that are complementary to user-developed innovations. Firms in fields where users are already very active in product design are experimenting with all these possibilities.

A start-up that is able to combine the potentials of hardware and software companies in one single business is Quirky. All their products receive contributions from every user through voting on differentiations to proposing other solutions. Submitting an idea costs about 10$ and each idea is voted upon by the community. During the design phase, professionals from Quirky and users contribute by discussing and voting on features and variations of the product. The last step is making the design manufacturable which is a process handled by Quirky's engineers and putting it on the market. Lastly, compensation is sent and given to everyone that contributed to the process, with the original creator able to earn thousands of dollars. Everyone in this process gets paid; for most of them it’s just pennies, but the original inventor can earn thousands of dollars.

Anderson’s argument notices how this business model uses the long tail of things in an interesting method: “The whole feels like a game. You don’t need to have any ideas of your own to participate and feel as though you’re helping create things, or at least improve them. And it suits everyone from words people (names and taglines) to visual thinkers (design). Top influencers participate in dozens of projects and can earn thousands of dollars. It can be addictive, they report. Partly it’s the act of improving ideas, but equally, it’s the gamble that the product you vote for will ultimately be made and become a big hit” (2012).



Products invented by real people like you.

Sharing your bright idea, whether it's a doodle or a working prototype, is the first step to becoming the next Quirky inventor. Submit your invention idea today—and boom!—it could be flying off store shelves in no time.

Figure 44 Quirky Website banner, Source: https://quirky.com

Figure 45 Global Village Construction Set. Source: https://www.opensourceecology.org/gvcs/

Founder of Open Source Ecology, Marcin Jakubowski became dissatisfied with his scientific career and decided to change his focus to farming and social innovations. Based in rural Missouri, this project envisioned creating the Global Village Construction Set, which put simply is a large blueprint for simple fabrication of everything required to start for a village that can be self-sustaining. A variety of industrial machines are fabricated through simple methods of and made available through a platform that advocates for low-cost and high performance, do-it-yourself machinery of 50 different types. Marcin Jakubowski states that through open means of production our lives can become self-sustaining without the sacrifice in living standards.

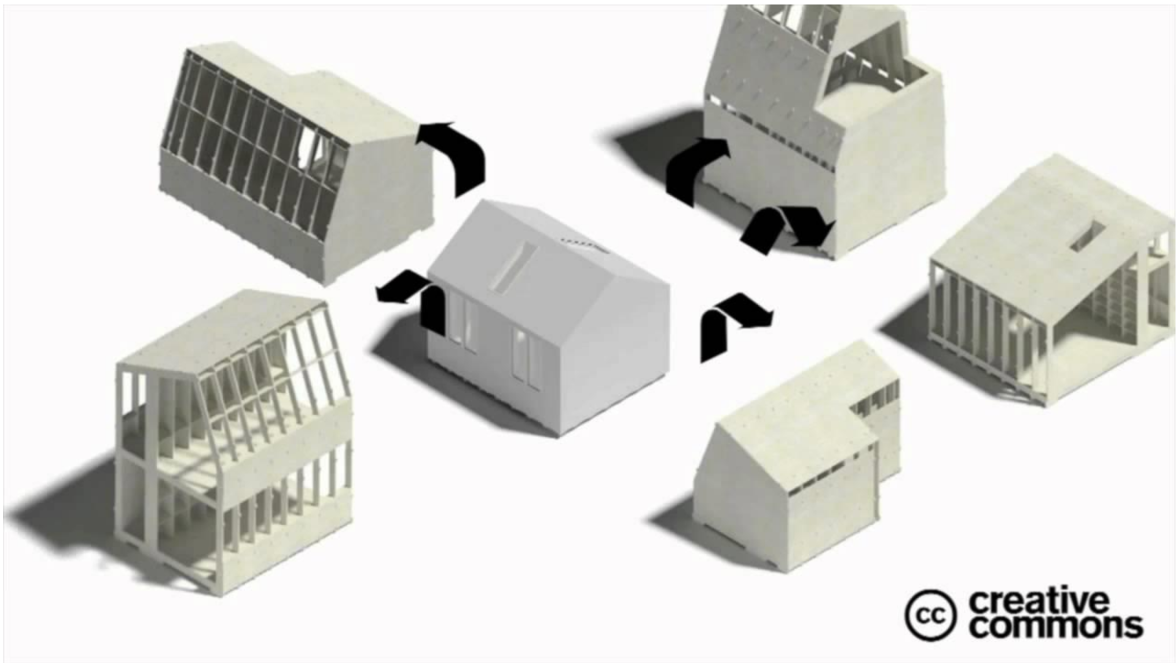


Figure 46 Wikihouse building system variations. Source: Wikihouse

Wikihouse is an open-source building started by Alistar Parvin and a team that aims at providing resource-light sustainable dwelling that can be digitally fabricated. Its main aim is to allow for an open-source architecture by giving users the tool to freely edit the design while the construction information is generated through their software. Theoretically, this function is a blueprint that anyone can download and manufacture through digital tools, creating a big IKEA set of construction elements that fit into each other through friction-based joints. Electrical systems and plumbing would use CC licenses in order to cut costs for users.

4.5.3 Potentials in Architecture

Sinclair's Open Architecture Network (OAN) emerges when thinking about the relation that architecture can have to open source. He presented an award-winning idea which advocated for knowledge sharing of humanitarian projects as some of the world's greatest problems can be solved through the work form of an Open Architecture Network. "The large-scale disasters we face are so profound, their momentum so fierce, that unless we put to use the energy and creativity of every person of goodwill, we cannot possibly overcome them" (Sinclair, 2011).

Although the idea shows a great premise, there are major flows still available

1. In OAN, designs are specific to cultures, material stock, clientele, and site context as well as climatic. This limits the relevance that it can have on other projects. The collection that of solutions that can be applied only once should be changed by a set of adaptable projects and spaces that would have more value. OAN lacks this sense of how efficiently it makes use of the potential of the new digital tools.
2. Learning from past experiences and old designs is an underlying idea behind OAN. The current model however still needs more iterations built of similar projects in order to build this shared knowledge. The contribution is all but impossible in AON as interested parties can over give basic feedback of either positive or negative but lack the means to contribute with ideas. If users could contribute with their ideas, the projects would be able to take advantage of the tools and build knowledge coming from the entire community. The evolution of the projects becomes next to impossible in this way.
3. The documentation of the projects of OAN, in the end, remains unsatisfactory with non-standardized drawings and often incomplete, making reproduction very difficult. Documentation is maintained only in the form of some project data and rasterized drawings. The link of digital information and physical product can be strengthened through digital tools but this will require that the construction information be embedded into and included in the form of blueprints.

Working with both amateur and professionals can combine the best of both sides while also enhancing designers in the process of construction and architecture. The individual nature of architecture beforehand does not necessarily fit into the opportunities created by digital tools. The spread of innovation and empowerment of future makers can shape the required changes to overcome the coming crises.

4.6 Design and construction integration

4.6.1 The changing role of the architect

"For centuries, being an architect also meant being a builder. Architects were not only the masters of spatial effects but were also closely involved in the construction of buildings. The knowledge of building techniques was implicit in architectural production; inventing the building's form implied inventing its means of construction, and vice versa. The design information was the construction information- one implied the other" (Kolarevic, 2003).

Master builders considered the chiefs in charge of all facets of constructions until the Middle Ages ended. Their job was to hold a central role that could oversee both the design and construction of their buildings as smoothly as possible. "Their knowledge of making not only allowed them to conceive the design of buildings but also gave them the opportunity to specifically formulate the construction sequence and engineer building practices." (Garber, 2009)

"The tradition of master builders, however, did not survive the cultural, societal, and economic shifts of the Renaissance. Leon Battista Alberti wrote that architecture was separate from construction, differentiating architects and artists from master builders and craftsmen by their superior intellectual training. The theory was to provide the essence of architecture, and not the practical knowledge of construction" (Kolarevic, 2003). The uprising role that architects took over master builders emphasized a need for better collaboration between the two peers. Through a fluid exchange of information via verbal communication, the master-builder was able to be continuously present on the building site by exchanged information on all the building phases. Drawings were used to convey information from the architect to the construction team but models, a new method at the time, were also used to transmit design ideas. Some of these models were constructed to be big enough for the clients to walk inside. While conveying the idea of the project they also had more information about the final product such as materials or the techniques to be used for the construction.

“The rifts between architecture and construction started to widen dramatically in the mid-nineteenth century when drawings of the earlier period became contract documents" (Kolarevic, 2003). The appearance of other critical actors of the building industry happened around this time with the general contractor and the professional engineers becoming important to the architectural practice. With the expansion of the building team, the relationship between the architect and these individuals was defined contractually with a clear intention of defining the responsibilities of each party. This had consequences that are felt to this day. The change in the relationship between the architect and the contractor, the designer of the building, and the executor of the design, tuned into a collaboration that is strictly financial and highly legal with very little space for maneuvers.

“As architects placed more and more layers beneath themselves, the distance between them and the construction site increased. The design was split from the construction conceptually and legally. Architects detached themselves fully from the act of building, unintentionally giving up the power they once had, pushing the design to a side-line, and setting the profession on a path of increasing irrelevance in the twentieth century” (Kolarevic, 2003).

4.6.2 File to Factory

The last century and a half have been remembered for the great innovations that happened in the space between design and building. The connection enabled through digital practices intensified after the 90s and introduced what was called blob-architecture. Blob-architecture meant a type of architecture that could not be realized through traditional means of building. Inexperience in dealing with forms that did not resemble the standard orthogonal shapes led contractors at the time to declare blob-architecture as impossible to build or too risky. However other industries had already adopted the digital tools with the architecture practice falling behind. Industries of automotive, aerospace, or shipbuilding that were familiar with digitally-driven processes and non-standard shapes gave architects the ability to transform digital information into fabrication and construction information that can drive the machinery. Digital tools greatly expanded on the capabilities by enhancing the drawing process. In addition to this, digital information was utilized to build scale models that could provide the architect with feedback. Moreover, roughly the same digital information could be used to produce scale models giving valuable feedback. Out of simple necessity, the designers of non-standard architecture became the pioneers of using digital tools in construction.

Figure 47 Guggenheim Museum in Bilbao by Frank O Gehry (1997) was made possible through directly fabricating design information. Photo: Emilio I. Panizo

A need to export the information available was created due to a growing division between architects and builders. This division in modern times has been narrowed through the use of hundreds of drawings even for small or medium-scale projects. Preliminary practice with digital tools has shown although that through better communication and working closely together the need to export information in paper form can be eliminated. The same geometry that can be viewed out of a 3-D model can be directly fed to the machines in order to fabricate the parts. The new forming and direct connection between the practice of designing and building have been diminishing throughout the last three decades. “As communication among various parties increasingly involves the direct digital exchange of information, the legacy of the twentieth century in the form of drawing sets, shop drawings and specifications, will be inevitably relegated to the dustbin of history” (Kolarevic, 2003).

4.6.3 Integration of disciplines

Disciplines that face a large separation in the industry could potentially merge in a way comparable to architecture. This new challenge of digital processes requires architects and fabricators to cooperate as one legal entity. In this case, there is no distinction between architect and builder. “The amalgamation of what were, until recently, separate enterprises has already transformed other industries, such as aerospace, automotive and shipbuilding, but there has yet to be a similarly significant and industry-wide impact in the world of building design and construction. That change, however, has already started and is inevitable and unavoidable” (Kolarevic, 2003).

“In these fields (the design and fabrication of automobiles, airplanes, and ships), the process engineer has triumphed, while in building the architect continues to decline. The architect remains content, apparently, to focus on the appearance of things, while the process engineer goes beyond appearance into the deepest substance of making to invert the historic, craft-based relations between cost and time, on the one hand, and scope and quality, on the other. For the process engineer, the act of design has extended beyond the assembly line to the complete life-cycle of products. While the word of architecture has grown ever more wasteful, disposable, splintered, and specialized, the process engineer flourishes in the fluid integration of makers by dissolving, not reinforcing, boundaries between thinkers and makers” (Kieran & Timberlake, 2004).

As a response to the emerging unique request of expanding architectural practice, in 2002, Gehry Partners founded Gehry Technologies to further develop Digital Project, a version of CATIA[20] that was adapted and specialized for the special architectural projects. Digital Projects bring together different sides of the building process such as mechanical, structural, costs, and design codes to name a few. Gehry Technologies has now moved on to offer full-time consultant services as a consultant to Gehry Partners itself with a clear function of assisting processes that involve the management of digital construction. Similar to the master-builder age, this approach is quite innovative and traditional as it expands the role of the architect to include again the oversight of a building process a construction management task. More studios are following suit to this practice as famous architectural offices such as Foster & Partners, Nicholas Grimshaw, and Bernhard Franken are expanding their practice to a more integrated process of delivering projects that are

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[20] CATIA software is a multi-platform software suite for computer-aided design, computer-aided manufacturing, computer-aided engineering, PLM and 3D, developed by the French company Dassault Systèmes. https://www.3ds.com/fileadmin/Industries/Architecture-Engineering-Construction/Pdf/brochures/gerhy-digital-project-aec.pdf [last accessed on-line 12.09.2020]

complex and large (Iwamoto, 2009). Similar methods are followed even by younger architecture practices such as ShoP architects were a total control of design and construction with constant communication between fabricator and designer is at the helm of their philosophy.

Figure 48 Dunescapes by ShoP architecture is a project that the architects envisioned from the design to the construction (2000)

Mistakes committed during the transformation phase could potentially be reduced through a direct connection of the digital and physical processes. Estimates show an increase of 28-40% in efficiency (Kolarevic, 2003). We could potentially decrease the time of fabrication as well as costs and waste production. Incorporating fabrication thinking from the onset of design would have optimal effects on the overall quality of the final product. Fabrication times could decrease, along with production cost and waste. As efficiency is always welcome and these processes speak of enhanced possibilities later it would be normal that the architecture of the 21st century and its creation could be based on these digital processes.

"The knowledge of how to make – both everyday objects and highly-skilled creations – is one of humanity's most precious resources" (Charny, 2011). The Master builder of the 21st century should have in his repertoire a mix of both design and manufacturing skills. Being familiar with the tools of digital fabrication along its limitations and possibilities can enable architects to fully integrate art and craft. It is through the possession of this knowledge that architects can have a greater role in the final processes of fabrication as know and create the information the directly controls the digital fabrication machinery. Design and making intelligence in this sense will allow the new digital architect to merge what has once conceived a linear process of ‘form-structure-material’. In this new design process form, structure, and material are conceived almost simultaneously with each informing the other through the design process. “No longer a posteriori, the design engineer is now up-front at the earliest generative stage, bringing to the fore the design content of materialization and fabrication technologies” (Oxman, 2010).

A speech delivered by Walter Gropius in 1952 at the AIA in Chicago discussed how: “In the great periods of the past the architect was the master of the crafts or master builder who played a very prominent role within the whole production process of his time. But with the shift from crafts to industry the architect is no longer in this governing position” (Benevolo, 1977). Through digital fabrication, architects can reclaim a lost position in the construction and building industry that was slowly lost.

4.7 Re-integrating design and making

The division between the processes of design and construction are not the only roadblocks that need to be surpassed in the creation and construction of buildings. Through the many years, a division on the act of design was further broken down in art which become the domain of architects and science which now is the domain of many specialists. An educational split of architecture and engineering coincided also with the division between art and science. Even more educational programs were born out of this separation. New professions such as material scientists, product engineers, process engineers, and many other specialists could now all have the right to claim part of the finished product. Increased complexity in the design of our buildings contributed to ever greater fragmentation and specialization. With each new material, technique, or tool new consultants were born, slowly taking away control over the design and decision making from the architects.

“Architectural production over the past decade has been marked by a strong affection for the image. The seductive aesthetics of digital architectural modeling and visualization have often dominated over attention towards materiality and building construction. Ambivalent images were and still are, produced with digital tools. They display architectural visions that neglect the constraints of the physical laws and the constraints associated with building construction. Yet we know that architecture is not, and cannot be, just an image” (Weinand & Hudert, 2010).

The response of architecture was rather evasive. Rather than fight against an increasing marginalization, the architectural practice, mostly pushed by the architectural schools, developed a storytelling approach to their projects and a fascination with seductive images or architectural icons. The separation with the rest of the building industry became even larger. By focusing more on the creation of images and giving up control and responsibility over the construction phase to other specialists the architects allowed the building process to escape from the architectural sphere.

“Once, there was a seamless integration of the constituent elements of building through the person of the master builder, who had control over the materials, products, and construction of architecture. Today, there is little interaction among these disciplines, particularly between architect and builder on the one hand and product engineer and materials scientist on the other" (Kieran & Timberlake, 2004).

4.7.1 Opportunities for architects

Reading through unemployment statistics of recent years in the western building industry taking into account the large number of extreme challenges that currently humanity is fighting against there is both an opportunity as well as strong need to potentially improve the role of the architect. The focus should shift from the creation of eye candy images that focus on marketing to the creation and development of intelligent solutions that can answer the tough challenges presented to humanity. Rather than focus on original and extravagant ideas, these challenges demand attention on the performance of the solution. Their role can be reclaimed by "integrating the skills and intelligences at the core of architecture" (Kieran & Timberlake, 2004). The building industry must adopt significant changes as a response to the fast urbanization and constant depletion of natural resources. Unfortunately the building industry and market rarely allow architects the possibility to make significant or intelligent solutions to these problems.

Carter mentions how: "At a time when our population and the consequent demands for space and services continue to grow, when cities expand and, as is frequently suggested, buildings account for more than half of the energy consumed in the world, clearly both the number and nature of roles for the architect are increasing. However, these can be characterized as roles that the architect could and should not play in glorious isolation, but rather by working closely with other specialists. This would not only make it possible to develop integrative design proposals, but also enable architects to play more influential roles in the development of inspired proposals for the design, construction, operation, and management of buildings" (2010).

Influence on the design and production processes can be increased by architects that adopt digital tools. A fully integrated team, with the architect as a director connecting engineers and scientists, would be able to investigate and supervise all important aspects of a building process, continuously improving it.

4.7.2 Dealing with Data

The increase in the amount of data that a computer could handle also increased the amount of complexity that could be embedded in a digital design process naturally also increasing the complexity. Through the combination of enormous amounts of data and the increased evolution of digital tools, the information could be analyzed, tested, or even optimized based on certain criteria or parameters. In the contemporary world, these supercomputers could integrate into our buildings and give them levels of intelligence that were never possible before.

An established database that can inform various design processes can also accept more information over time growing. Hauschild mentions how around 98% of planning, calculation, and optimization is already conducted through digital data (2011). The database could collect information from different areas and disciplines, incorporating the knowledge and data from both amateurs and professionals. Even intelligence from history could be incorporated into these data systems. Work that has been built and has stood the test of time can provide a valuable resource for intelligent solutions.

Normally an architect searches for new solutions by analyzing his own past experiences and a limited amount of documented references. All relevant information that certain settings required could instead be selected and presented to the architect enriching his experiences. Furthermore, this database could also be enriched through historical data that contain information such as representational aspects or even political agendas. Nature can be a very interesting inspiration that has yet to be fully explored. Biomimicry (gr. bios - life; mimesis - to imitate) is a discipline of applying nature’s principles and it does not only changes the ways we think about designing, producing, transporting, and distributing goods and services, but also provides opportunities to deal with complex environmental and economic problems (Ivanic, et al., 2015). Architecture has often drawn inspiration from nature and having precise information could greatly improve solutions that architects are able to propose.

4.7.3 Digital Tools for Architecture

Digital tools have already over the last three decades have already impacted and become part of the design process at various scales and degrees, although it is worth noting that much of this change has mostly been manifested in visualization or in conventional drawings and management. More advanced tools that offer analytical and generative design capabilities and can open up new conceptual exploration have come into the mainstream discourse in recent years. Some software gives architects the ability to build their own set of tools and design processes based on computer algorithms. Others are based on the usage of Virtual Reality goggles that allow the user to experience a virtual world on a real scale with depth and perception. Augmented Reality on the other hand is based on overlaying information onto the real world opening up possibilities on what information can be for our buildings. By exploiting these new design realms and the ability to build our own tools new dynamic processes of design can expand on the current practice greatly.

Although these tools can seem powerful, their functionality is still under the control of the creator and thus can never take over the process. While computational tools can direct the designer to an answer, they do not offer a solution. The quality and coherence of the design remain under the responsibility of the designer itself.

“The only constant in our world is changing. And as engineers, we need not resist this critical process of improvement of the built environment, but we must seek to think outside of the box for solutions for tomorrow’s problems — solutions that ultimately ensure the highest design quality for our clients.” (Schwitter, 2005)

4.7.4 Building Information Modelling

BIM has seen an application into mainstream media with almost all studios and architectural practices recognizing the capabilities that it can offer and advantages.

BIM is an acronym for Building Information Modelling which in itself represents a single and informed tool that connects all aspects of design. Through a shared model that shows the same information to the whole design team, design collaboration has never been as easy as with BIM. “The challenge is (and has been for more than three decades of computer-aided design) how to develop an information model that facilitates all stages of building, from conceptual design to construction (and beyond, for facilities management), and provides for a seamless digital collaborative environment among all parties in the building process” (Kolarevic, 2003). This statement by Branko Kolarevic seems to have become reality in the last decade where BIM has seen the widespread application.

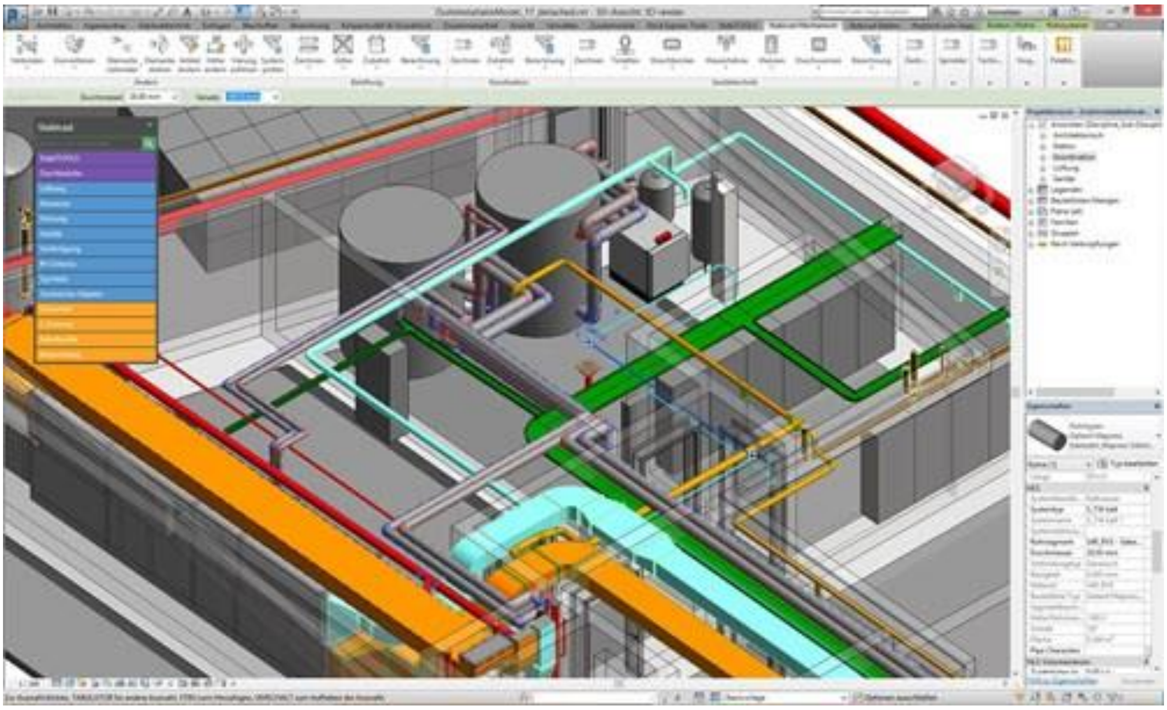

Figure 49 Interface of Revit, a BIM software by Autodesk showing design groups working simultaneously on the same model where architecture, electrical engineering, and VAC and plumbing can share a design environment.

BIM allows anyone who is part of the design team, be that architects or electrical engineers to add their own layers to the design. In the building information model, all participants in the design and construction process can add their own layers. By always being connected to databases of data, new tools for design would allow the designs to go through more analysis and simulation that can improve the final product. Drawings can be converted directly to fabrication and construction information, decreasing the more gap between drawing and making. The design proposal through all its staged can become more informed and structured overlaying information from materials to construction techniques.

“All complex human endeavors, including architecture, require a regulating structure to organize the inherent chaos that underlies its making. Our regulatory structures today are information management tools, not the idealized mathematical constructs of classical architecture. Modern humanism is communication, not geometry. Communication tools allow architects and our collaborators to conceive, discuss, explore, and understand every detail before we produce it. The process is accessible to all, including the user and client. Architects are no longer limited to the fragmentary representation of physical ideas; we can now fully pre-form them. This composite understanding of architecture before it actually becomes substance offers a deep understanding of the elements of architecture that affect our daily lives. Refabricating architecture leads toward a new humanism” (Kieran & Timberlake, 2004).

Used in the right way, BIM could become a powerful tool leading to innovation in architecture and in the process of its making. However, it could also dilute the architect's influence through collaboration or impose rigidity on the design process that constrains creativity.

“As proponents of BIM, we need to acknowledge the implications of the massive expansion of data and move on from a performative analytical model to a more comprehensive conceptualization of information modeling that opens up creative options leading to new qualities and relationships and does not just streamline a process. It should expand the ways we use data rather than merely generating taxonomies or collecting an envelope of constraints. Some of the best designs have been those that have broken the rules and gone beyond technical optimizations or the prescribed constraints of clients and municipalities. Rather than limiting our choices, information modeling can open us up to the new way of thinking and its massive potential” (Ottchen, 2009).

A single design environment and model although raises new issues about design responsibility between the working team. Responsibility for the quality of work achieved by the design team falls to the coordinator of the information model. This can be mitigated by sharing responsibility between a few members of the design team in key disciplines. Firms that develop designs and also build have the architects and contractors share and work together under a legal framework where responsibility is divided between actors. The solution that Gehry's office has adopted is outsourcing the coordination of the production for the BIM model. This however raises the question if the architect loses more power over the design process through the creation of a new role aimed at managing the data from outside.

"It is this role the information master builder- that represents the greatest opportunity for architects to return to their master-builder roots. The architectural profession will seal its fate if it abandons the overall process and information integration and management to construction and engineering firms, some of which have already realized that the emerging dynamic, geographically distributed, digital networks of design and production expertise are the future mode of operation for the building industry" (Kolarevic, 2003).

4.7.5 Performative Architecture

Through the integration in a seamless process of analysis and design of buildings through building information model design, a coherent and collaborative design experience between engineering and architecture is established. "These technologies allow for a medium in which notions of creativity and innovation merge through performance operations, cost efficiencies, and material and system simulations that are iterated digitally throughout the design process. Buildings can be understood according to how they perform as opposed to what they look like" (Garber, 2009). By defining the performance of a building in early design stages instead of following a linear process of form finding and subsequent processes of optimization, through digital technologies the performance of the building itself can become the design principle.

Figure 50 Kunsthaus is an example of performative qualities in architecture. Peter Cook (2003) Source: http://www.flickr.com/photos/koratien/8732427965/

Quantitative hard data is not the only issue in that performative architecture phase. “In this new information- and simulation-driven design context, the paradigm of performance-based design can be approached very broadly — its meaning spans multiple realms, from spatial, social and cultural to purely technical (structural, thermal, acoustical, etc.). The increasing emphasis on building performance — from the cultural and social context to building physics — is influencing building design, its processes, and practices, by blurring the distinctions between geometry and analysis, between appearance and performance” (Kolaveric & Malkawi, 2005).

Many performance-related aspects can impact design and solutions while also having goals that conflict with each other. The optimization of a few parameters that generate the design is not the goal and point of performative architecture. Creative solutions in balancing aspects of quantitative and qualitative data that can affect the performative aspect of architecture have become a key challenge for architects that use the information for their designs.

Aesthetic qualities are not neglected while shifting from one design process that was based on originality and visual appearance to a process that values performative issues without neglecting aesthetic quality. Exactly the opposite is true, like a quote by Buckminster Fuller says: “When I am working on a problem, I never think about beauty. But when I have finished, if the solution is not beautiful, I know it is wrong.” This approach resembles nature more than others. Beauty in nature is never a purpose but rather an underlying effect that the performance approach of living organisms brings. Although we know this, nature is still regarded as a beautiful wonder.

Although issues of aesthetics can be quite subjective, a spread on applied projects that value performance during the design face has shown and proven that performance-driven processes can also produce visually striking results. Engineering architects such as Pier Luigi Nervi or Eladio Dieste focused on structural performance while creating visually impressive buildings. New performance-driven studios of today like Zaha Hadid Architects or Foster & Partners show interesting results through these design methods.

Digital practices and processes in design and construction hold the ability to narrow the gap created through the educational split between art and science in architecture. This split was also the reason the professions of architecture and engineering have been growing further apart and more disconnected. “By integrating the design, analysis, manufacture, and assembly of buildings around digital technologies, architects, engineers and builders have an opportunity to fundamentally redefine the relationships between conception and production. By reinventing the role of a ‘master builder' the currently separate disciplines of architecture, engineering and construction can be integrated into a relatively seamless digital collaborative enterprise, thus bridging the gap between designing and producing” (Kolarevic, 2003).

“The architect can force the integration for the several spun-off disciplines of architecture – construction, product engineering, and materials science – all with the aim of reuniting substance with intent” (Kieran & Timberlake, 2004). Through information management, architects can now go back to taking the central role which they had in history, a gate where all information passes and is distributed to other practices, able to read and take advantage of information with a crucial decision making role. As an active participant in all stages of construction and design, this new architect is tasked with balancing requirements and desires throughout separate professions and processes.

“The architect can once again become the master builder by integrating the skills and intelligence at the core of architecture. This new master builder transforms the singular mind glorified in schools and media to a new genius of collective intelligence. Today’s master architect is an amalgam of material scientist, product engineer, process engineer, user, and client who creates architecture informed by commodity and art. By recognizing commodity as an equal partner to art, architecture is made as accessible, affordable, and sustainable as the most technically sophisticated consumer products available today”, (Kieran & Timberlake, 2004).

The roof for the level of ability that the activities that the new master-builder architects are quite high. Throughout his academic career, an architect should be trained in developing the new characteristics of the profession. The aim should shift from creating an architectural vision that is followed from the start of design until the end, to a process that gradually forms itself while considering and combining all possibilities and information that are available. “Educational institutions are the ones who have the power (and, hopefully, the foresight) to prepare future generations of professionals for the emerging practices of the digital age”, (Kolarevic, 2003).

Broad knowledge from all disciplines close to architecture is asked from architects working in this new digital realm where cost and construction feasibility are required are requirements on top of the ability to teamwork and manage interdisciplinary groups. They should have enough skills in order to easily connect and tap into a collective pool of knowledge of the whole design team. Through the act of communication with all fields involved, the architect is able to absorb more advanced knowledge and feedback that can directly impact the design process and quality of result. “An architect knows something about everything. An engineer knows everything about one thing”, (Frederic, 2007).

The focus on the appearance of things should move to the background in order to allow performance to be valued more. Processes will inform outcomes that will inform processes. The architect of today must comprehend the shifts happening and adopt the new data-driven process over the product-driven one. Users and builders of architecture and related fields to it like material science, software engineering, or digital fabrication all belong to this process. Through the utilization of digital tools, the diverse group of actors and complex flow of data are combined into a flowing integrated process. Quality of design, feasibility, and costs are returned under the architect who can now control these processes and steer design through the use of this new collective intelligence.

Through a restructuring of the design and production process, the structure and level of compensation that each infidel member deserves must be reimaged. With greater responsibility coming from the architect as a director of sorts, more rewards will follow. “Individuals capable of performing such a complex and demanding role are rare and will therefore be sought after. The added economic value they [modern master-builders] can provide should elevate their salaries to the equivalents of those of top lawyers and doctors” (Gauget, 2009). Enhanced communication and lower risk in streamlined processes of design would entail a greater reward for architects. Shop-drawings could become obsolete through and save time for example through the usage of digital design and fabrication.

4.8 Closing the loop

Through a shifting industry from a global mass production to mass customizations that are local and contextual, the closure of our resource cycle can be achieved. By combining production and repair locations of physical goods, materials that are non –renewable become much easier to collect, recover, and reuse. These new advancements have also impacted have changed costs for stages of production and development as well as marketing and transportation, while on the opposite side, costs of material have grown. This change provides a bigger incentive on our side to recycle and reuse materials while also contributing to less CO_2

“Some people, I am afraid, see lean as a pathway to restoring the large scale manufacturing giants the United States economy has been famous for since the past half-century. The cheap fossil fuel energy sources that have always supported such production operations cannot be taken for granted any longer. One proposal that has great merit is that of rebuilding our economy around smaller scale, locally-focused organizations that provide just as high a standard living as people now enjoy, but with far less energy and resource consumption” (Johnson 2005).

An enclosed loop can be envisioned where factories extract resources from immediate surroundings. These resources become an inspiration for the products to design where digital tools become drivers in design and manufacturing. Digital fabrication holds the potential to activate processes that were exclusively locked behind big industries. The possibilities, in this case, become quite interesting as we local production systems and processes can be set up with the only drawback being the requirement to train a broader audience in the tools. Again these can be mitigated through the creation of easier, and more comprehensible tools where the architect designs the process in a way that can be exploited by anyone. As mentioned in chapter 3, our own waste can become the resource that we can feed to this process, thus promoting a circular economy model. Most products turn into waste for many different reasons. Promoting a future where this waste can activate a series of processes that can be used for designing and building and reused again not only responds to a climate crisis but promotes local economy and production.

5. CASE STUDIES

5.1 Introduction

The first chapters of the thesis served the purpose of exploring the two main components that this thesis discusses. The first one being waste and the potential it holds as a building resource and the second one being that of the digital tools available today and the potential they hold in activating waste material as a resource. Waste in this case is a material that has been thrown away, out of its life cycle or intended purpose. Recovering it becomes the main idea and recovered waste materials can take new forms and be part of new processes. Digital tools refer to digital fabrication and computational/parametric design and create with waste. As design and manufacturing in the notions explained in chapter 4 become interconnected through data, these processes are seen joined. The aim of this chapter is to understand the current practice of building with waste through digital tools.

As explained in chapter 3, building with waste requires that we change the way in which we view waste. Throughout history, the changing of materials into something desirable or useful to building processes have required human intervention. Natural stones have been used in their found state for building processes throughout history but most other materials needed to be shaped into standard forms through different processes that fit into determined processes. The idea of viewing waste as a resource is clearly embraced by Ilka and Andreas Ruby (2010) with our built environment becoming the source itself from which to extract the materials. It's quite logical to think of automating the mining process through technology, especially with the advances of the automation industry, although the possibilities can extend further. Projects such as Mine the Scrap (Certain Measures, 2015) or show exactly this ability to quickly digitize found objects into the digital realm and feed that information/data into design processes.

The practical projects chosen represent a meaningful response to processes fostered by digital fabrication machines as well as incredible flexibility in design software. Each of the materials selected and used allow the designers the claim that it is very little to almost 0 consumption occurring as a result of their designs. In some cases, the materials used by the designers are from off-the-shelf units that are often lacking any architectural typology or precedent (Beorkrem, 2017). This requires them to build new and novel methods that are constrained by the parameters of the materials. The design process involves a series of both physical and digital models, using the constraints of the system to determine how a form could be applied at the scale of the human body.

The work of Ronald Resch, at the University of Utah in the 1970s, exemplifies the type of projects which are attempting to be 100% recyclable. Resch studied how adaptations to topological paper forms could be created using a computational interface. These variations operated within very tight parameters; “only folding of the flat sheet was allowed, no cutting or gluing, and the folded edges were forced to be straight-line segments; no curves” (Resch, 1973). The products were highly constrained, they resulted in patterns that were elegant and they had an embedded structural logic. And while our interest does not lie in this kind of example, the 100% efficiency garnered through Resch’s rules results in an excellent precedent for other uses of Origami and sheet folding techniques. This is exemplified in Tina Hovsepian’s Cardborigami[21] (2007) design, which is both efficient and socially ethical.

There should be an awareness of the temporality of architecture that should define the necessity of design to be aware of the consumption of materials required for the construction. (Beorkrem, 2017). Whether the materials are recovered on route to a landfill or they are a part of a lifecycle, which will bring them a second life after they are disassembled, there should be a planned future for each product ahead. The selected case studies fall into three main categories as shown by the diagram:

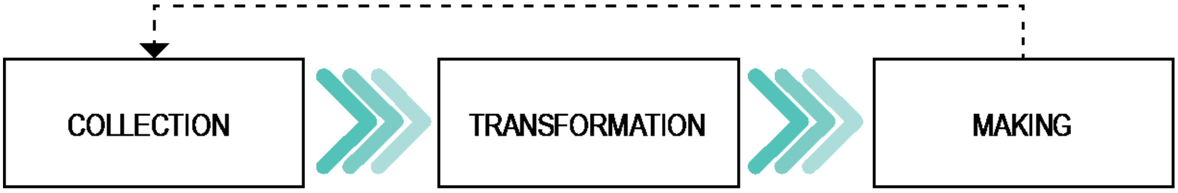

Figure 51 Types of processes studied. Source: Author

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[21] Cardborigami, a nonprofit startup, shares its name with the fully collapsible, water-resistant, portable cardboard shelter model that Hovsepian developed while studying architecture at the University of Southern California.

5.2 Collect

Projects in the collect category are projected that in one way or another deal with collecting materials from their direct environment. As even the simple collection and categorization can be complex tasks that require a lot of manpower, projects in this category automate and use technology in order to facilitate the creation of a material stock that is followed by information and data on their composition and shape.

5.2.1 Peccioli-E

Figure 52 Wall-E stacking blocks of garbage, credits: Pixar Studios (2008)

Pixar Studios released the movie Wall-E in 2008 with great success and with a dire message for our society. The movie focused on a small garbage disposal robot left behind by humans who escaped a trash covered planet earth. Wall-E, a cleaning and garbage disposal robot unit is seen collecting the waste he finds (often finding things he treasures), compressing it into cubic blocks. Wall-E stacks those blocks on top of each other forming tall garbage towers that rival the skyline of the abandoned cities. While the movie shows a bleak future it is impossible not to think of the ease with which this tiny robot is turning common garbage into building blocks. It is also very reminiscent of the automation industry today, where we see robots being employed in order to collect or treat the waste that we produce. And while that looks like science-fiction we are not that far off from that future.

Peccioli, a small medieval town in Italy, became one of the first places in the world where a robot was used to carry out public service in the urban environment (from 15 June 2010 to 7 August 2010). Thirty-five real users accepted to trash their domestic waste using the robot DustCart, a mobile robot designed to collect, transport, and discharge rubbish bags in complete autonomy. During the testing period, the robot safely traveled along the public streets of Peccioli, carrying out its daily service and sharing the urban environment with the passers-by, bicycles, and cars, without causing any problems. (Salvini, et al., 2011)

Figure 53 The DustCart Robot, an autonomous service robot designed to collect waste door-to-door. Photo: inhabitat.com

The objects of the test were two robot prototypes of the DustCart, which is a mobile autonomous service robot, designed to carry out the door-to-door, separate waste collection on demand. The main components of the robot are a mobile platform, a two-wheel robot based on Segway, and a bin container that supports the collection, transport, and discharge of the collected waste. The batteries on the back of the robot allowed it to work for approximately 10 hours every day. Navigation through the urban environment was made possible through special sensors and other components (Ferri, et al., 2010) that allowed the robot to autonomously avoid obstacles while moving. The robot interacted with humans through a touch screen interface on its front which had simple operation such as the user specifying the type of waste being given to the robot by pressing the corresponding icon on the screen. Vocal massages with the robot thanking the users were also present.

Figure 54 DustCart moving on the Robot lane indicated by the yellow line. Photo: Giancarlo Teti

The on-demand service that DustCart provided to the inhabitants of Peccioli during the test period consisted on a door-to-door waste collection. The initial configuration of the robot was set up in order to collect three types of waste: undifferentiated, paper, and plastic. The request of the DustCart service was carried out through a toll-free number and was managed by the Ambient intelligent infrastructure (AmI) which scheduled and allocated robots. To request the DustCart service, users had to call a toll-free number. The calls were managed automatically by the ambient intelligent (AmI)[22] infrastructure that both scheduled and allocated robots to tasks. Users were informed through an SMS that a robot had arrived to collect their waste.

During the test period, the robot operated for 47 days and collected a total of 560.3 kg of waste. Although somewhat successful in its limited testing time and location.

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[22] The users involved in the test were registered in the AmI software, and their telephone numbers were stored in the AmI database along with the robots and collection points. The software allowed us to associate the users to collection points. The AmI software communicates with the robots through a wireless network.

The authors (Salvini, et al., 2011) pointed out problems of legal regulations of autonomous robots as well as social acceptance as some of the main issues that need to be overcome. The door-to-door service was highly appreciated by the inhabitants of Peccioli as it allowed them to dispose of waste without leaving their homes. The ability of DustCart to work as an autonomous waste collector in urban environments can become a game-changer for waste collection. Especially if we think of the robot as able to identify the waste itself and categorize it in terms of its composition and shape. This would benefit the recycling industry immensely as well as allow for valuable materials to be easily identified and re-introduced for a new life cycle.

5.2.2 W.A.R

Waste Robotics[23] partnered with FANUC in order to create a Waste Autonomous Recycling (W.A.R) technology as a way to answer the incredible output of waste (over 800 million tons of waste) that North American people generate each year. Only 35% of the generated waste is recycled due to the required processes of division and a dwindling workforce that is now unwilling to perform dull, dirty, and repetitive tasks. Waste Robotics developed the WAR software in order to allow multi-sensor scanning and real-time artificial intelligence analysis that can perform and scan waste for its chemical composition while also recognizing its shape. WAR is able to compute and calculate grappling strategies as well as picking sequences in real-time to perform robotic extraction. Its main aim is to allow and drive robotic arms to perform tracking and sorting of various types of recyclables. Fully automated robots provide reliable, constant and quality waste sorting for recycling centers.

The main aim of the robot here is a simple sorting through chemical composition and shape through the use of its multi-sensor system. These systems and machines can be easily programmed to perform sorting through certain criteria. Rather than just sorting, the scanning can serve as a way to point out and catalog 'valuable' waste. Just the ability to point out waste that can be valuable creates a transformation on the waste. The same as the builder that finds the perfect stone to add to his collection of stones so he can build his wall, the machine can find perfect pieces that can be used for building processes.

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[23] https://www.wasterobotic.com. [last accessed on-line 22.09.2020]

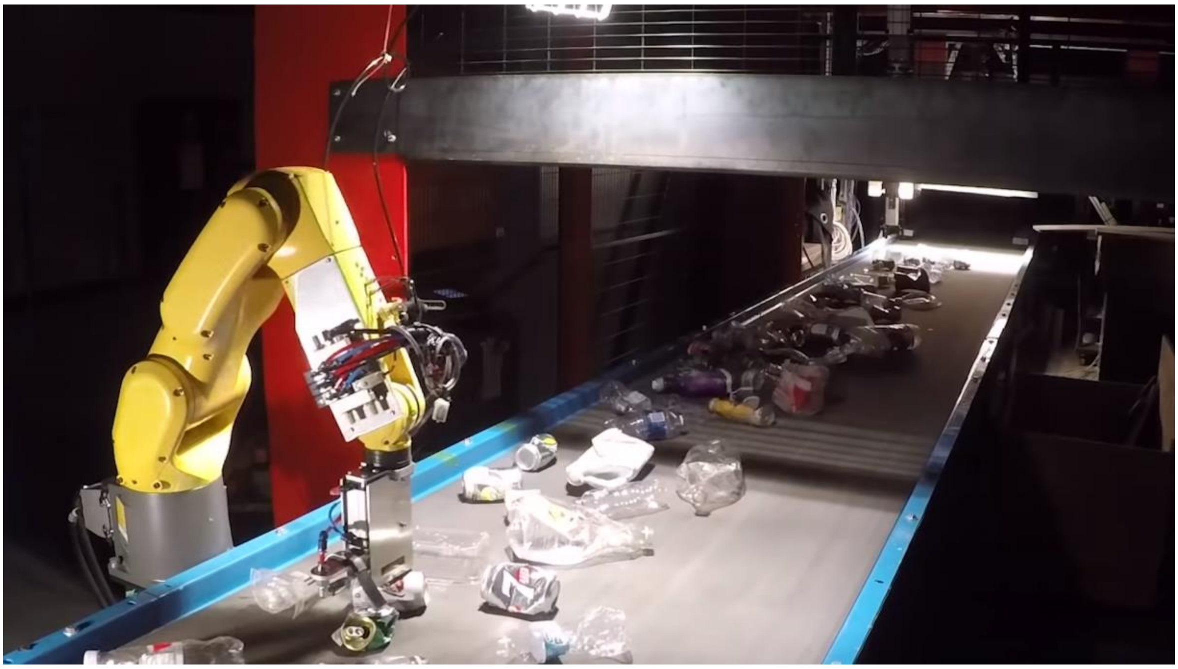

Figure 55 The Waste Autonomous Recycling technology sorting through plastic waste. Source: FANUC

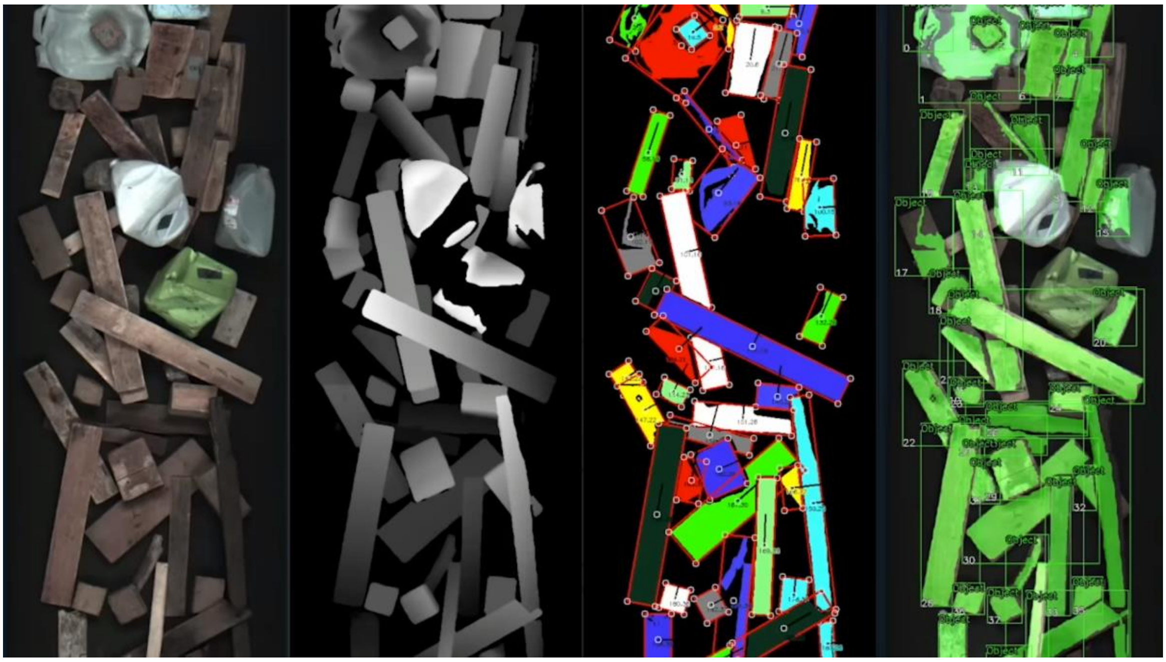

Figure 56 Multi-sensor system for W.A.R used to sort through chemical composition and shape. Source: FANUC

5.3 Transform

The transform category is reserved for projects that directly translate incoming material into information that can be used to feed a process of digital design. Technologies and methods such as 3-D scanning and digital fabrication are applied in these cases in order to transform something that can be perceived as useless into a useful design element. The transformation in this sense is not only on how we perceive that material but also how that material and its perceived qualities are transformed into a new position, configuration, or use.

5.3.1 Certain Measures

Mine the Scrap is a great example of a process that transforms waste through digital tools. Created by Certain Measures[24] (2015) as an installation, Mine the Scrap is a data-driven process that generates designs algorithmically from available scrap. Through computer scanning and automation in construction, this project exemplifies the possible application of digital tools for waste reuse. A project that is completely driven by an algorithm transforms irregular and non-uniform pieces of scrap from constructions into a new form. Through pattern recognition technology the algorithm in a way can transform neglected waste scrap into useful objects. Through a sophisticated process of scanning and classifying (Fig 57) each scanned piece into a new structure, mine the scrap is able to find a use for each piece in a new artifact.

By combining the technologies used in self-driving cars and face recognition through a customized shape and pattern detection, ‘Mine the Scrap’ utilizes big data to face the challenge of waste. It is practically creating a search engine for waste that uses the result of the search engine to find the best materials available for a certain design solution. This essentially means that ‘Mine the Scrap’ does not solely create a minimal waste lifecycle for materials but also creates a new design process that is fundamentally informed by the resources available.

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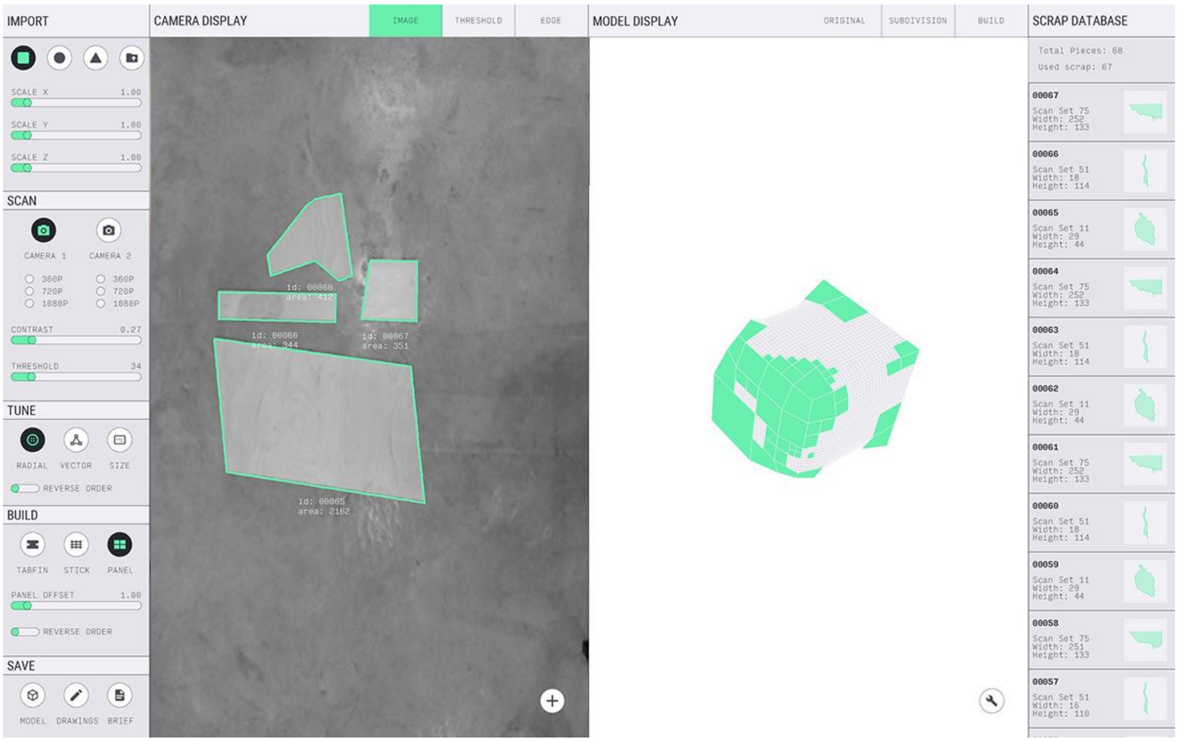
[24] The design team involved Tobias Nolte, Andrew Witt, Mike Degen, Jason Tucker, Cody Glen, Claire Kuang, David Hamm and their installation and was exhibited from 2015 to 2016. https://certainmeasures.com/mts_installation.html [last accessed on-line 12.09.2020]



SCALE X 1.00
SCALE Y 1.00
SCALE Z 1.00

○ 360P ○ 360P
○ 720P ○ 720P
○ 1080P ○ 1080P

CONTRAST 0.27
THRESHOLD 34
REVERSE ORDER
PANEL OFFSET 1.00
REVERSE ORDER

Total Pieces: 68
Used scrap: 67

00067
Scan Set 75
Width: 252
Height: 133

00066
Scan Set 51
Width: 18
Height: 114

00065
Scan Set 11
Width: 29
Height: 44

00064
Scan Set 75
Width: 252
Height: 133

00063
Scan Set 51
Width: 18
Height: 114

00062
Scan Set 11
Width: 29
Height: 44

00061
Scan Set 75
Width: 252
Height: 133

00060
Scan Set 51
Width: 18
Height: 114

00059
Scan Set 11
Width: 29
Height: 44

00058
Scan Set 75
Width: 251
Height: 133

00057
Scan Set 51
Width: 16
Height: 110

Figure 57 Mine the Scrap software analyzing the scrap and generating possible designs and allocation of scrap pieces. Source: Certain Measures (2016)

Figure 58 Mine the Scrap's algorithm sorting through pieces of scrap source: Certain Measures (2015)

Figure 59 Mine the Scrap installation finished. Source: Certain Measures (2015)

Figure 60 CloudFill finished product. Source: Certain Measures (2019)

5.4 Make

The make category includes projects where the main feature studied was the manufacturing and application of digital tools to design and making a goal. Make also refers to the Maker’s movement itself, were making things through digital tools should become second nature the same way that printing with an inkjet printer become to most people. Here the projects are analyzed for their applicability and strategies of fabrication while using products and materials that are not conventional. All three projects use products that are either recycled or pre-cycled as a resource that falls into the field of interest for this thesis.

All projects show an investigation into the fabrication methods as well as parameters taken into account. When designing objects for fabrication, material parameters become design parameters as well. Thickness, length, flexibility, and so on can be induced all or partially into the design process and exploration in order to later automate the manufacturing. Lastly, final results all show the utilization of materials and methods of connection. Connections are a very important aspect of designing for reuse and recovering the material later as they can decide whether a material can still be recycled or it has been corrupted through the use of chemicals or adhesives.

5.4.1 Public Farm 1

Project by: Work Architecture Company (Work.AC) (2008)

Figure 61 Public Farm 1. Photo: LERA

Public Farm 1[25] is an installation that creatively uses cardboard from concrete formwork tubes or as they are conventionally known, sono-tubes (Beorkrem, 2017). Their typical use is for underground concrete piers as a protection for the edges from any concrete pour. Typically these tubes are used as formwork for underground concrete piers, to protect the edge of any concrete pour. The feature of interest here is that cardboard tubes are fairly inexpensive, recyclable, and biodegradable. The idea behind the final installation is that of an elevated farm that can create community engagement with the premise of planting a unique garden with a variety of different vegetables and herbs. The installation was designed primarily as an airborne farm, to create community engagement in the planting of a unique garden. The tubes bear the load of the installation with each structural column being designated by a different program. Each structural column was designated by a program for the area. The installation included 18 photovoltaic solar cells for generating power.

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[25] The installation was designed by Young Architects for the Museum of Modern Arts of New York https://www.archdaily.com/708/ps1-young-architects-program-2008-work-architecture-company [last accessed on-line: 22.08.2020]

The arrangement of the tubes was done in a daisy-shaped pattern of 6 elements (Fig 62). These units were pre-assembled as singular elements. The centers of each unit or daisy served as either a structural common or an opening serving the purpose of picking the vegetables. The form of the installation is ultimately based on a simple surface created through a well-developed set of customized components that double as building blocks for an extensive set of uses. Custom CNC-cut discs bolted to each cylinder provide the base for the installation of the garden components but also structural integrity for the whole system. These discs provide both structural rigidity for each cylinder, but also a base for the installation of the garden components. Each cylinder was trimmed using a plywood box that steadied the tubes and framed the right diagonal edge for each cut. They were all attached using the same key blocks forming the set of 6 'daisy'. Each set of daisies was pre-assembled on a sloped form and placed on the surface later with a crane (Fig 64).

• Consistent joinery allows for efficient assembly.
• Installation of the garden creates other layers of interaction and benefit from organizational logic.'

Software: Rhinoceros 3-D

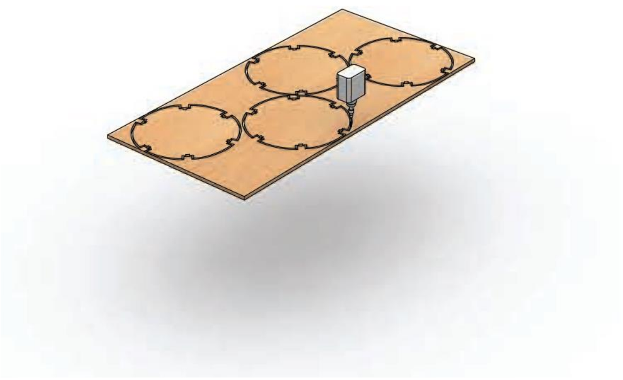

Figure 62 Daisy unit using key blocks and plywood discs to secure units. Source: Beorkrem (2017)

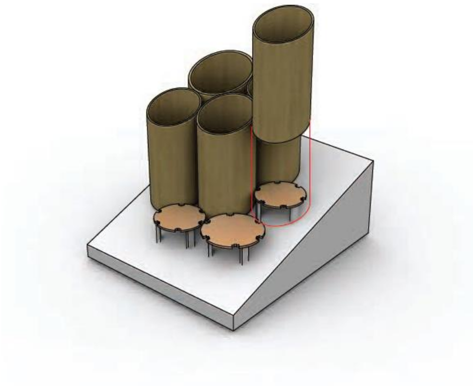

Figure 63 Cut sheet with plywood inserts with cutouts for structural blocks. Source: Beorkrem (2017)

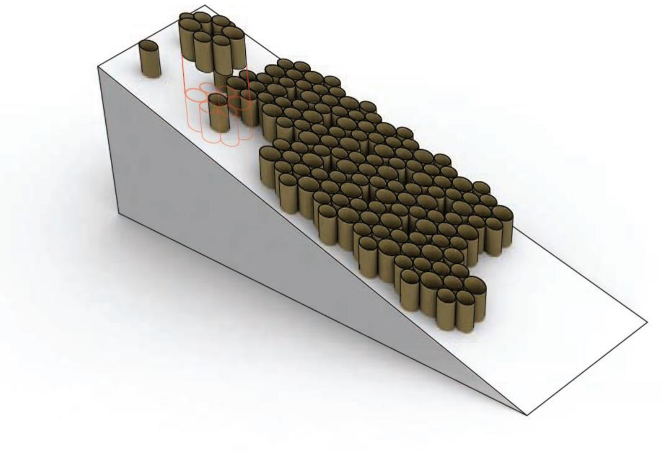

Figure 64 Rendering of Final Installation on a slope. Source: Beorkrem (2017)

Material Reflection

- Concrete formwork tubes are relatively inexpensive, water-resistant, and biodegradable.
- Consistent surface allows for efficiency in cuts and assembly.

5.4.2 Packed

Project: Michele Leidi, Min-Chieh Chen and Dominik Zausinger, ETH Zurich (2010)

Supervisor: Tom Pawlofsky

Figure 65 Packed was constructed using 409 truncated cones. Photo: Dezeen

Packed is a built project that is defined first and foremost by the parameters of efficiency that come from the restrictions. The main restriction in this case is the need for the project to be fabricated in Switzerland and constructed in Shanghai. The installation was assembled for the Shanghai Museum of Arts and Crafts as part of the exhibition 3-D Paper Art. The construction which boasts 409 individual truncated cones each with 28 layers of corrugated cardboard show a construction method that can be adapted to different variations and shapes. Each cone's radii is defined by its ability to rest inside the other in order to save material and shipping volume. Cardboard sheets of 1800mm x 1250mm were used to cut each cone from a total amount of 1900 sheets used (Beorkrem, 2017).

The material parameters have different effects on the final form of the installation with some being more consequential than the other. Tapered cones that point towards the center are organized in a way to form a perfect spherical dome. This system however could also be adapted to other shapes. In this particular case, the dome of the sphere also works as a structurally stable system. In a way, the final In this instance, the dome of the sphere also provides a structurally stable system. The final shape creates the idea of a circle packing or nesting.

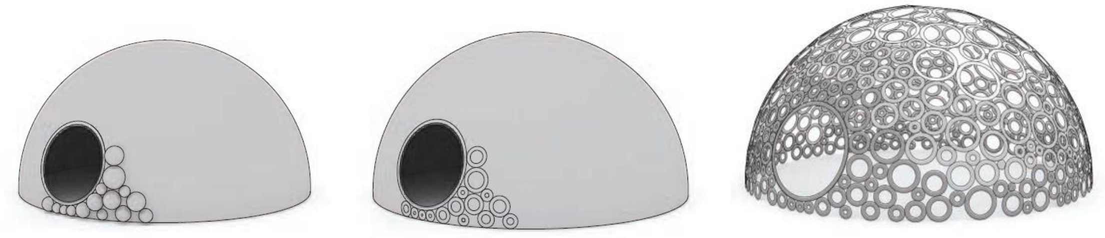

Figure 66 Initial set of spheres mapped to the dome (a) intersection of spheres with the dome (b) Set of spheres and offsets intersected with the dome. Source: Beorkrem (2017)

The example shown above by Christopher Boerkrem in his book Material Strategies in Digital Fabrication (2017) shows a sphere packing method instead of a circle packing. A pre-given set of radii for the circles should be pre-determined in order to allow for efficient cut sheets and shipping. For example, 5cm wide circles of diameter 10cm, 15cm, 20cm, 25cm can all be cut from inside one another and as can normally also be packed as cones inside each other as long as the tapper uses the same angle. The first layer of the system begins by locating a ring of spheres whose tangents touch one another and touch the edge of the dome (Fig 66b).

Sequent spheres would be mapped onto the surface through a triangulation of the relationship between two or three adjacent circles. The length of the system should easily transfer itself through the dome as long as the centers of each circle is on the surface and adjacent spheres are met at the tangent points. Each circle should be offset or scaled from its center point to the calculated thickness for efficiency (Fig 66c). Each unit can be tagged to guide and identify its position in the final assembly. Marks at the tangent connection can be used in order to ensure that circles join at the appropriate location. Each cone was glued together from its 28 layers and was waterproofed (Fig 67b). Due to the requirement of the cones to be shipped to

Shanghai they were nestled into each other. Once on-site, the assembly took place on-site and used zip-ties as a fast solution for the connections as they create a flexible, easily changed structural method to connect each component. Groups of cones were attached to one another on the ground and lifted into place on the dome, and attached to others already in place (Fig 68).

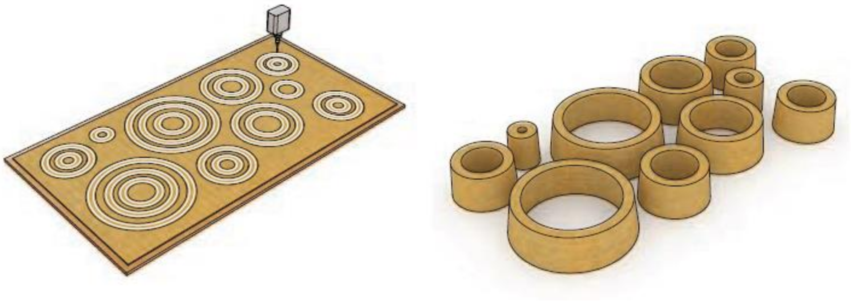

Figure 67 (a) Nested rings to be cut. (b) Assembled cones of stacked cardboard profiles. Source: Beorkrem (2017)

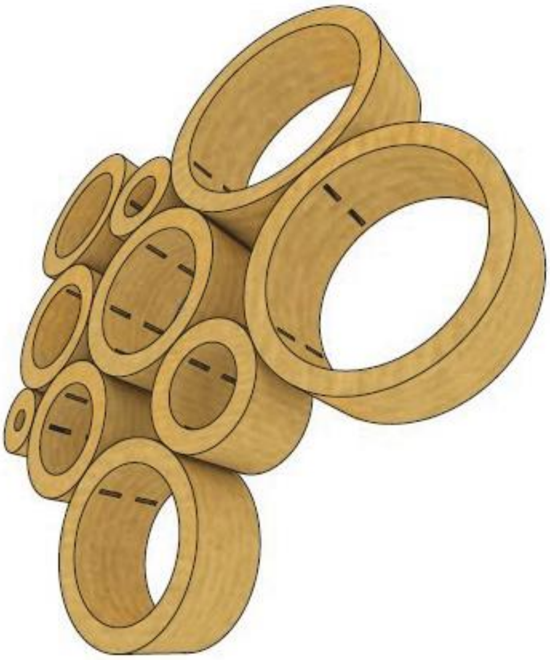

Figure 68 Pre-assembled unit together with the zip-ties. Source: Beorkrem (2017)

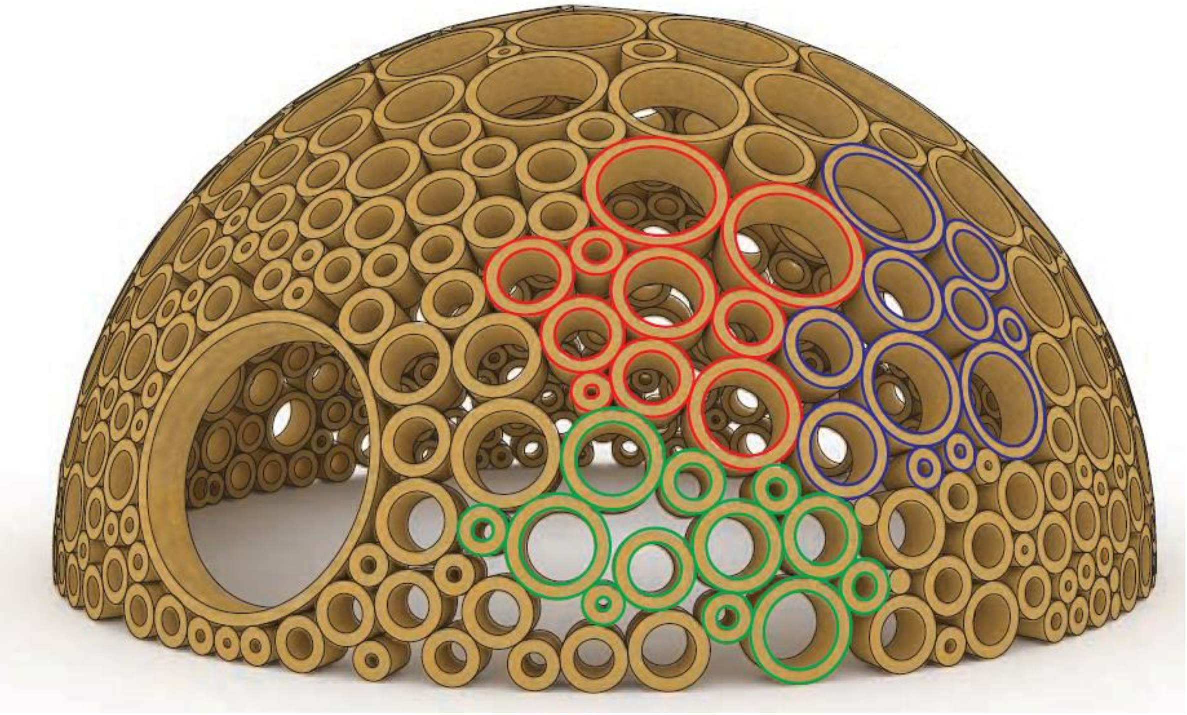

Figure 69 Entire dome assembled highlighting sub-assembly components in different colors. Source: Beorkrem (2017)

Material Constraints

The use of circular building blocks saves material, minimizes the production process and shipping volume for a project which is being manufactured thousands of miles from its final home.

The dome shape of the system ensures an equal transfer of loads and allows for each cone to have the same center point.

Software: Rhinoceros 3-D and Grasshopper for sphere packing

5.4.3 Pipe Furniture

On-Site Paris

Sebastien Wierinck

Figure 70 Pipe Furniture. Source: Sebastien Wienrick (2017)

The series of installations designed by Sebastien Wierinck use digitally fabricated skeletons as a framework to shape plastic tubing into new furniture. Two simple systems are used in this installation for the purpose of suspending and bracing the pipes in the desired configuration. The bundle of pipes serves as a piece of human-scale furniture that pieces together a smooth and comfortable surface. The manufactured sections frame the conditions of the final shape as well as the human conditions in which the tubes are allowed to 'flow'. Zip-ties are used to support and brace the tubes that rise up to the ceiling together.

Wierinck's installations are all developed around an awareness of the performative criteria of the plastic tubing (Beorkrem, 2017). Parameters taking into consideration for the tubes are the spanning distance, the radii for the curvature as well as the relationship between the human body and the seating material created through the bundle of tubes. While the steel profiles determine the profile of the tubes, their position on the steel frames is free to slide, move, or either rotate between the profiles. This degree of freedom during the installation means that the final form was not necessarily decided on the computer before but the profiles and spacing can be organized differently once on site. A parameter that is applied during the making phase. While the assumptions raised in the computer by the designer can be followed, the final shape will be a result of physical on-site changes of the steel frame profiles. They are held in place through horizontal bracing along the x-axis. This bracing locks the sectional components together into a substructure.

Figure 71 Base profiles for bench (a) and the result of loft between profiles (b) source: Beorkrem (2017)

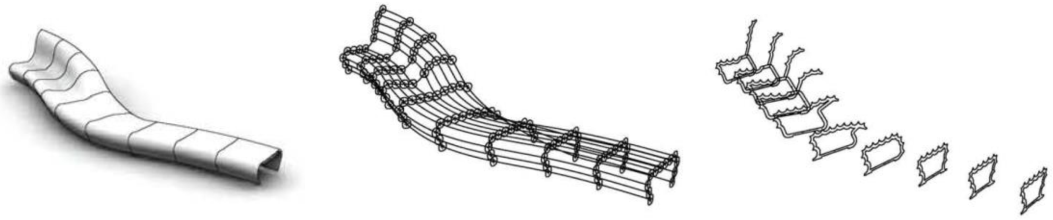

Figure 72 Contour of bench profiles (a) Circles are created along with the profiles, each center connected to define pipes (b) each pipe is subtracted from the profile (c) source: Beorkrem (2017)

The primary use of the tubing is that of underground gables that can carry either water, gas, internet, or electricity. There is a requirement for a bottom-up process to be adopted due to the system being less computational in this case. It is a process that defies the form rather than starting from the form of the system itself. The final shape can be obtained by locating each cross-section in place and finding reference points for connecting splines that are allowed to snake from one profile to the next (Fig 71b). The splines although just representational already give a preview of the final result. As the tubes rise to connect to the sealing, the previous relationship to the frames is left behind, and instead, relationships between each tube are created.

The end conditions of each profile are left to hang from the last point connection and show the natural elastic bending shape of the tubing. Each section profile was either laser cut or water-jet cut from steel and clearly represent a programmatic condition at a certain location. Small punctures are done to the tubes to allow for the zip tie connections and groupings. Lighting elements are added at the end of each tube as a way to conceal the awkward end condition.

Figure 73 Group of structural members (a), Final rendering of a bench (b) source: Beorkrem (2017)

Material Constraints:

The system is based on the location of the structural units which locate the pipes as they flow through space.

The diameter of the pipe defines the radius of its position on the structural system and how tight of a radius it is capable of forming. The hung form of the pipes from the ceiling are completely in tension and would bend more with smaller diameter pipes.

Software: Rhinoceros 3-D and Grasshopper

5.5 Observations

The analyzed case studied was purposely divided into different categories as their relevance to the purpose of the study itself was interesting for specific reasons. As they were not all realized projects and artifacts but also involved digital processes and technologies that are able to deal with the material in one way or another, making that material available for a building process. As the division explained at the start of the chapter of three categories is directly related to the output of each process.

Collection deals with the ability of a process to collect material from its surrounding, in the same way, the urban poor search for valuable materials in wastelands. Although the process in itself here has the advantage of being directly informed of its composition from its input or the ability to identify the material collected. The DustCart robot in Peccioli reminds you most of the robots from science fiction movies such as ‘Wall-E’ (2018) or ‘I, Robot’ (2004) where an autonomous robotic system is able to identify and collect waste while also having the information of how best to dispose of it. On the other hand, W.A.R takes a more industrial approach to the process. While relying on the ability of the technology to identify, through machine sensors, the chemical composition as well as the geometrical shape of incoming waste, the robot is able to pick and choose valuable objects for recycling or reusing through the incoming waste (Fig 56). The final product is an efficient autonomous system that is able to sort and categorize waste through a set of criteria. Seeing as both technologies have been available for a while now it becomes quite logical to think of a technology that is able to combine the two, the service of the friendly robot and the efficacy of top-of-the-line robotic automation.

Transformation in architecture and design has a very broad meaning. Even if we think of transformation in the sense of design we might still need to touch on a very broad topic. For the purpose of the research, we can define transformation as a series of permutations of manipulations applied to a concept, structure, or organization with a defined set of conditions without procuring a loss of identity. In an even easier example, pre-defined tools used in 3-D modeling software such as AutoCAD or Rhinoceros3D have commands such as Move, Rotate, Mirror, etc in the Transformations category. Meaning that even though the simple act of moving something we can transform it into something new. Mine The Scrap goes beyond that idea and through 3-D scanning of scrap material it is able to transform it into a valuable design piece. The project shows a wide range of possible applications of 3-D scanning technologies as well as algorithmic designs in order to deal with the complexity of the scrap material. The creation of a search engine that taps into an archive of scrap opens immense possibilities for designs. Unfortunately, all these possibilities are strictly tied to the available materials in the archive. The design processes changes to a bottom-up.

Making refers to the process of transforming digital data and ideas into a built prototype. It involves all the processes of material consideration, digital fabrication parameters as well as optimization of assembly processes that normally goes into every project. The three case studies shown are great examples of processes that start with the idea of using pre-cycled[26] materials. Each project shows careful consideration of the parameters of the materials selected as parameters that also drive the design forward. As the materials are devoid of architectural use beforehand, digital fabrication becomes the link between transforming and making through these materials. Connecters or guides are cut from plywood or metal while trying to keep the connections as flexible as possible to allow adjustments during assembly. The projects in each case show control over the material and fabrication parameters.

Each process shown in (Table 2) falls under the category assigned while still showing signs of crossing over creating a workflow. With machine sensor collecting and identifying certain materials and feeding them to a 3-D scanning system that is able to feed the data to an algorithm that optimizes form based on available material. All this while also optimizing fabrication parameters with material considerations in mind in order to design a system that not only is easy to assemble through digitally manufactured joints but also allows ease of disassembly and reuse of materials involved due to only using friction-based and non-adhesive connections. Materials

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[26] Pre-cycled projects strive in the application of off-the-shelf products that can be re used after the first intended use as an architectural installation (Beorkrem, 2017)

coming out of these processes can be ‘transformed’ for another cycle of use or go back to being recycled.

Table 2 Elements that each case study project shows for each category. Source: Author

COLLECT	TRANSFORM	MAKE
Autonomous collection	Parametrization of material	Material considerations
Human interaction	Archiving of materials	Fabrication parameters
Machine Sensors	Algorithmic generation	Assembly strategy
Urban Interaction	Reuse of existing	Disassembly strategy
Waste identification	Optimization	Connection methods
Waste sorting		Reuse

6. PRACTICE BASED

6.1 Overview

The literature review and case studies presented during this thesis helped in the purpose of understanding of the main processes where digital tools can become impactful when dealing with waste. The habit of refusing our own waste as a possible resource comes as a result of the bad stigma that follows it. On the other hand, recycling results show that we are passing up on a possible resource that can greatly impact the effect we have on the planet. Most solutions to waste boil down to incinerators which ultimately result in an even bigger carbon footprint due to it mostly being burned. In today’s age, it is estimated that there are more resources being used than we can mine from the earth itself. As our cities continuously grow and expand, more and more of the earth’s resources are now found in our built environment. Therefore the process of urban mining (Ruby & Ruby, 2010) comes as a logical solution. Recycling, as stated above, becomes an effective way to get raw materials that can be reintroduced in the production chain, lowering the carbon footprint as the cost of remanufacturing a material is a lot less than manufacturing it from scratch. In this logic, the city itself and it's waste become the perfect source or ‘mine’ for new construction processes.

Figure 74 Roma Camp in Tirana where shelters and housing are built from the waste collected from landfills. Photo: L. Plani

This has been a kind of unconscious process before, where the need for shelter precedes over the quality of materials used to make such shelter. A kind of vernacular approach to building with what the land offers with the main difference is that nowadays the land also offers waste. The initial life cycle of the product in this case is of little concern to the user, with the ability for the product to perform another purpose coming into focus. As the intended purpose falls into the background, geometry, and ability of the recovered material to aggregate with other objects becomes integral. This means seeing any waste from other processes with the potential of serving more than the intended first life-cycle. The definition used by Hebeel, Heisel, and Wisniewska during their book 'Building from waste' on recycling says: "recycling takes given objects in their context and re-applies them in different contexts and with different functions with little or no physical modifications." (2015) And while this definition basically opens up a resource that is presumably worthless to society, this merely welcomes the possibility of tapping into a resource but does not change that resource as applicable to building processes. That has to happen through a process of transformation of our design and construction methods but also views on the material.

The architectural design process, especially in the digital design era, consists mostly of designing a digital model through an endless representation of materials in the digital world. Digital tools excel at precision, which is passed upon to our manufactured products through digital fabrication. Even components specifically manufactured to be used as part of new processes are standardized. Unfortunately, this precision is often lost after the first life cycle of the product making the process of transforming these materials more complex. As this creates a new challenge, digital tools can help overcome complexity. As shown during Chapter 5, 3-D scanning and machine vision can be used in order to create a digital representation of the objects in a digital environment. Algorithmic design can deal with the complexity of the design as well as add an optimization process to find the best solution. Assembly and building processes can then be created, with digital fabrication used to manufacture joints and connections between pieces that not only can make the final result buildable but can also help and inform the assembly process. The implications of such a method in this case fall into the result already observed during the case studies. The design process must first and foremost start from a careful consideration as well as a digital representation of the selected material stock.

The following projects conducted as part of the practice of this research explore different parts of the mentioned processes with a focus on recovering materials from their current life cycle and using them in a new setting. Digital tools take center stage in all but the first project, that of UrRe 2.0 in Struga (2018), where recovered materials are ‘transformed’ into new configurations. UrRe 2.0 focuses on the process of recovering waste material from the immediate environment which becomes even more important due to new regulations being introduced. The diagrid bamboo structure focuses on recovering bamboo material, a natural material that does not qualify as waste but becomes interesting as a practice case of recovering material. An exercise in 3-D scanning is conducted in order to better understand the limitations that technology has. The last two practice projects focus on trying to achieve a buildable result while using a pre-cycled material of PVC pipes along digitally fabricated joints that inform the assembly and allow disassembly. The process is then extended into a design class with the purpose of seeing it applied to a different solution while using the same or similar algorithmic process.

6.2 UrRe Workshop 2.0, Struga

UrRe[27] is born as a project of community involvement in Struga, Macedonia, organized by the EU and organization such as CreativeActive Struga, EU for You, and the Local Development Agency. The workshop is born as a way to promote community engagement in urban design processes especially due to changes in Macedonian law which sees public space ownership passing from the municipalities to neighborhood administration. Due to the implementation time and also to a history of neglect even under municipality ownership, the fear that these areas would fall into a process of degradation became real. The workshop aimed at finding a solution and creating a set of operations that can be replicated in different neighborhoods in Struga. A lack of funding, previous disorganization by local authorities, and disbelief between the inhabitants made the task harder. A participatory process was followed during the discussion and design phase in order to create a sense of ownership and agency in the new spaces.

It quickly became clear that these processes for these neighborhoods would have no funding with habitats that were directly connected unwilling to pay due to mistrust. This is how the idea of engaging the community in using local recovered materials that they would view as waste became a reality. Waste in this case would imply anything abandoned or seen as worthless in the area. The workshop below follows closely a lot of the principles explained in Chapter 3. Starting from Urban Mining as a way to find the resources needed to understand the underlying qualities of the waste that was “mined” around Struga. Design and solution were thought of only after the participatory process and after having a stock of materials that could be used for the interventions.

6.2.1 Methodology

There is no simple solution or one fit all approach to identifying an effective participatory method. Therefore, aiming to engage the most marginalized communities especially young people and children, as the sub-category of

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[27] CreativeActive Struga, the organizers held the 2nd workshop of this nature in Struga. More results can be found in the link: http://creativeactive.org/urre-2-0-urban-shelter/ [last accessed on-line 16.08.2020]

vulnerable groups, to thrive and involve in active participation of urban life, a combination of a range of complementary participatory methods shall be used. For each phase of the workshop, a specific participatory method was implemented.

- Online Survey and Facebook-based campaign
- Area mapping
- Partnership with the community
- Meeting with the local governance
- Waste collection and categorization / Mining
- Designing
- Child-friendly and participatory Design Process
- Future Recommendations

As short term recommendations and action was taken during the workshop, as the fastest and cheapest way to answer to this problem, designs that focus on the ‘do-it-yourself’ culture using recovered materials from the area was proposed. These, while lower in quality, offer the cheapest alternative to create transformation in the area. They are accessible to almost everyone that can use basic tools and require basic knowledge of manipulating the materials that are recovered. Obviously working with these materials, especially in the participatory planning process can have drawbacks. One main concern that came from this suggestion was the sanitary side of working with materials regarded as waste. This was easily overcome by treating materials properly through the cleaning or transforming them.

Figure 75 Views from site 1 showing the current condition. Source: UrRe 2.0 (2018)

6.2.2 Results

Figure 76 Participatory design. Using kids as generators of ideas for their space. Credits: UrRe 2.0 (2018)

A workshop for kids was developed where they were asked to design a playground of their dream. On the other hand, a large model was prepared in order to generate discussion amongst adults in relation to specific topics we considered crucial; such as materials, parking area, kids’ corner, safety, etc.

Figure 78 Clean up process, using the recovered materials for the interventions. Pallets serve as planters, tires as borders, and crates are turned into bins by habitants. Credits: UrRe 2.0 Workshop (2018)

Material and human resources

Materials gathered through recycling can be of various forms and functions and most importantly can be adapted to fit new uses that the community needs. Simple shipping pallets, collected from markets or shops can be adapted as outdoor furniture through simple woodworking techniques like cutting and assembling. Benches, tables, orchards organizers, fences, bicycle parking, movable platforms, etc. can be made through little effort and practical knowledge. Recovered tires that can be found in numerous scrap tire yards, and easily gifted by mechanical shops can be a free solution to be used as space dividers, sitting elements, flower pots, children's playgrounds, etc. Other materials that can be cheap or provided by the community resources like stones, flowers, paint, beer cases, plastic bottles, bolts, and nails can be adapted by the community using DIY techniques to transform the objects and the space to either temporary or final solutions.

Figure 79 Catalogue of actions proposed during the workshop with practical actions taken on site. Credits: UrRe 2.0 Workshop (2018)

6.2.4 Observations

Although no digital tools were used (apart from normal drawing) during the UrRe 2.0 workshop, the challenge of proposing waste or recovered material as design solutions proved interesting. The final project and intervention were limited to a single neighborhood in Struga. While fairly successful in transforming a space and creating functional urban furniture and design elements, the project served as a pilot for other public spaces in Struga. In the interest of our research, the ability to quickly respond to a design problem through the use of 'local waste' shows once again the ability of waste to be a resource when viewed as one. The impact of waste being a dirty, unhealthy, and non-sanitary material was easily changeable when inhabitants were faced with the cost of the alternatives but also when they were the ones to collect the waste itself. They were also quite ready to take part in all parts of the processes, as becoming part of building and making created a different connection between user and space. While the average citizen probably does not have the skills to build or design their own furniture, through the use of open-source design and support from local experts, these processes can become the norm. Especially for citizens which are unable to pay the new upkeep fees that this new ownership of public spaces implies, recovered materials could make the difference.

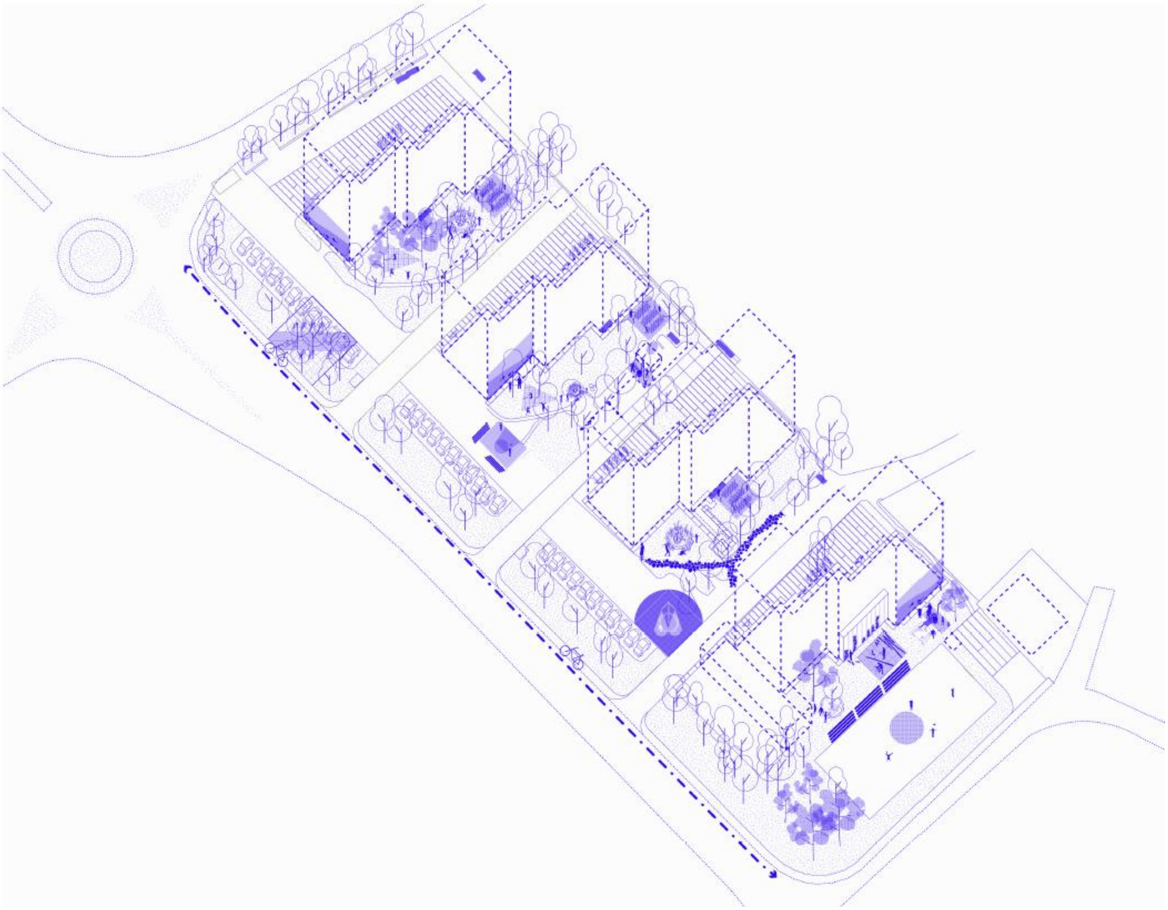

Figure 80 Collection of proposed actions and interventions for the neighborhood, source: UrRe 2.0 (2018)

6.3 Parametric Bamboo Spatial Structure

Recovering materials requires the user to take materials out of the first process before reusing that material for a new one. The next experiment tries to transform material from another installation as a useful resource for the next one. As this material is bamboo, a natural material that is not usually regarded as waste the question and focus here lays more on the process of transforming the material into a new installation rather than questions about recycling. Although organic matter can decompose without causing waste, we see some value in re-using some materials before returning them to the earth. It is important to note that even though biological materials degrade in nature, they lose that ability if treated with protective coatings.


Estruturas
Espaciais
Paramétricas
em Bambu

workshop de projeto e fabrico
Junho 5-23, 2018

Promovido no âmbito do curso de Estruturas Especiais do MiArq (EAUM), o workshop centra-se no desenvolvimento de estratégias de modelação paramétrica para o desenho e fabrico de uma estrutura espacial em bambu.

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Figure 81 'Estruturas Espaciais Parametricas em bambu' workshop poster, source: Parametric Bamboo Spatial Structures (2018)

The workshop “Parametric Special Structures in Bamboo” was held in June 2018 and was presented in the form of a workshop held as part of the ‘Special Structures’ class of Minho University. The workshop would be a design and building workshop, with the main aim being to build a structure in reused bamboo while also introducing digital tools and parametric design basics to the participating group of students. And although organic matter can decompose without causing waste, we see some value in re-using some materials before returning them to the earth. Bamboo has been also used widely in construction before with many examples and showing great applicability in the building industry.

6.3.1 Methodology

The main aims of the workshop were to achieve two things: introduce students to digital tools and parametric design and design and build a structure reusing the bamboo from another construction. The workshop agenda was limited to 5 days spread out in three weeks with the software tutorials and design happening early and the construction phase happening in the final days. Bamboo was the material of choice as already available from the previous workshop (Fig 82).

The first part of the workshop involved an introduction to the 3-D modeling software of Rhinoceros3-D and Grasshopper, a plug-in that turns Rhinoceros3-D into a parametric software with a visual algorithm editor interface. During this phase, the students were presented with the basics of Rhinoceros3-D and Grasshopper. Due to time constraints and prior knowledge from the students of the tools, the workshop would focus on using a pre-prepared algorithm but with enough freedom of control through a set of parameters. Designs had to be proposed following a certain type of structure (diagrid) and utilizing as much bamboo from the previous installation as desired. While full reuse was not a condition, the students were still asked to use as much material as possible. Students would present their results and vote on the best project which would then be built.

The building phase would happen at the end of the workshop in order to have enough time to analyze and optimize the proposal of the students through the algorithm. The building phase had to be spread out in two working days with the assembly process being as simple as possible. Assembly could not use any adhesive for the joints.

The aim is to use the algorithm as a design tool that revolved around the material usage itself. Meaning that every design choice made would come informed directly from the algorithm of the outcome, in terms of spatial configuration, but also in terms of material consumption. Each design solution would then take into account not only the design itself and its performance but also the impact that the design had on the pool of material. The structure is to be built in front of the school cafeteria with a function to be defined by the students themselves as well as size and scope to be discussed during the voting phase.

Reciprocal
Bamboo
Structures

workshop in design and fabrication
17-19 June, 2017

The workshop focus on the design and assembly of a reciprocal bamboo structure in the outer space of the building of the School of Architecture of the University of Minho.

Coordinators
Prof. Paulo Cruz & Prof. Bruno Figueiredo

Figure 82 Reciprocal Bamboo Structure, the first cycle of the material. Credits: Minho University (2017)

6.3.2 Material

The material of choice would be bamboo so the properties of the material relevant to the project must be understood. Bamboo rods are known for their round shape, segmented and jointed length as well as their hollow interior. The internodes can have a varied thickness and length largely depending on the species and the environment. The peripheral zone of the bamboo (or outer culm) has smaller vascular bundles while in contrast, the inner part has bigger but fewer bundles. The number of vascular bundles in bamboo culm is reduced from top to bottom, while the density remains relatively unchanged. “The composition of a bamboo culm consists of 50% parenchyma, 40% fiber, and 10% conducting tissue” (Liesse, 1998). Bamboo is considered a very strong construction material with compression strength up to two times that of concrete and almost the same tensile strength as steel (Anagal, et al., 2010). Splitting bamboo offers a flexible and easy method of construction although splitting it can decrease the strength of it as well as cause structural deformations and deflections (Marina, 2015). In this case, the flexibility would work to our advantage

Bamboo offers great flexibility due to its ability to bend but also due to its strong resistance. As we have seen in previous cases, the first step would be a collection process of the bamboo from its previous use to the new one while cataloging the material. The bamboo rods were mostly of different diameters and even the ones that were sold as the same diameter had differences. It became clear in this case that the most constant parameter in these bamboo rods would be the length. Although diameter (⌀) is defined as a round constant number, due to bamboo being a natural material it cannot be defined as a static parameter but rather a changing parameter throughout each element. Simple tests with the purpose to understand the bending capabilities of the split bamboo were conducted. It becomes clear that the split bamboo would provide a much more flexible material that would be easier to manage in certain structures. Furthermore, splitting it could potentially triple the amount of material available although this coming at the cost of limiting future reuse possibilities.

6.3.3 Inspirations

As the aim was to have the algorithm help the students design a certain structure that would facilitate the whole process, the type of structure needed to be decided before designing the algorithm. Research processes involving structure that require linear materials was conducted, with structures that used actual bamboo as a material taking central focus. The Warka Tower is a structure that was conceived by the team at Architecture and Vision[28] and Arturo Vittori. It is a structure made that draws inspiration from the tree by the same name although the sizes themselves differ. It is a latticed bamboo structure lined with an orange polyester mesh that works as a water harvester (Stinson, 2017). It has been highly successful at introducing a structure that can be easily assembled on-site, in communities where water resources are low.

Diagrids are structural systems consisting of diamond-shaped modules where lateral stiffness is more provided than in conventional structures. In recent years diagrids have grown in popularity due to the offered structural flexibility and elegance. The main distinguishing characteristic is that vertical columns at the periphery are eliminated in diagrid structures. Due to the triangulated configuration forming in the diagrid structural system as a result of the modules, loads such as

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[28] http://www.architectureandvision.com/portfolio/073-warka-water-2012/ [last accessed on-line 22.07.2020]

gravity or lateral are carried and distributed in a uniform and regular pattern. In addition, by using diagonals, less amount of material is used. Also, due to the elimination of columns, much more space is available that allows for more flexibility in the structure. (Khan & Shinde, 2015)

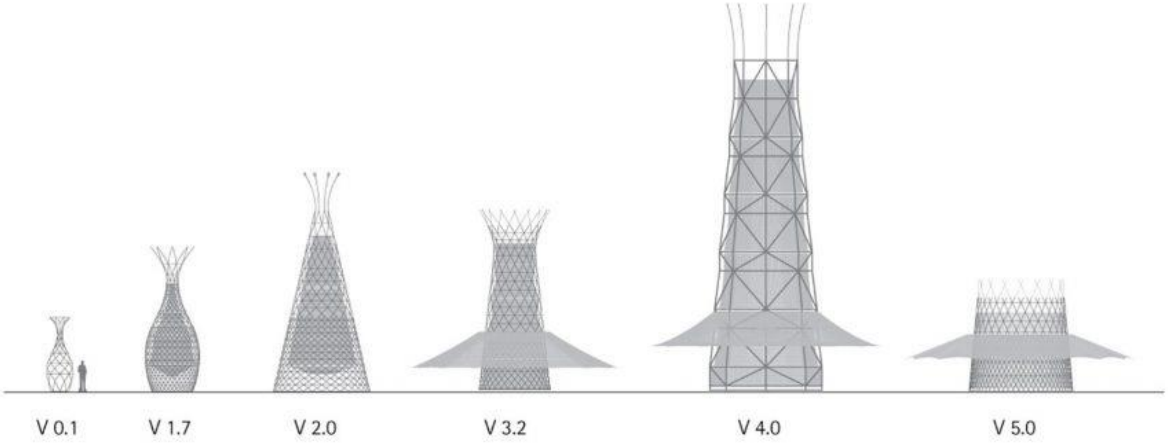

Figure 83 Warka Tower possible configurations using the same method. Source: Dezeen[29]

Due to the Warka Tower case as well as the above-mentioned advantages, the diagrid structural model will serve as a starting point for the design of the algorithm. It is worth mentioning that the flexibility allowed by the structural system itself also allows for more flexibility and complexity that can be incorporated in the algorithm itself.

6.3.4 Algorithm

The starting criteria to design the algorithm were outlined in the subchapters above. The first and starting criteria must be the length of the bamboo, the only constant parameter (apart from the very few pieces of 2.5m) throughout a non-standard material such as the bamboo. It is important at this point to have a clear understanding of the parameters that can be controlled by the user in order to change the design outcome while still achieving buildable solutions from each possible iteration generated. As the tool to be used will be Grasshopper, a visual algorithm editor, parameters and algorithmic operations will be represented by algorithmic components each dealing with specific transformations in different parts of the process.

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[29] https://www.dezeen.com/2016/11/10/video-interview-arturo-vittori-warka-water-tower-ethiopia-sustainable-clean-drinking-water-movie/ [last accessed on-line 12.07.2020]

As the structure of choice is a diagrid structure based on the Warka Tower it made sense to start with a circle at the basis that is copied multiple times along a Z-axis in order to define the total height of the structure. The full algorithm shown in Figure 65 is then divided into parts according to the function each part has towards the final design. The algorithm is capable of generating a preview of the design as well as giving an estimate of materials used which then informs the user whether the controlled parameters result in the desired design outcome. Material usage can be optimized until the desired result is achieved. The process and parameters shown in Figure 66 are a step by step division of the control offered by the parameters as well as the degree of control and impact that these parameters have on the design.

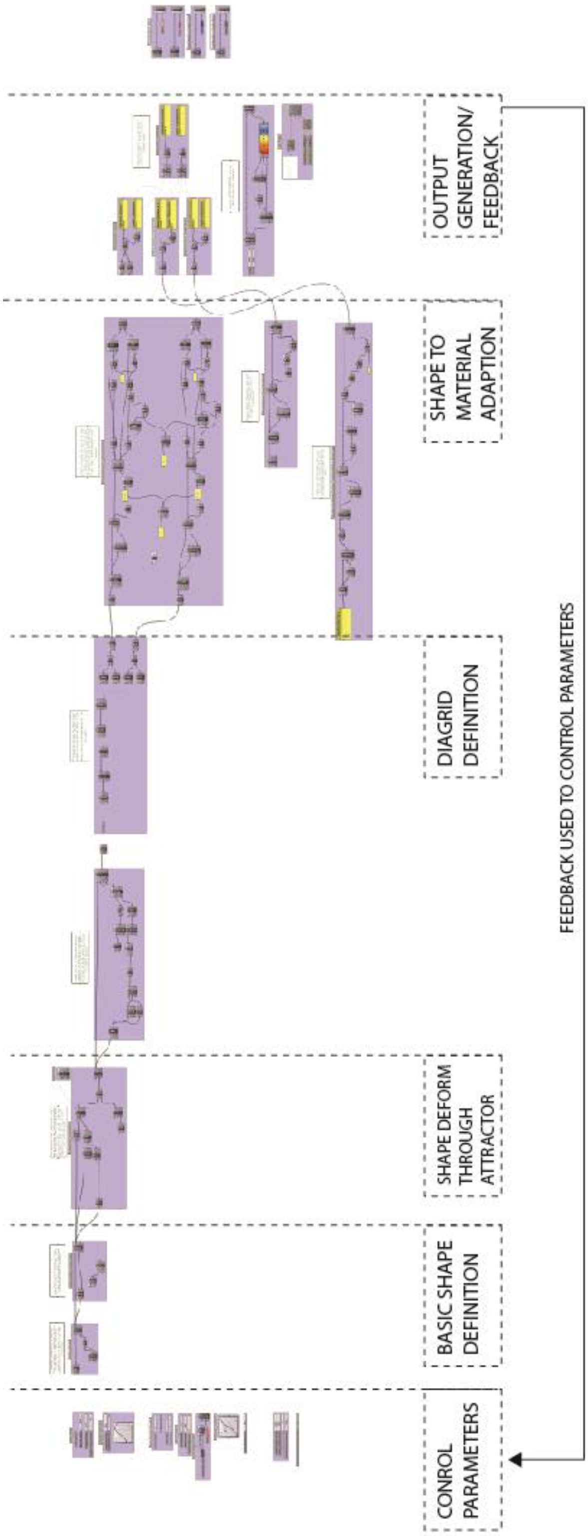
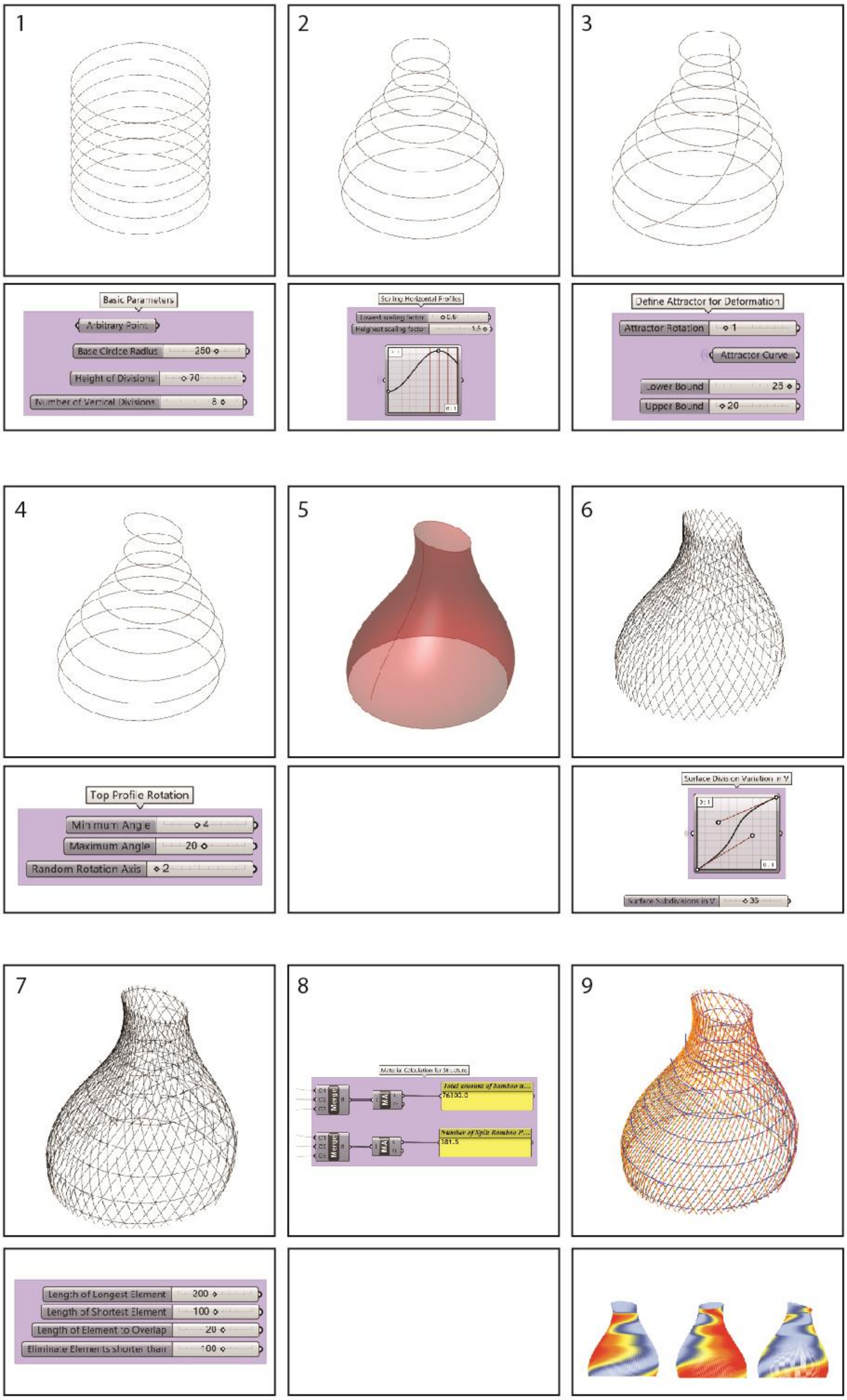


Figure 84 Final Grasshopper definition. The outcome being both design and estimate of materials informs the user when controlling parameters. Source: Author



Basic Parameters
Base Circle Radius 250
Height of Divisions 70
Number of Vertical Divisions 8

Scaling Horizontal Profiles
Lowest scaling factor 0.6
Heighest scaling factor 1.5

Define Attractor for Deformation
Attractor Rotation 1
Lower Bound 25
Upper Bound 20

Top Profile Rotation
Minimum Angle 4
Maximum Angle 20
Random Rotation Axis 2

Surface Division Variation in V
Surface Subdivisions in V 35

Length of Longest Element 200
Length of Shortest Element 100
Length of Element to Overlap 20
Eliminate Elements shorter than 100

Material Calculation for Structure
Total amount of bamboo a... 76300.0
Number of Split Bamboo P... 381.5

Figure 85 Process of algorithm and parameters controlled for the generation of the structure. Source: Author

Definition breakdown[30] *(Fig 85):*

1) The algorithm starts with an arbitrary point (a) that can be set from Rhinoceros or defined parametrically. The point feeds the generation of a circle where the radius (b) can be controlled. The circle is then copied alongside a Z-axis starting from its center. The number of copies, as well as distance from each, are controlled by sliders (c) and (d), where multiplying the number of divisions with the distance between them gives us the height of the structure.
2) In order to have a larger degree of freedom in the shapes generated a graph mapper (b) alongside a lower and highest scaling factor (a) were added. The Graph Mapper is a two-dimensional interface with which we can modify numerical values by plotting the input along the Graph's X-Axis and outputting the corresponding value along the Y-Axis at the X value intersection of the Graph. It is extremely useful for modulating a set of values within an institutive, grip-based interface.[31] Changing the lowest and highest values of scaling factors, along with different possible graphs, allows for many design solutions to be explored quickly and with instant feedback.
3) Another design variable was added in order to add to the range of possible design solutions. An attractor curve (b) is generated by defining a set of shifting points from each horizontal curve (a) and interpolating a curve between them. The attractor's job is to pull each horizontal circle towards the attractor. This results in each circle's center not being aligned to the others. The sliders controlling the upper and lower bounds (c) are there to define the maximum pull that the attractor has.
4) The top and last profile are then rotated alongside a randomly generated rotation axis (b) and controlled by the two sliders through the maximum and minimum rotation angles (a).
5) A preview of the resulting surface is generated for visualization purposes as it allows the user to understand and make early design decisions.
6) The surface generated in step 6 is used as a basis for the generation of diagrid. In order to achieve that the IsoTrim component, which divides the surface alongside its U and V domains, is used. Connecting opposing vertex

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[30] Parameters for each section have been labelled from (a) to (d) going from top to bottom Units are set in centimeters

[31] Grasshopper Primer – ModeLAB, https://modelab.gitbooks.io/grasshopper-primer/1-foundations/1-2/3_data-types.html

points of each rectangular surface with lines creates the diamond-shaped pattern of a diagrid structure also provides a visualization of the outcome. Slider (b) controls the V divisions alongside the surface also controlling the density of the structure itself. The U division is directly fed from the parameter in 1(d) in order to maintain the same division in U as defined at the start. Another graph mapper (a) is used in this case to control the span and a changing division density. This design parameter was added in order to provide a side of the structure denser that could also provide some shading depending on the function.

7) In this step, the material of choice is finally introduced into the parametric process. In order to have a process that can adapt to the material of choice. As mentioned above, with bamboo being the material of choice, some design choices have to be made at this step which is directly correlated to the material. As mentioned above the only recurring parameter between the pieces was its length of 200cm defined in the first slider (a). This meant that each continuous diagonal line is divided into pieces of 200cm each in length. Pieces left over that are smaller than 100cm are then eliminated (b) from the design as they would require bamboo to be cut more. Since we are using split rods, the width of each bamboo will be different but similar for each. In order to have the continuous diagonal elements a connection using zip ties and overlapping the bamboo was tried both for the overlap (c) and the intersections. As the connection needed to be fast, and easily removable. Seeing as the design is now defined from the length of the bamboo we are using rather than a computational division based on the computer model.

Figure 86 Overlapping bamboo connections for Vertical elements tried with zip ties and metallic wire, photo: author (2018)

8) This part serves purely to visualize material usage through the structure. It takes all pieces from both the diagonal as well as horizontal elements. (for the horizontal elements the 250cm bamboo roods were used after being split in order to allow for more bending) It is a clear estimate of the potential that the structure has to reuse as much of the material available according to the design criteria. This can then inform the user of possible parameter changes to the definition in order to achieve an outcome that uses less or more material.
9) The final visualization is a preview of the outcome, color-coded by the direction of each piece. A secondary skin was explored during the design phase in order to provide more shading but was later scrapped from the final design. The three schemes represent a point cloud of the form visualizing the minimum and maximum curvatures with red being the lowest and blue the highest.

The definition was part of the initial tutorial about the tools and was provided to the students.

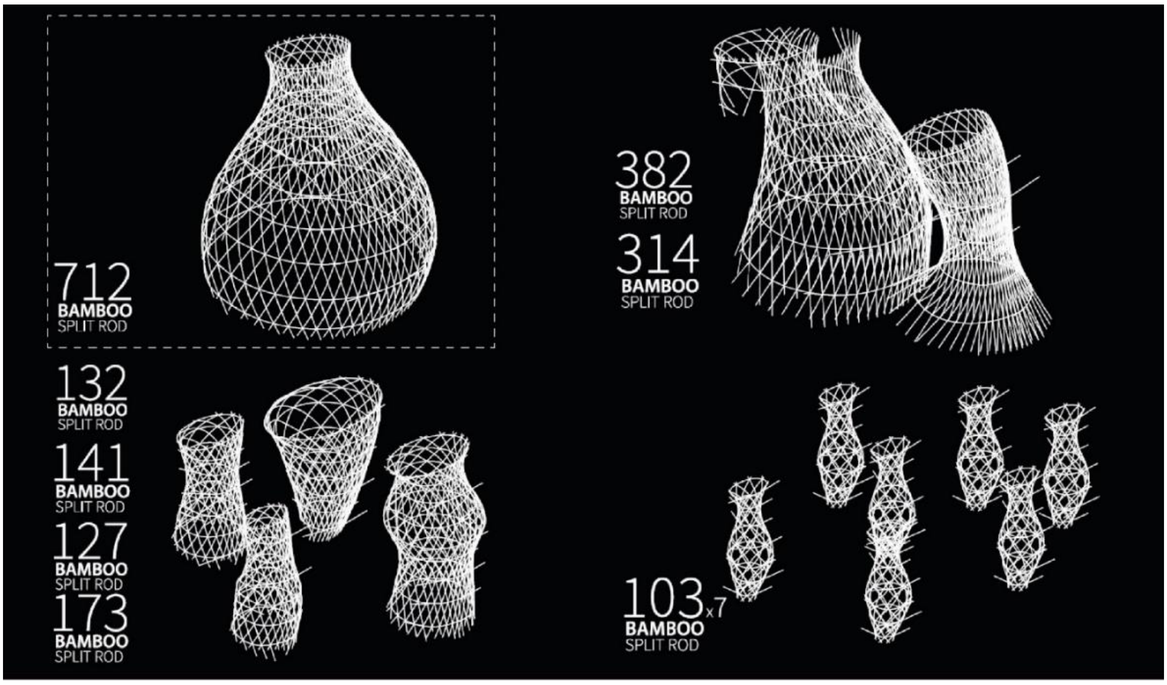

Figure 87 Results of the Workshop at U Minho and some of the proposals generated by students during the workshop source: author (2018)

6.3.5 Assembly

The construction of the bamboo structure would be informed obviously by the result of the algorithm but preparations were made beforehand on some key aspects of the construction process. Firstly a document explaining the construction process divided into three parts was prepared by the supporting staff of the workshop in order to be distributed to each student.[32] This booklet served as a guide to the assembly process. Students who did not know the design from the previous phase could consult this document and be able to take part in the assembly. Each student working on the assembly part needed no tools. A preparation phase before the assembly took place where bamboo was marked with the connection positions as well. Bamboo was split using a bamboo splitter, where each bamboo rod transforms into three bamboo strips.

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[32] The booklet was prepared by students João Moreira and Tatiana Ocampos. https://drive.google.com/file/d/1khmS7vZCW7IcT3GRGfdAB7_wvk5AVIA3/view?usp=sharing [last accessed on-line: 17.7.2020]

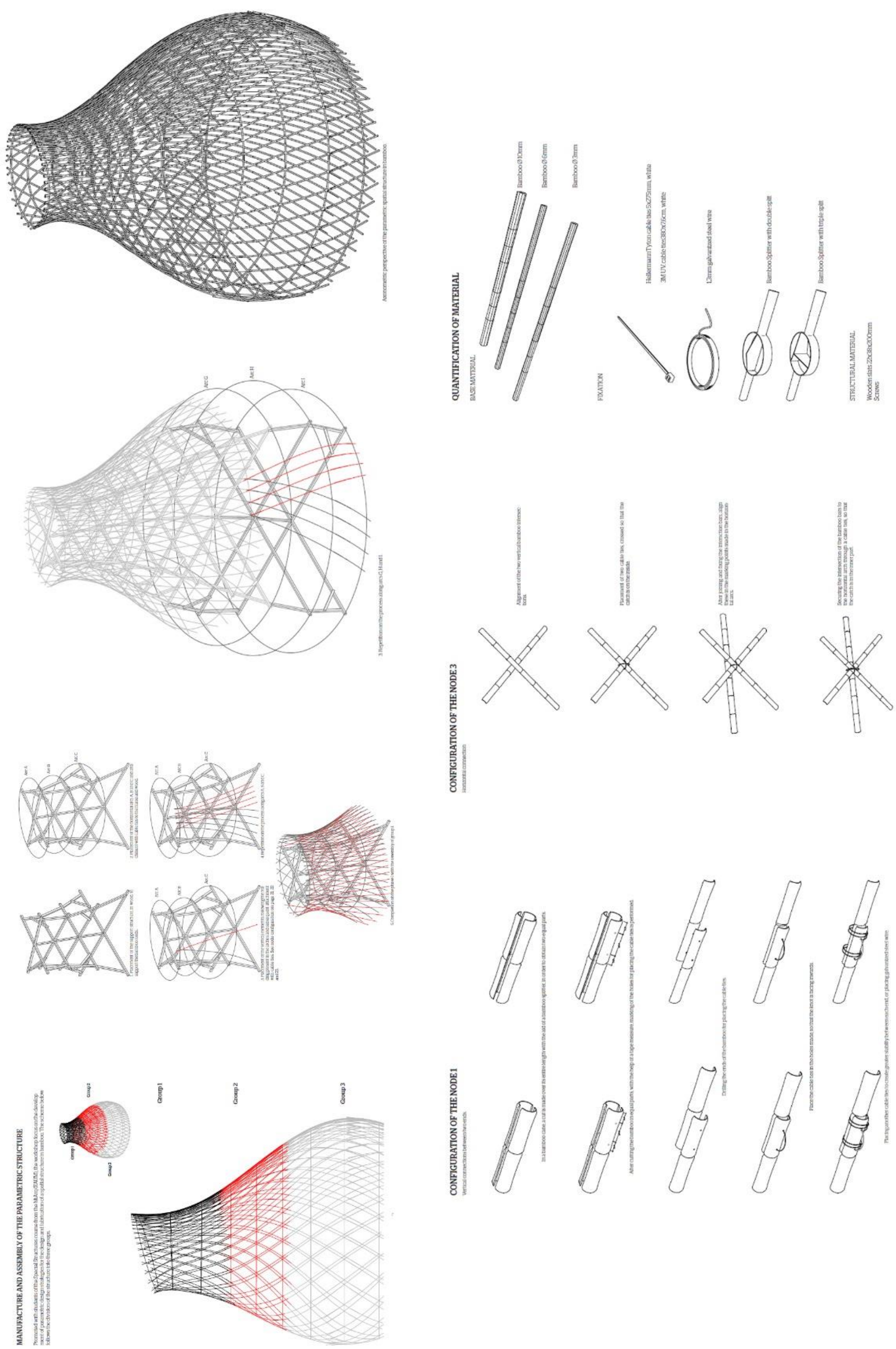

Figure 88 Pages from the pre-prepared construction booklet, showing assembly process source: Parametric Bamboo Spatial Structures Workshop (2018)

Assembly would start with the upper part due to the smaller scale but also easy to lift the part and build continue with the bottom two parts. Each bamboo strip placed would be followed by another in the opposite direction in order to allow the strips to overlap and underlap along as the structure is assembled. As the structure could be moved, no markings or preparations were needed on the ground. The horizontal profiles of the structure do not coincide with each other on the Z-axis, so a support and guide structure was generated. The guide would work in three parts (Fig 90a) to coincide with the assembly and built from 60x40mm wooden elements (Fig 90b).

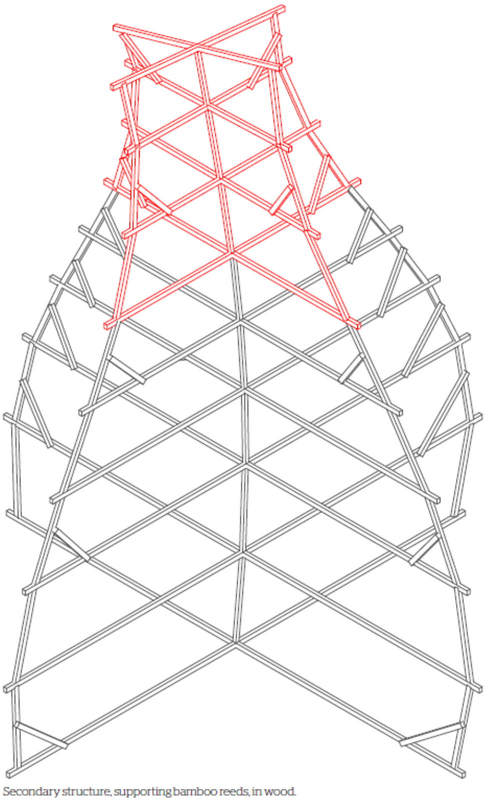

Figure 89 Secondary Structure, with the first part, highlighted in red. Source: Parametric Bamboo Spatial Structures Workshop (2018)

The horizontal rings were created by connecting bamboo strips from the ends in order to extend their length and wrapping it around the horizontal crosses on the support structure. The strips were connected at the ends with 20cm (which was defined during the algorithm design phase) overlapping and joined with zip ties (as shown in Figure 87). Pieces are marked to identify where the vertical bamboo strips would connect with the horizontal rings. Zip ties are used to keep the closed circle together. Strips are assembled by alternating the directions after each strip. Using zip ties for the connection allows us to work around irregularities of the bamboo strips and make adjustments on the fly. Each finished part is lifted on top of the sequent guide structure in order to be assembled. The already placed strips of two meters each are connected and elongated from their ends using the zip ties and the 20cm overlapping method. Once the assembly gets into a rhythm the process starts becoming quite straightforward and faster. Zip ties in this prove to be an advantage as they can be re-adjusted or replaced on the spot without damaging any part of the materials.

After the structure is assembled, the guide inner structure (Fig. 93) can be dismantled from the inside by one person leaving the outer diagrid structure. An entrance is then opened in the end spanning 70cm in width by cutting part of the horizontal structure. The side where the diagrid has a bigger gap between vertical elements is used for this purpose. The end result is a structure nearly six meters tall with a base diameter of 5.5m built entirely of recovered bamboo that was split. The preparation and assembly phase (once the collection and transformation phases are done) took less than the planned 3 days of construction, instead of being completed in 2 days or 16 hours of work. The assembly part rarely needed more than 4 people in order to complete certain tasks and most could easily continue the process by taking over from someone. The students that took part in the workshop had no prior experience designing with parametric design tools or working on similar building workshops, proving the ease of assembly in this case. The bamboo installation was part of the university’s backyard for a few months before being disassembled.

Figure 90 (a) Marking the horizontal structure for the connections (b) assembly of the first part photo: author (2018)

Figure 91 (a) assembly of the first part, placing bamboo strips (c) Assembly almost finished with all three parts photo: author (2018)

Figure 92 During the assembly of the second part. Photo: Author (2018)

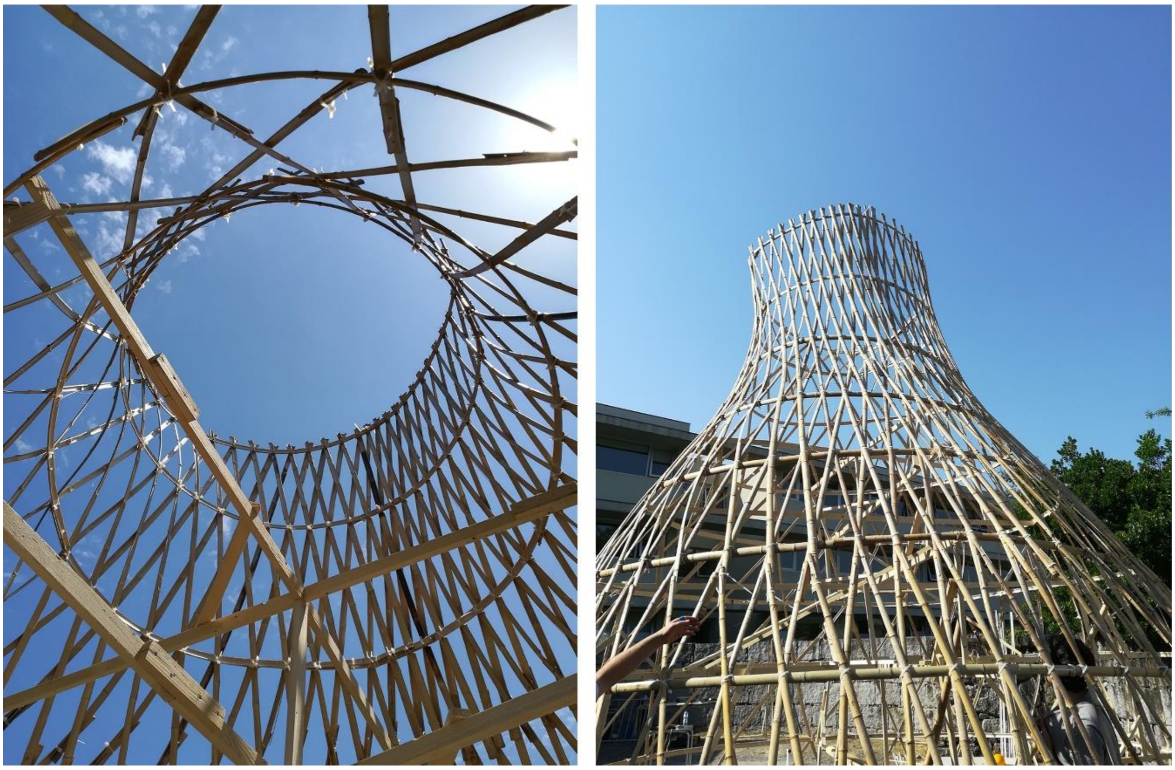

Figure 93 View from the inner part with guide structure visible (a) view from the outer part (b). Photo: author (2018)

Figure 94 Finished bamboo structure. Photo: Jona Rapi (2018)

Figure 95 View of the structure from outside the school cafeteria yard. Photo: Author (2018)

6.3.6 Observations

This workshop allowed us to observe the assembly of the structure but also the possibility to see how a digital design process can be coupled with effectiveness with analog techniques. Students who just learned about parametric design and using parameters to manipulate a digital form were presented with new tools in order to achieve this. Bamboo cannot be regarded as a material that has a standard and in this case, the standard part is chosen for this specific design purpose. Bamboo, "is a high-strength, rapidly-renewable, low-carbon sustainable building material, but represents a small fraction of global construction" (Van Der Lugt, 2017). Therefore it can be adapted to many uses, especially more uses outside of the small but growing presence in the construction industry or after completion of the first intended life cycle. Justified concerns do arise about the durability of the untreated bamboo and its longevity. Temporary structures look a more suitable solution in this case, with the ability to reuse the material as an important characteristic of the process as the endpoint can become the starting point for the next structure. In this case, we delay returning the bamboo to the earth as waste in order to reuse the material at its maximum potential.

As the algorithm provided with a value of the usage of material, that part can be automated through an optimization algorithm. Galapagos is an evolutionary solving algorithm that allows for the optimization of design parameters based on maximizing or minimizing design parameters towards a fitness number. In our case, the fitness number could easily be e relation between the material used and the volumetric result. In this case, we can think of Galapagos as a way to optimize the best material, especially when needing to split the material available between multiple structures. Furthermore, the method used required no further fabrication of pieces or elements other than the secondary structure which used standard square wooden rods. This method limits itself to identifying the constant and very measurable parameters in a natural material that should normally be anything but standard. This is not different much different from what the industry normally does, which is to take material from nature that is not standard and make them standard. Ironically, tools of digital fabrication work in a different way, requiring standard materials to turn them into non-standard shapes (Iwamoto, 2009).

The idea of using the inherent geometrical quality of bamboo in a digital realm becomes even more interesting in the case of future iterations. 3-D scanning can be seen as a viable answer. Mario Carpo noted how scanning has become a widespread process, especially within the forestry industry as a way to allow timber members to maximize the output and production of standard lumber. This widespread availability of scanning with the technology makes it easily applicable in architecture “The only way to deal with the inherent capriciousness of ‘living’ materials is to react to their whims and volitions on the spot and on the fly” (Carpo, 2017). In the structure seen above, this was addressed in the form of manual adjustments to positions as the zip tie nodes allowed that. It was a highly manual process.

On the other hand, 3-D Scanning opens up possibilities as it allows for direct analog to digital translation allowing for manipulations to be made on the material itself too. In their paper ‘Digital Fabrication of Standardless Materials”, Macdonald, Hauptman, and Schumann propose a bamboo design based on scanning bamboo rods and creating joinery specific to them through subtractive manufacturing. This opens up possibilities of working with non-standard materials. Waste or recovered products could easily be defined as compromised standard materials. As they put it this method is “…proposing a system that is both responsive to a given material supply by allowing the assembly to adjust to working with the specifics of the part, as well as retaining the ability of the design to achieve the intentions of the author in the larger assembly” (McDonald, et al., 2019). This correlates directly to what has been discussed in previous chapters, where the idea of a design based on available stock of materials is seen as a viable method when dealing with recovered materials.

6.4 PVC pipes and 3-D printed joints for a diagrid structure

Plastic has become one of the most threatening dangers that our environment faces. The same amount of oil is required both as raw material and as oil burned to create the energy for a single plastic bag. It is estimated that one kilogram of CO_2 is emitted in the air for the production of just five average plastic bags. There is a possibility to save almost half that amount if we could approach waste through recycling instead of burning and locking it away (Hebbel, et al., 2015). And while recycling still requires some amount of energy in order to recycle the waste, recovering the material and re-using it is arguably the cleaner alternative. The material's life cycle is extended because of the new use and the material fulfills a new role given to it by the designer.

The previous process (6.3) involved a non-standard natural material that does not produce waste per se but that still has value in re-using it. As a continuation of the process started at Minho, the idea to find a substitute material to do the same in Albania. A material that could substitute bamboo in the creation of a diagrid structure was thought keeping in mind the context of the workshop is in Albania. As a result, the material had to be linear and easily available. Albania does not have a successful history with recycling and waste management (1.2.3) and as an interesting solution and one that can be applicable in the future, PVC pipes were selected. PVC pipes are plastic linear pipes that are commonly used for different applications and industries and come in varied forms. They are resistant and made to live with our buildings for years to come. Widely available in every shop that deals with construction hardware they presented a great object to use in an architectural installation that also easily turns into waste. As Tirana is a city heavily under transformation, the opportunity to find and mine this kind of material was interesting.

Tirana resource container

Due to the post-1990 massive margination towards the metropolitan area of Albania, comprising the territory between Tirana and Durres, people squatted land wherever they could, giving rise to sprawled informal areas that surrounded the main cities and their periurban areas. In the case of Tirana, with the city growing and expanding, over years the western Ring Road became a space dedicated to connecting all these areas, very organically rising as due to all the geographical conditions and circumstances, rather than being an outcome of any form of city planning, or long-term visioning (Kaçani, 2019). Only later in 2012 JICA (Japan International Cooperation Agency) recognized it as a strategic infrastructural axis for the city, an outcome which was recognized by the General Local Plan of the city in 2016, coined as the “Great-Western City Ring”. The project was proposed by the Ministry of Infrastructure a year later, but it was not signed, therefore, becoming a subject of conflict, considering that it declared that 317 objects would be destroyed, among which 163 were in the process of legalization (hence to be disqualified), 123 objects had ownership certificates (who were compensated with the cadastral area/market value), and there was missing information for the rest of the objects (Kaçani, 2019). The demolitions began at the end of 2019, to continue through the beginning of 2020, and all this translated into nearly 1000 inhabitants forcedly evicted by their homes. Large-scale demolitions didn’t start until autumn 2019 and therefore, could not have been implemented as a material resource for this case in full. The area, due to its informal character and non-controlled construction of previous years still offered a good opportunity to get the resources needed even though not directly ‘mined’.

6.4.1 Methodology

The aim of this second experiment was to build another diagrid structure during a workshop at Polis University using found PVC pipes and additive manufacturing. PVC pipes would act as the main building element instead of bamboo, with the geometrical parameters of the PVC pipes to be introduced into the algorithm. The pipes will be collected or ‘mined’ near Polis University, as the highway represents one of the areas that are still under development, with many open or unfinished construction sites as well as a plethora of construction supply shops and manufacturers. The workshop would be followed by students of Polis University and Lawrence Tech, with mixed working groups. Due to time limitations and tools, the aim shifted to creating a 1:1 prototype of a PVC diagrid structure based on the amount of material collected as the main purpose. Students were required to use the algorithm provided to design and build scaled models of their ideas with defined material stock. The material themselves had to be representative of PVC pipes in scale and were substituted by wooden dowels for this exercise. An addition to the algorithm is the generation of joints for the structure with the aim of 3-D printing them. The joints would therefore become a guide during the assembly as they would be unique to each position in space. All connections will be friction-based or easily removable. The structure was assembled in a 1:1 prototype in the backyard of Polis University.

6.4.2 Materials and Tools

PVC tubes are a very common material used for purposes such as electrical wiring, plumbing, etc. They can range from different lengths, diameter, and material thickness depending on the manufacturer and on the purpose. Due to the large number of constructions happening in Tirana in the past years and in the “Unaza e Re” area they are commonly found, often even undamaged as surplus material. In order to find the materials needed, the team took a ride around the shops and construction sites of Unaza e Re, asking for any spare PVC pipes they had. One of the shops had 23 PVC pipes used for electrical wiring. Slightly damaged at the ends, or slightly cut, the pipes had lost their sale value and therefore were destined to be returned or turned into waste. Flexible pipes for the horizontal profiles were bought, but could as easily been found. Their flexibility allows for the pipes to bend into a circular form.

Rhinoceros3-D and Grasshopper were used as the software of choice due to the design flexibility they offer. Students had basic Grasshopper training and understanding which allowed them to experiment with the definition more, adding parts and functions when needing to deviate from the provided grasshopper definition. The definition itself was a modified version of the one used in the bamboo diagrid structure with the option to generate nodes at the intersection of the elements.

Figure 96 (a) Chris Westerlund, workshop collaborator securing the PVC pipes, (b) PVC pipes together with the flexible pipes to be used for horizontal rings. Photos: author

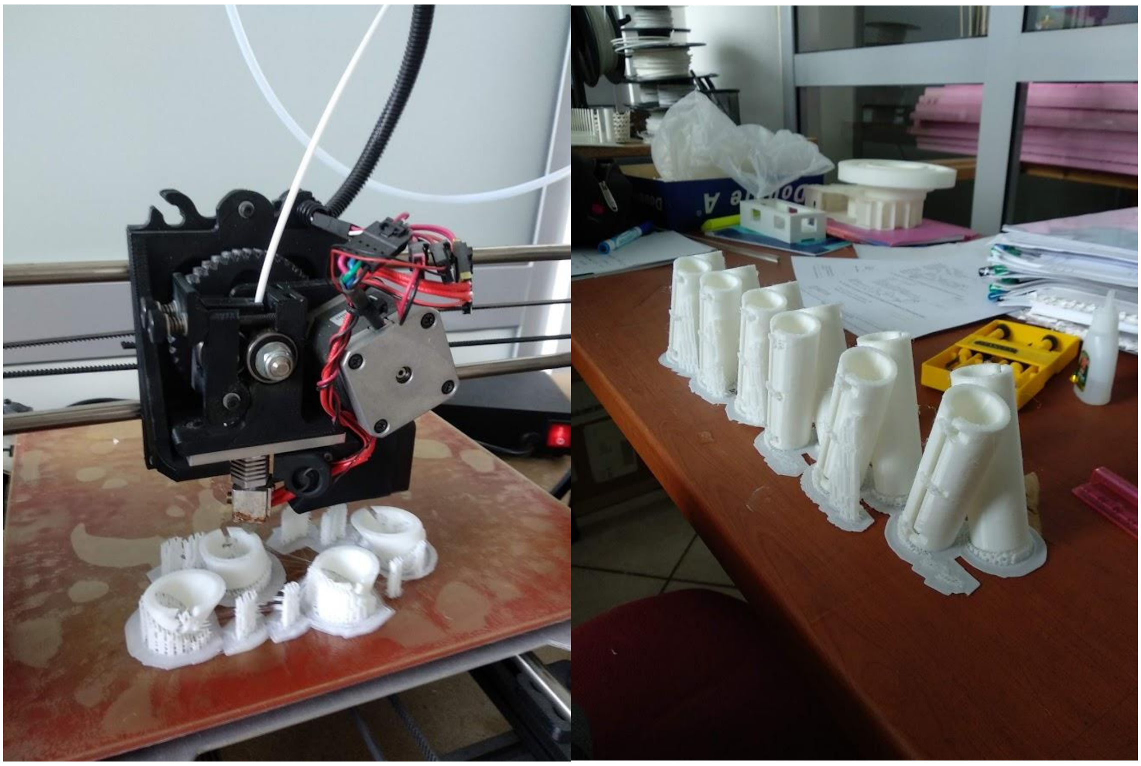

Figure 97 (a) Lulzbot 3-D while printing the joints (b) First results printed. Photos: author (2019)

As the joints were designed to be 3-D printed, the main tool, in this case, would be a 3-D printer itself which would allow the manufacturing of the joints needed for the structure. Polis University's Digital Fabrication Laboratory equipment and their 3-D printer would serve as the main output to print the joints. The 3-D printer is a Lulzbot TAZ 4, able to print in PLA and ABS. the material for printing would be PLA as it has produced better results with the printer in previous tests. Printing filament comes in standard packages of 1kg each, costing around 23$/kg[33]. Normal tools available in the Polis Fabrication Laboratory such as a saw or hammer were used during tests in the lab with the joints but were not needed during the final assembly. The structure was assembled in the Polis backyard garden.

6.4.3 Scaled Models

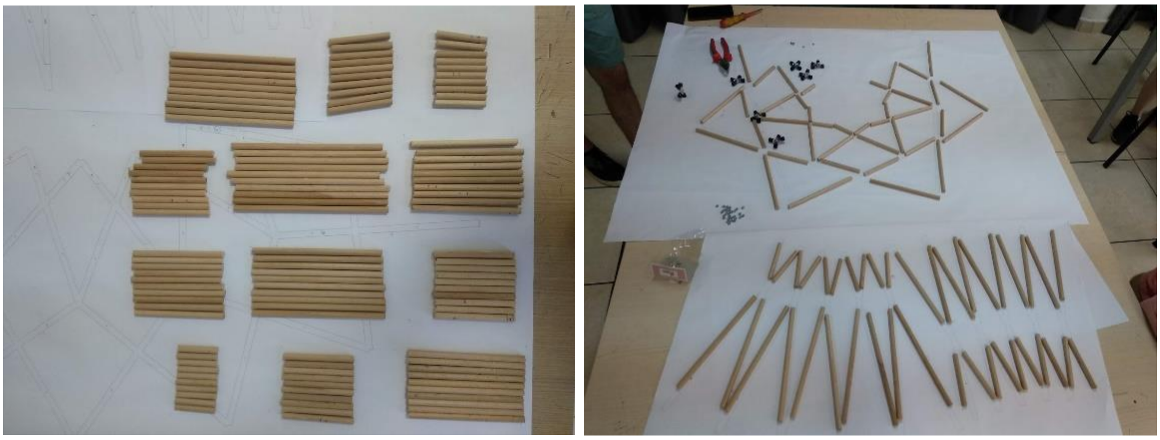

Figure 98 Model prepared for assembly (a), (b) Structures flattened, and printed out as guides. Photos: Author (2019)

During the workshop, students produced their own designs based on the provided algorithm. All three student groups working on the scale models chose wooden dowels as a starting material as it was relatively cheap and easy to cut. While the first plan was for every student to print their nodes, unfortunately, the printer we had at our disposal was not able to keep up with the speed of printing the joints for the 1:1 structure. Another solution for the joints on the scaled models was adopted by using electrical insulation connectors bought at the hardware store[34]. They followed a similar workflow to the 1:1 prototype where the nodes were created on a flattened

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[33] https://www.amazon.com/3D-Printing-Filament/b?ie=UTF8&node=6066129011 [last accessed on-line 21.08.2020]

[34] Different kinds were used by the groups but usually that meant just a manufacturer change as the shop did not have enough of one kind https://www.megateksa.com/al/sq/products/8793

print of the model (Fig 97). Each group created a proposal for their design as to where in the city they could be implemented and the possible function.

The first group's proposal was to be built in the 'Selvia' area, enclosing the historical cypress tree which gave name to the neighborhood. The cypress tree is in danger to be cut down due to future developments being planned on the site. The idea was to create a 'protecting' structure around the tree, a sort of barrier, or personal space for the tree itself (Fig 97b).

Figure 99 (a) Selvia area in Tirana with its iconic Cypress tree. Source: google maps (b) model built to be assembled around the tree. Photo: Author (2019)

Another exercise abandoned the typical diagrid structure used for a different approach. As of 2016, the space in front of the gallery has changed because of the addition of the Serpentine Pavilion winner project of 2013, The Cloud by Sou Fujimoto[35]. The pavilion has only been rented temporarily by the municipality of Tirana. Due to the influence, it has had, thoughts on what could follow it have become generators for new ideas. The second group proposes another pavilion in front of the gallery, one that uses PVC pipes as well as transparent PVC surfaces

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[35] The Cloud won the 2013 Serpentine Pavilion. As of 2016, it has been rented to Tirana and placed in the front yard of the national gallery. It has become a space for activities and cultural events, quickly becoming part of the Tirana cultural life. https://www.reja.al/about-2/rreth-rese/

to enclose certain areas (Fig 99b). This pavilion would not be built vertically as the other proposal, but rather horizontally.

Figure 100 The Cloud by Sou Fujimoto in front of the National Gallery. Source: google maps (a) Model of the proposed Pavilion during the workshop (b). Photo: Author (2019)

Figure 101 The group during the final presentation of their proposal (a) Work in progress on their scaled model (b) Photo: Author (2019)

Another group worked on an idea less based on a specific context, but rather based on their experience taking the bus from the University and back to Tirana every day. Their idea was derived from the need to quickly add bus stops. Apart from the PVC structure, textile mesh shadings, usually used to cover construction sites, will be added to the upper parts to provide more comfort in the sun. Working with students provided with the insight that the methodology could easily be applied to different kinds of structures, derived from the manipulation of the digital model and algorithm.

6.4.4 Prototype

Figure 102 Class work during the workshop at Polis University, Photo: Author (2019)

The scaled models provided a proof of concept to build on while finishing the 1:1 prototype. As explained, the algorithm used is a very similar approach to the one used for the bamboo structure due to the nature of the structures being both diagrids but offered a simplified output as the focus fell on generating the 3-D printable joints. The final design and form were decided as soon as a precise idea of the available material stock was created. Due to limitations of the 3-D printer used in terms of printing speed, time was of the essence and printing had to start as soon as possible. Joints were generated based on the design output from the algorithm. There were two possible connections types, either double joints (parts were vertical elements intersected) or triple joints (where vertical elements intersected with horizontal elements). The position on each joint on the horizontal pipes was marked beforehand with pieces of tape.

During the process of printing, we noticed that the first joints printed not only were strong enough but also used a lot of material and time to print. The thickness of the material and length of the joints was parametrically changed in order to make the process of printing faster. This meant that the first printed connections would be more resistant than the last ones, and performance could be easily noticed on the prototype after. All the models of joints printed can be seen below with differences in material and length visible from top to bottom as a way to maximize performance and printing speed (Fig. 104).

Figure 103 Joints being prepared for 3-D printing in the Polis Lab (a), Testing the joints ease of assembly through friction (b) Photo: Sara Codarin

Figure 104 Joint difference from last to first printed joints. Thickness and length of joints were reduced. Photo: author

The printed joints facilitate the assembly phase due to each being unique to a certain position. This meant that each joint that was marked with the correct position before and could easily inform the assembly phase through their position in space in the 3-D model. The horizontal profiles are pre-prepared with the corresponding joints in each place (Fig 106a). Pre-preparing the joints with the horizontal profiles speeds up the assembly process on site (Fig. 106b). Zip ties were used on this occasion too, although they were less needed structurally and more of a precaution.

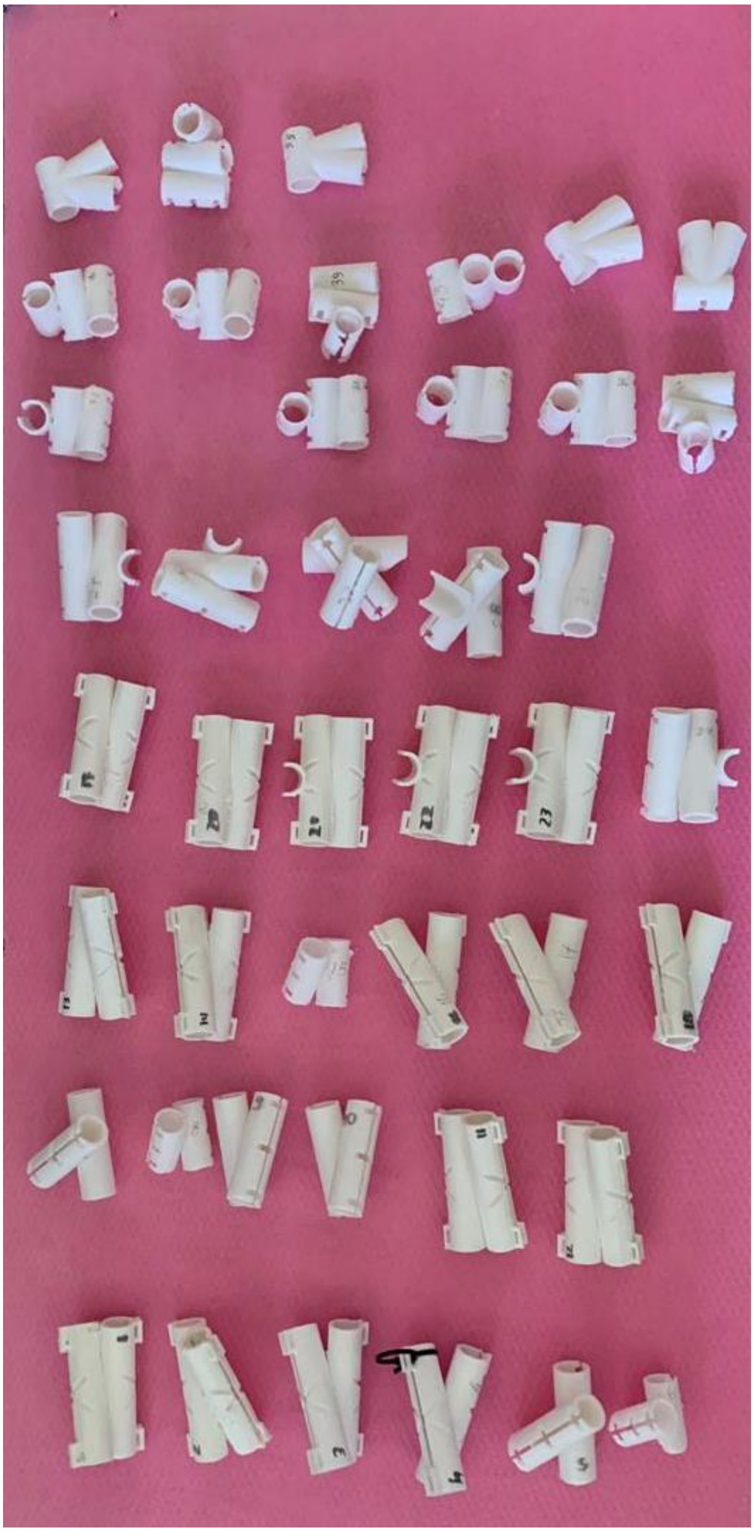

Figure 105 Collection of joints printed for the PVC structure. Photo: Sara Codarin (2019)

Figure 106 horizontal profile created by connected their ends (a), photo: Chris Westerlund, Laying out the elements before the assembly (b). Photo: Author (2019)

The self-informed nature of the assembly process allowed even students who did not follow the design phase but just understood the system from the algorithm to pick up the assembly where one left of. The elasticity of the plastic in the PVC pipes works to the advantage of the assembly as the bending properties provide a margin of tolerance. Configuring the PVC structure through this method turns to be a straightforward, ‘easy to pick up and continue’ process of assembly. The structure is assembled in two parts, with the first part spanning the length of the PVC pipe elements and the joints connecting them at the ends. The last part is joined apart from the structure and connected at the end to the already assembled section. In total the structure used 6 green PVC flexible pipes (2 for each horizontal profile) and 24 PVC pipes about 70m/l. In total 44 Nodes were 3-D printed for this prototype. The assembly process documented (Fig. 106) required only two hours of assembly time, with the most time-consuming task being the manufacturing and printing of the joints themselves.

Figure 107 Assembly process of the PVC pipe structure and details. Photos: Author and Sara Codarin

Figure 108 PVC pipes diagrid structure with 3-D printed joints. Photo: Sara Codarin (2019)

6.4.5 Observations

Generating designs that are highly customizable has already proved to be easier and faster with digital technologies. The ability to generate designs through simple control of parameters can be very effective in the exploration of the design solutions. The intersection of computational design and the ability to directly translate 3-D models to data for manufacturing parts can change how and where we produce and manufacture our designs. As freeform digital models that can present complex forms are harder to manage in real life, a digital part of the whole can be made physical to inform the assembly itself.

The obtained PVC pipes used for this case retained the diameter of their manufacturing cycle but a change in one of the diameters could easily be addressed as mass customizing each joint would have no economic added value or consume more time (see 4.3). Design-wise, having a different diameter would require just the adjustment of one parameter. While PVC pipes do fall neatly under the category of pre-cycled materials as they have had their function changed and life cycle extended through an unintended use, it is interesting to think of how they can be recovered more frequently and reused. As the algorithm has proved to work for a certain type of structure (the diagrid in our case) is highly possible to keep adapting its parameters every time we want to introduce new materials.

The diagram illustrated (Fig. 109) shows the processes involved from the moment after the material collection to the final outcome. Although using the word-final here would be rather incorrect. The structure was designed from conception to use non-adhesive joints in order to not contaminate the used material. This would allow the material to be easily disassembled and collected after it has completed its cycle. The ability to reuse the material and recover it again means that the end result for one iteration becomes the start for the next one. While the pipes can be easily reused in the same state, the joints that were manufactured specifically for this purpose remain unique to a certain design. While the pipes can continue to be reused until the material structure is damaged, the 3-D printed joints remain unique to the original design. As the joints used plastic filament, it can potentially be recycled too, with All3-DP[36] offering a filament recycler as the solution to plastic 3-

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[36] The 3D printer filament recycler's guide https://all3dp.com/2/the-3d-printer-filament-recycler-s-guide/ [last accessed on-line 22.06.2020]

D printers waste. As all the joints use the same base material they can easily be reused. This would potentially mean that a structure could undergo the same process of assembly and disassembly for temporary uses as many times as needed and in many different forms. More material could be added with time, changing the range of solutions that the algorithm can offer.

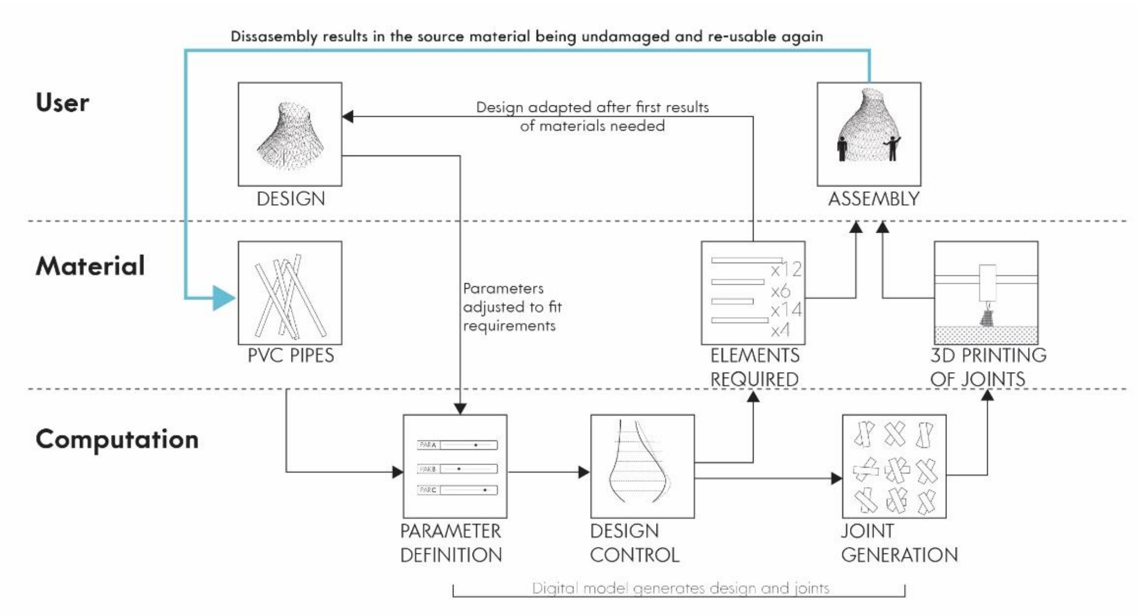


Figure 109 Diagram showing the workflow of the installation and the levels responsible for each part. The final outcome can become the starting point for a new installation. Source: Author (2020)

The PVC structure stayed in the Polis backyard for 3 months before being disassembled. The structure resisted a 5.5 magnitude earthquake that hit Tirana and Durres on September the 24th. The possibility of coupling digital processes with materials seen as waste could prove a great way to put into use a resource that would otherwise turn into the problem that our environment is facing. Also the ability to collect and build with materials that you can find as unwanted could be a very effective way to respond to situations where the speed of response or budget is of the issue. One such solution can be thought of when dealing with a homeless shelter, disaster relief structures, where the ability to respond with quick, local, and found materials could be the difference for many. There is the concern of the technology and tools that can be perceived as advanced and difficult.

6.5 Class Practice

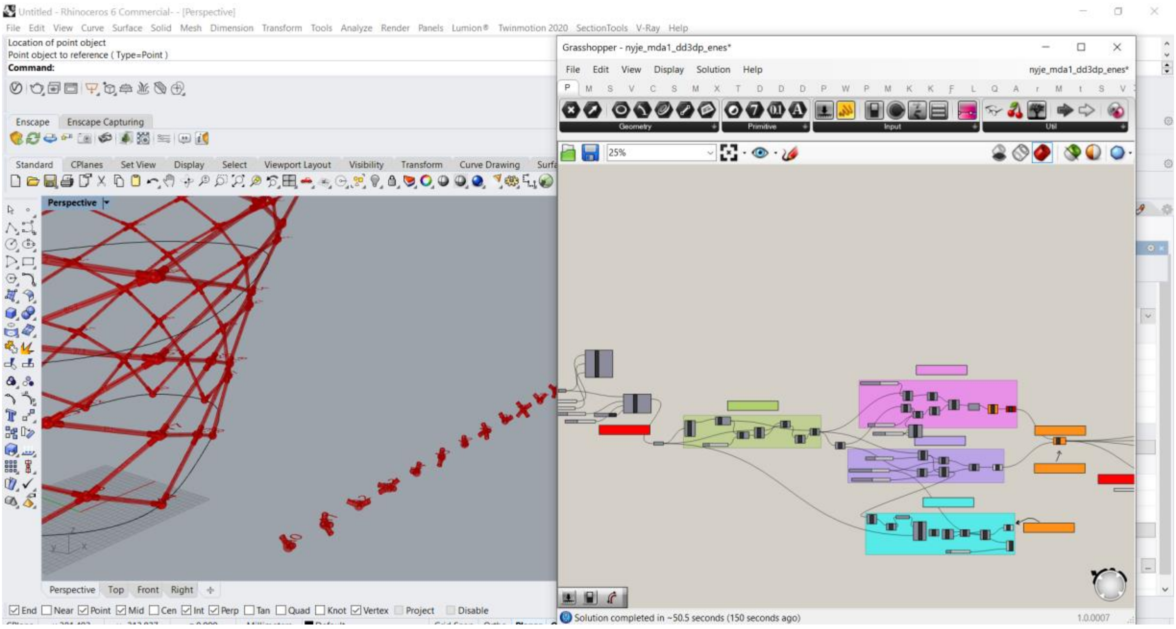
As a way to further the idea of the use of digital tools as a way to activate recovered or pre-cycled materials for building processes, the algorithm and methods were tested during a design class at Polis University. During the “Digital Design 3-D & Parametric” class followed by the Applied Design students, a similar exercise and design problem was presented to the students. The main aim, in this case, would be to validate the application of an algorithm that generates joints based on a designed proposal and most importantly that adapts to any design change. In this case, the algorithm would deal only with the generation of joints, freeing up the shape that would be designed from the previous diagrid structure constraints. Interesting for our investigation, in this case, is the ability of any designer to provide a certain design and to be able to make it easy to manufacture. By feeding the initial design to the algorithm it is able to generate joints that can be 3-D printed. While the initial aim was to have buildable models, the COVID-19 pandemic changed the plans to online classes which meant the results had to be digital. The class was held from March 2020 to June 2020 as an online class.

6.5.1 Methodology

The class followed a series of lectures and tutorials that gave the design students a basic understanding of the parametric tools used as well as parametric principles when designing. A series of examples and previous experiences were presented to the students while also analyzing the processes behind each example. The tutorials were focused on Rhinoceros3-D and Grasshopper as design tools given in a certain framework. Exercises focused on Subtractive Manufacturing and Additive Manufacturing were conducted during the class in order to provide students with a full understanding of digital fabrication methods and their applicability. This knowledge served as the basis for the final exercise.

The final exercise required the class to use an algorithm provided by the course instructors that was able to generate joints at the intersection of lines. The initial parameters of the algorithm were customized for PVC tubes but could easily be changed by each student. Students were asked to think of the design of a structure that used linear elements and required the usage of pre-cycled materials. This meant that the material parameters had to match those of the selected materials by each student and the algorithm would quickly adapt not only to the form that each student designs but also to its shape. The design of the structure itself was left to student decisions as not the use of parametric tools was required.

6.5.2 Joint Generation



Location of point object
Point object to reference (Type=Point)
Command:

Solution completed in ~50.5 seconds (150 seconds ago)

Figure 110 Rhinoceros and Grasshopper interface with the algorithm generating the joints for another diagrid structure as an example showed to the students. Source: Author (2020)

The algorithm presented to the students was prepared to receive a collection of lines that represented the designs created by the students. At each intersection of lines, a point is extracted and used as the center for the generation of each joint. Spheres are created at these points where the radii parameter of the sphere defines the size of the central part of each joint. Boolean subtractions were used to remove materials and create hollow parts where the linear materials would be inserted. The depth of these opening could be controlled through a parameter too, with the definition providing information on changes to the stock materials needed. All the joints are generated in one process with little limitations to the number of connections each joint can have. This needed to be regulated manually from the users as to many connections in one joint could weaken the joint and material used. All the generated joints were output in a matrix, ready to be 3-D printed and tagged with alphanumerical values. These created coordinates and clear positions and correlations between the parts and their configuration on the whole. The ease of the tool was highly appreciated in this case as it allowed the students to deal with the design and automate processes of manufacturing.

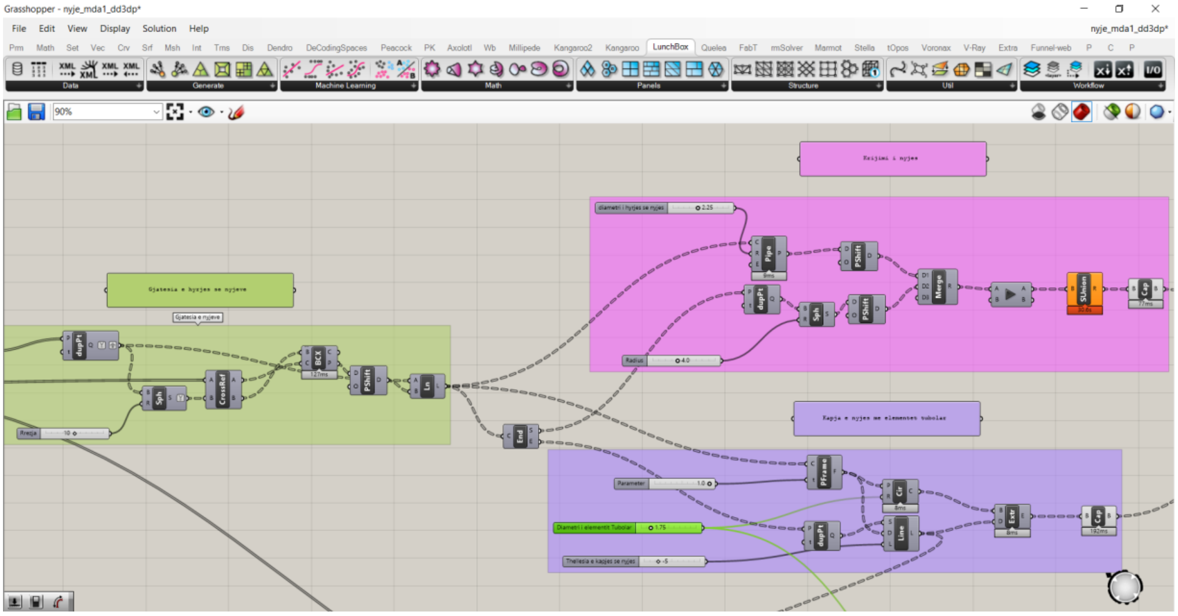
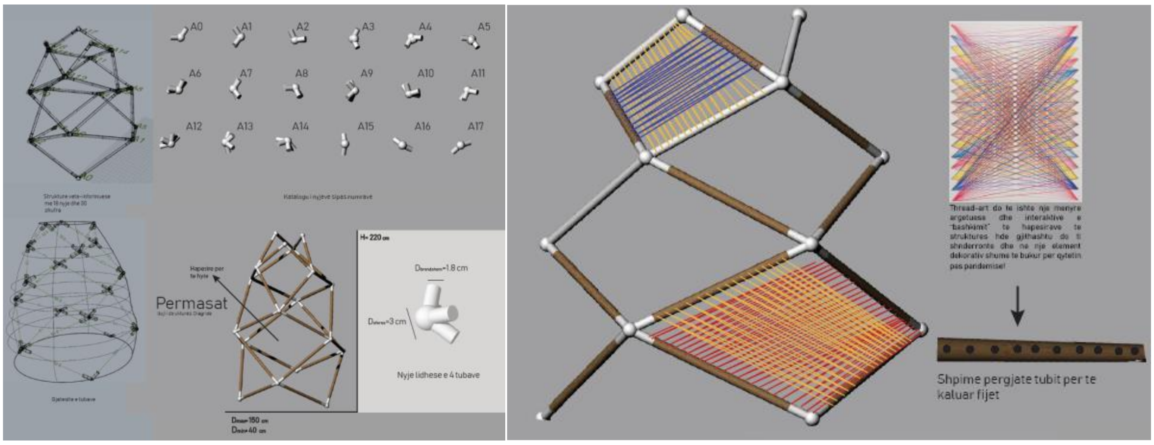


Figure 111 Parts of the definition that define the joints location through the intersection of lines and create the 3-D printable joints. Source: Author (2020)

6.5.3 Results

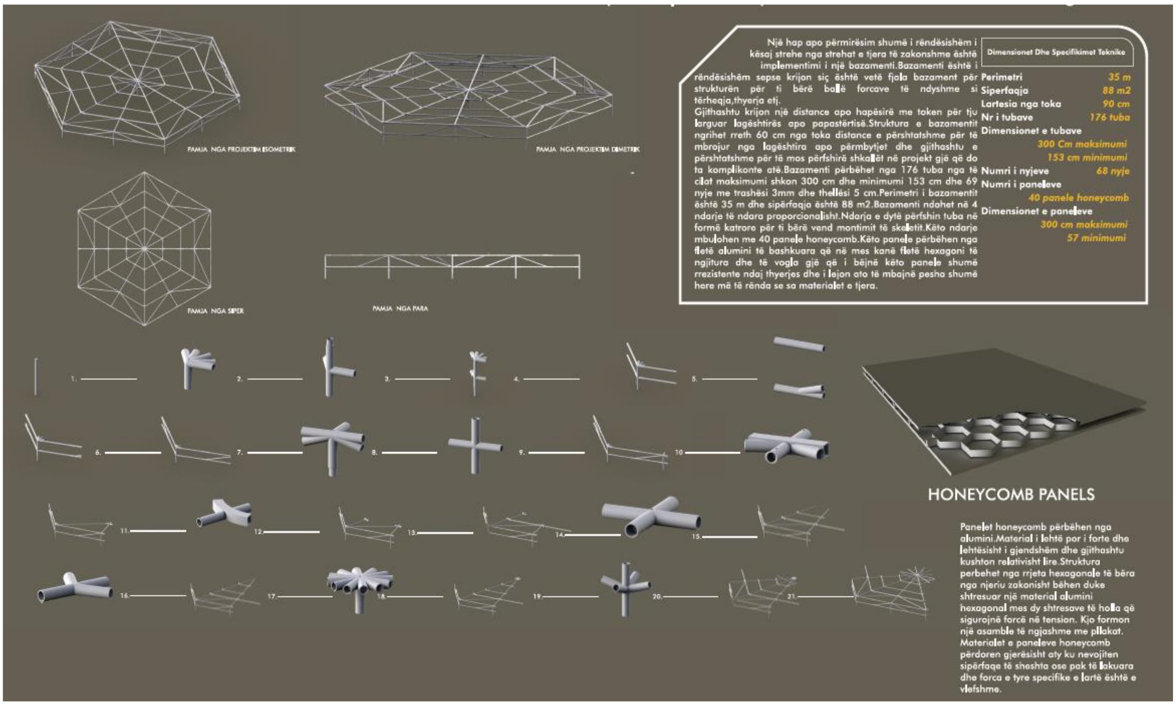
The final results had to be presented through online presentation and drawing boards with enough information on the final outcome, the 3-D printable joints, and materials selected. Students used the tool in order to realize different types of products and installations, with them drawing the bases and the algorithm dealing with the generative part of the joints. These allowed the students to focus on the design and use the algorithm as a tool or as a software function. Final results showed a clear focus on the design phase, where the automation of the generative part and the control that the algorithm offered them through the changeable parameters was seen as a powerful tool by the students. The class presented their work, online on the 25th of June, 2020. Although there was a clear lack of physical models in comparison to the previous experiments due to hardware limitations and inability to work at the laboratory, some of the projects showed control over the tools that allowed the students to turn their designs into buildable prototypes.



Thread-art do te ishte nje menyre argetuese dhe interaktive e "bashkimit" te hapesirave te struktures hde gjithashtu do ti shnderronte dhe ne nje element dekorativ shume te bukur per qytetin pas pandemise!

Figure 112 Social Distancing Structure. Credits: Kejsi Turku (2020)

Kejsi Turku (Fig 112) proposed a structure that would impose social distancing in public areas. Able to be assembled and disassembled at will, the structure was designed to be assembled movable to different areas.



Një hap apo përmirësim shumë i rëndësishëm i kësaj strehe nga strehat e tjera të zakonshme është implementimi i një bazamenti.Bazamenti është i rëndësishëm sepse krijon siç është vetë fjala bazament për strukturën për ti bërë ballë forcave të ndyshme si tërheqja,thyerja etj.
Gjithashtu krijon një distance apo hapësirë me token për tju larguar lagështirës apo papastërtisë.Struktura e bazamentit ngrihet rreth 60 cm nga toka distance e përshtatshme për të mbrojur nga lagështira apo përmbytjet dhe gjithashtu e përshtatshme për të mos përfshirë shkallët në projekt gjë që do ta komplikonte atë.Bazamenti përbëhet nga 176 tuba nga të cilat maksimumi shkon 300 cm dhe minimumi 153 cm dhe 69 nyje me trashësi 3mm dhe thellësi 5 cm.Perimetri i bazamentit është 35 m dhe sipërfaqja është 88 m2.Bazamenti ndahet në 4 ndarje të ndara proporcionalisht.Ndarja e dytë përfshin tuba në formë katrore për ti bërë vend montimit të skeletit.Këto ndarje mbulohen me 40 panele honeycomb.Këto panele përbëhen nga fletë alumini të bashkuara që në mes kanë fletë hexagoni të ngjitura dhe të vogla gjë që i bëjnë këto panele shumë rrezistente ndaj thyerjes dhe i lejon ato të mbajnë pesha shumë here më të rënda se sa materialet e tjera.

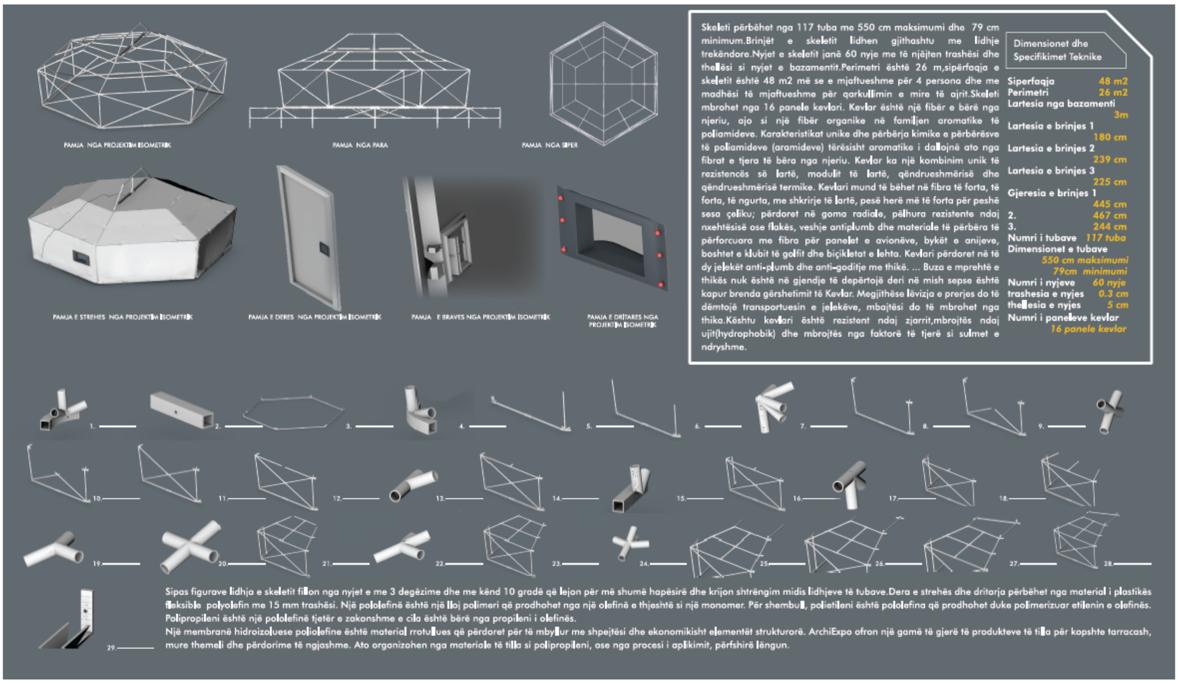
Dimensionet Dhe Specifikimet Teknike	
Perimetri	35 m
Siperfaqja	88 m2
Lartesia nga toka	90 cm
Nr i tubave	176 tuba
Dimensionet e tubave	300 Cm maksimumi 153 cm minimumi
Numri i nyjeve	68 nyje
Numri i paneleve	40 panele honeycomb
Dimensionet e paneleve	300 cm maksimumi 57 minimumi

HONEYCOMB PANELS

Panelet honeycomb përbëhen nga alumini.Material i lehtë por i forte dhe lehtësisht i gjendshëm dhe gjithashtu kushton relativisht lire.Struktura perbehet nga rrjeta hexagonale të bëra nga njeriu zakonisht bëhen duke shtresuar një material alumini hexagonal mes dy shtresave të holla që sigurojnë forcë në tension. Kjo formon një asamble të ngjashme me pllakat. Materialet e paneleve honeycomb përdoren gjerësisht aty ku nevojiten sipërfaqe të sheshta ose pak të lakuara dhe forca e tyre specifike e lartë është e vlefshme.

Figure 113 Emergency Honeycomb shelter. Credits: Enes Hajredini (2020)

Enes Hajredini investigates the ability of digital tools to quickly adapt the design and for fast prototyping (Fig. 113). The devastating earthquakes that hit Albania on November 26th, left many people homeless, and found the Albanian government unprepared. This inspired him to think of construction systems that can be used for fast response emergency situations. Gathering linear materials from the immediate surrounding or using pre-cycled materials, Enes proposes 3-D printable joints as an easy and fast construction method that informs the user throughout the assembly.



Skeleti përbëhet nga 117 tuba me 550 cm maksimumi dhe 79 cm minimum.Brinjët e skeletit lidhen gjithashtu me lidhje trekëndore.Nyjet e skeletit janë 60 nyje me të njëjten trashësi dhe thellësi si nyjet e bazamentit.Perimetri është 26 m,sipërfaqja e skeletit është 48 m2 më se e mjaftueshme për 4 persona dhe me madhësi të mjaftueshme për qarkullimin e mire të ajrit.Skeleti mbrohet nga 16 panele kevlari. Kevlar është një fibër e bërë nga njeriu, ajo si një fibër organike në familjen aromatike të poliamideve. Karakteristikat unike dhe përbërja kimike e përbërësve të poliamideve (aramideve) tërësisht aromatike i dallojnë ato nga fibrat e tjera të bëra nga njeriu. Kevlar ka një kombinim unik të rezistencës së lartë, modulit të lartë, qëndrueshmërisë dhe qëndrueshmërisë termike. Kevlari mund të bëhet në fibra të forta, të forta, të ngurta, me shkrirje të lartë, pesë herë më të forta për peshë sesa çeliku; përdoret në goma radiale, pëlhura rezistente ndaj nxehtësisë ose flakës, veshje antiplumb dhe materiale të përbëra të përforcuara me fibra për panelet e avionëve, bykët e anijeve, boshtet e klubit të golfit dhe biçikletat e lehta. Kevlari përdoret në të dy jelekët anti-plumb dhe anti-goditje me thikë. ... Buza e mprehtë e thikës nuk është në gjendje të depërtojë deri në mish sepse është kapur brenda gërshetimit të Kevlar. Megjithëse lëvizja e prerjes do të dëmtojë transportuesin e jelekëve, mbajtësi do të mbrohet nga thika.Kështu kevlari është rezistent ndaj zjarrit,mbrojtës ndaj ujit(hydrophobik) dhe mbrojtës nga faktorë të tjerë si sulmet e ndryshme.

Dimensionet dhe Specifikimet Teknike

Siperfaqja	48 m2
Perimetri	26 m2
Lartesia nga bazamenti	3m
Lartesia e brinjes 1	180 cm
Lartesia e brinjes 2	239 cm
Lartesia e brinjes 3	225 cm
Gjeresia e brinjes 1	445 cm
2.	467 cm
3.	244 cm
Numri i tubave	117 tuba
Dimensionet e tubave	550 cm maksimumi 79cm minimumi
Numri i nyjeve	60 nyje
trashesia e nyjes	0.3 cm
thellesia e nyjes	5 cm
Numri i paneleve kevlar	16 panele kevlar

Sipas figurave lidhja e skeletit fillon nga nyjet e me 3 degëzime dhe me kënd 10 gradë që lejon për më shumë hapësirë dhe krijon shtrëngim midis lidhjeve të tubave.Dera e strehës dhe dritarja përbëhet nga material i plastikës fleksible polyolefin me 15 mm trashësi. Një pololefinë është një lloj polimeri që prodhohet nga një olefinë e thjeshtë si një monomer. Për shembull, polietileni është pololefina që prodhohet duke polimerizuar etilenin e olefinës. Polipropileni është një pololefinë tjetër e zakonshme e cila është bërë nga propileni i olefinës.
Një membranë hidroizoluese poliolefine është material rrotullues që përdoret për të mbyllur me shpejtësi dhe ekonomikisht elementët strukturorë. ArchiExpo ofron një gamë të gjerë të produkteve të tilla për kopshte tarracash, mure themeli dhe përdorime të ngjashme. Ato organizohen nga materiale të tilla si polipropileni, ose nga procesi i aplikimit, përfshirë lëngun.

Figure 114 Honeycomb shelter elements. Credits: Enes Hajredini (2020)

Igla Licaj proposes a structure to be used as an urban canopy (Fig. 115) as an installation. While the main focus in this case does not fall on the function but rather on the ability of the method to create quickly changing urban elements.

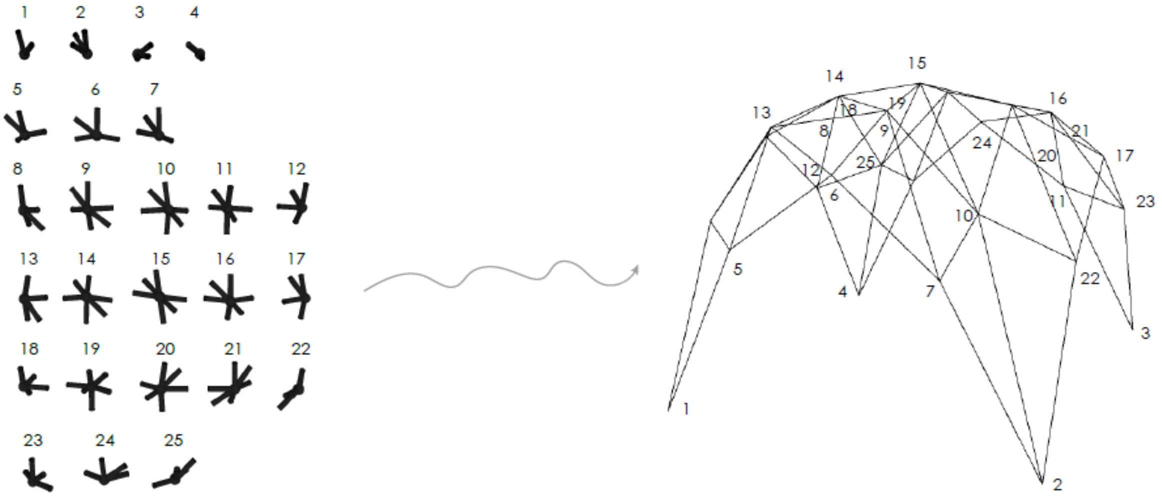


Figure 115 Urban Shelter structure. Credits: Igla Licaj (2020)

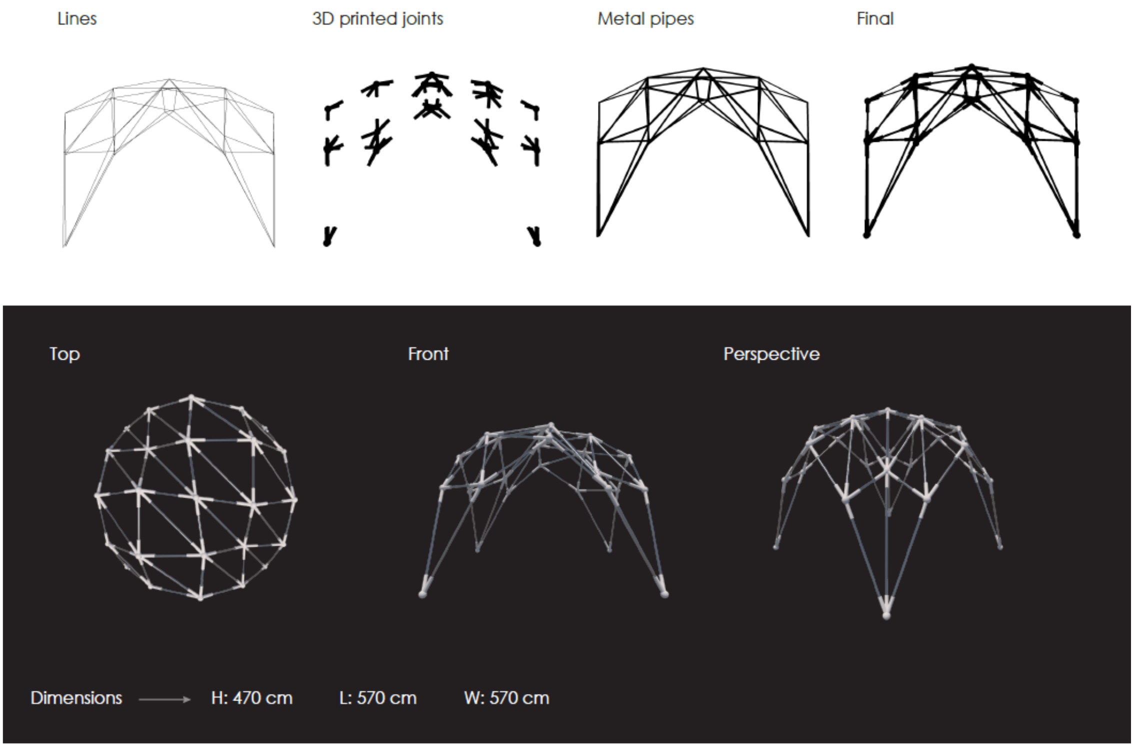


Figure 116 Credits: Igla Licaj (2020)

6.5.4 Observations

Digital tools have become integral in every process that requires design and making as they facilitate and equip the designer with a set of tools that are highly customizable and controllable. The ability of computers to quickly calculate and compute a range of solutions based on certain criteria cannot be matched by the human brain. While the human brain is far more equipped to handle and adapt to design problems, there are computational tools that can free the time of the designer by automating processes that can be tedious. The creation of joints can be regarded as such a process especially when dealing with non-standard forms and solutions. Here the computer is more than capable of handling that kind of complexity and by creating customizable tools that deal with complex problems we can open up new possibilities. Possibilities in this case can open up in the materials chosen, as the definition can adapt to different conditions. The drawback here is that the definition is focused on a certain type of process and with a certain expectable result. If we create more tools to cover more design problems, we could activate a wider range of materials to be used.

6.6 Reflections

Through the experiments shown above, the aim was to understand a set of strategies and principles that can be applied to cases where digital tools and waste or recovered materials can be a resource. Although the architecture process has evolved recently through the use of digital tools, few practitioners s. It is undeniable that until now it has used resources without much thought on the consequences. Our way of life and building has proven to be anything but sustainable. Our cities are now being the biggest containers of resources and not our planet and it is only normal that we look for ways to use that resource.

The projects and experiments conducted above are born from the possibility of recovering materials and reusing them in a new life cycle. Through this process not only do we delay the materials from going into a wasteland but we can also extend their life and their impact on the environment. While the current practice is based upon pre-manufactured standard materials, serving very specific purposes, interestingly enough, using digital tools allows us to break free of this standard and embrace the non-standard. Digital tools in this sense are used as literal tools that bridge the gap in the complexity of dealing with materials that do not fall into the standard categorization. The projects above showed elements of all the three categories described during Chapter 6 with the collection, transformation, and making all represented.

The example of the workshop in Struga (6.2) on one hand had very little use for the digital tools while the collection of recovered material was completely manual. The biggest takeaway is how the perception of the users changed on the materials themselves when confronted with the cost of the possibilities. What was seen as useless junk suddenly turned into useful material that can be used to transform urban spaces and urban conditions. Suddenly the junk thrown around became useful and a target for the children collecting, easily transformable into applicable interventions. The Parametric Bamboo Spatial Structure (6.3) collected material from a built structure and through careful consideration of the material properties split them in order to create new possibilities. Digital tools in this case show great flexibility as they allowed the possibility to take into account different scenarios where the algorithm itself was based on optimizing the available material stock in relevance to the design solution. Digital fabrication on the other hand opens up an even bigger range of solutions in dealing and recovering materials. While the showed example used pre-cycled PVC pipes (6.4) as the basis and an algorithm to generate the joints, it still follows the same logic. The joints are generated through an algorithm that adapts to any design change as 3-D printable models, fed to a 3-D printer, and autonomously printed. The joints themselves facilitate assembly as they guide the user during the process. All these while not using any adhesive which allows for complete disassembly and if needed another cycle with the material completely (Fig 109). Lastly, the exploration through a design class showed how users with little knowledge of scripting in grasshopper can easily control their design solutions to facilitate a design problem through the control and understanding of certain parameters. Especially the last part showed how these new technologies can facilitate tedious parts of design while making it easier to use materials that are not standard but can be recovered from other processes.

There is a whole ‘mine’ of valuable materials that designers can activate with the right tools and processes. While recycled materials and recycled goods have been the talk of the moment, extending the life cycle of materials through the application of those materials to new uses can be very effective in design. While their range and application can be limited, it can greatly be expanded through the use of digital tools in the design and manufacturing phase. And while we are used to doing that now in the digital age, the way we apply them can be a big difference. Reflecting on all the studied projects and what they achieved, should we make find ways to recover materials every day through digital tools, we could have a database of material that can be free and are ready to use. Where people with basic knowledge are able to download and edit a possible design that chooses through those materials, send the files to the nearest digital fabrication laboratory and have them manufactured. This could promote a more local production line than ever before where every output we create becomes the input for new processes.

7. DISCUSSION

7.1 Discussion

7.1. ‘Wasting’ a potential

Our way of life has proven time and time again to be unsustainable and self-destructive. Waste, a by-product of almost every society has changed in its composition because we have our ways, from how we design products, to how we build architecture. The idea in itself is contradictory as waste in itself is a product of the process of building. As one creates the other, the whole discussion should fall on how we can take the waste and make it useful again. In their Goals for Sustainable Development the UN made a statement that if the population of the earth reaches 9.6 billion by 2050[37], we would need three planets worth of resources in order to maintain our way of life. The way we are using our resources is clearly not sustainable and if we want to keep our lifestyle, we need to find ways to reuse what we have already transformed into a product.

Construction and architecture on the other end have been largely responsible for this, as methods of construction contribute to a large part of global waste. Principles of circular economy in this case have tried to direct architects and designers for many years but have failed to translate to actual and real change in the manufacturing industry. Recycling, the third way to avoid waste in Lansik’s scale (Fig 20), although impactful, does not happen nearly enough. Therefore the solutions of reducing the waste or reusing it logically take higher priority.

If we think of the reduction of waste, products showed in 3.3.4 named as designed waste products achieve a good result. Subsequent life cycles of the materials are designed from the start, taken into account by the designer itself, and embedded in the product. The perception of consumers in this case completely changes as they understand the value of the 2nd life of the product. These products are often sent to the designated place, where the 2nd life cycle has value. United Bottles for example can be adapted from being a bottle to a source for the construction of shelters. Envisioning future life cycles of the product should be a requirement for our future cities (Hebbel, et al., 2015). On the other hand, possibilities in design here are also embedded in the product. Configuration and uses have been designed from the

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[37] https://www.un.org/sustainabledevelopment/sustainable-consumption-production/ [last accessed on-line 11.10.2020]

start. In this case, the method is functional but requires industries, who base their profit on consumption, to adhere to new policies and methods. Designers should also be trained from educational systems to think in a more holistic way for the end cycle of their products.

Reuse is the most interesting one in cases where the previous is not possible. As discussed in 1.2.3, countries like Albania that are in rapid urbanization processes still struggle in the waste management department. Although goals are set by the EU on the amount of waste that should be recycled, Albania is failing to keep up, actually recycling less in recent years. Recovering materials for reuse on the other hand has always been a specialty of the urban poor. Images of landfills being searched for materials that still hold value have been very representative of the 20th and 21st centuries. These materials may not have an architectural value that can be used for buildings but it still does not stop them from being used. Informal urban settlements, especially in city outskirts are often made of scraps and pieces brought together from landfills. There is potential here that can still be exploited, as transforming the material into a valuable resource can help promote CE principles and find new solutions in design.

7.1.2 Makers can help

Digital tools and their usage have defined architectural practice more than any other tool in the last three decades. Practices of digital design and digital fabrication have slowly moved from being industry and professional exclusives to large accessible tools that everyone with the desire to learn. Digital fabrication tools are becoming as accessible to the average user as 2-D printers were 30 years ago (Anderson, 2012). Production of goods has never been easier, as the ability to freely download models of the internet and print them has democratized production. Digital tools in this case become enablers of innovation. The large spread of Digital Fabrication Laboratories is certainly becoming an enabler in allowing almost anyone to fabricate his ideas.

Architects that delve into digital tools have seen their process of design drastically change and evolve. Products do not have to be designed anymore as the process can be designed instead in the form of algorithms that automate design actions and create new tools for architects. These tools can be shared among others, as open-source projects allowing almost everyone to access and benefit from them. They can be freely edited to allow for the process to generate numerous results, without needing anything from the original creator. Design solutions can be generated even from non-professionals while still having the process and quality being guaranteed by professionals.

Digital Fabrication laboratories in this case can turn into Hubs of design and making. Places where ideas and designs can be turned into products and solutions. While digital fabrication laboratories have been liberated from their status of exclusiveness, communities of makers can gather around these spaces. Sharing ideas and knowledge can bring to new innovative solutions in the usage of digital tools. Furthermore, as these places have both a local and global presence, the knowledge gained and tools used can come from all over the world, while the resources and interaction can be local, tied to the place, and tied to the community.

7.1.3 Cases

The process of transforming waste into a useful material covers far more than just design and construction, as the transformation can happen during other moments too. If we want to discuss a procedure of transforming waste into a material used for building, more than just the design phase needs to be discussed. During chapter 5, the list of cases selected to set out to investigate procedures that change the pejorative stigma of waste through the use of digital tools. Digital tools in this case serve as enablers of the process. The cases selected have been divided into categories for the reason that each of them represents one part of the whole.

The collection phase represents one of the most problematic phases. We pay our municipality in order to collect waste and hide it away from us confirming that it has no value. The collection of waste is not enough, as categorization needs to be made in order to activate the material for other processes. Cases like DustCart in Peccioli are reminiscent of the sci-fi movie Wall-E, where automated friendly robots deal with processes that we do not want to. DustCart (5.2.1) in this case automates an interactive process that involves the human counterpart. Through it, each individual becomes conscious of what they are giving away is enhanced while information of what the robot is taking back is registered. W.A.R (5.2.2) takes this concept further, by utilizing machine technology to chemically and geometrically categorize and divide waste. A clear division of waste material into appropriate categories can facilitate processes of recycling and most importantly for us, processes of reusing. Transformation of waste can happen through the act of design. Although interestingly enough, Transformation acts in the digital realm of architecture software are connected even to processes such as moving something. Mine the Scrap (5.3.1) takes advantage of digital tools in order to automate the process of designing with waste. The ability to directly read and catalog waste by creating a digital archive, or ‘Warehouse of Waste’ remains an interesting possibility. As local communities in need of cheap design solutions can easily tap into this resource. Automation of design through algorithms on the other hand should be viewed carefully. Understanding of construction and building processes still goes further than understanding a few parameters in an algorithm and should be supervised by architects. Lastly, projects that make and build from waste have the clear goal of using a material devoid of an architectural function. These projects couple of materials of waste with fabrication techniques in order to create new artifacts. Interestingly enough, the material itself although can go through fabrication processes tries to retain as many of its qualities as possible. This not only allows for the material to either transition to another life cycle after that one but also the ability to recycle it freely. Joinery in this case is seen as an important aspect, as joints that do not corrupt the material allow for processes of assembly and disassembly. This is reminiscent of ephemeral architecture.

7.1.4 Practice

The practice part set out to understand the procedures of transforming waste into a buildable material. The implications that we need to think about in this case are quite different from normal design processes. Firstly, the normal design process involves a linear approach to it, where the product is slowly built with a clear image of what the final result will be. Designing and building with waste starts first and foremost from the waste itself. This shows a more local and self-aware approach to designing, where the design itself starts from the material and not the other way around where the material is chosen at the end of the design. This requires a shift in design methods, where we design with a limited and well-defined stock of materials.

Designs become specific to a culture (Sinclair, 2011) as waste in itself is specific to place and culture.

Waste needs to overcome the bad reputation it has gained through the centuries. Designs that involve waste also need to educate the users on the values of it. This is especially easier in poorer countries, where waste reduction and reuse comes as a necessity. UrRe (6.2) experience showed a participatory design process where the users are involved in both collection and making can change the perception of materials at end-of-life from the user side. This change not only happened with the acceptance of the material itself but also through the involvement in the decision-making and building process. While this process still needs to be directed by professionals, clear guidelines can be established that create a stock of usable material from the start.

Natural materials such as bamboo on the other hand do not pose a threat to our environment due to their ability to become part of the earth again. As long as they remain untreated with chemicals and do not have hazardous joinery materials, they can easily decompose in landfills. We do see some value although extending the life cycle of natural materials beyond the first use (Hebbel, et al., 2015). So rather than the material itself, the reuse process is worth discussing. As the question is similar to the methods mentioned above, where material stock dictates the design, the algorithm used for the design itself is based on the same principle. Disassembly of the previous configuration and assembly into a new happen can transition smoothly through one iteration of design to the other. Building techniques, if kept simple and well documented digitally, can be comprehended by non-professionals. The ability to transition materials from one configuration to the other is not new, but the consciousness of designing for a transitioning material requires more real-life applications.

Through digital fabrication, the manufacturing of different parts that are all unique can be an automated process. As learned from the cases in 5.4, connections allow the possibility to configure waste materials in different methods and functions. The tools created for the prototype in 6.4 allowed designers to think of the final design shape based on material constraints without worrying about the tediousness of drawing each joint. By automating the process through an algorithm, the design is freed from time-intensive and often repetitive tasks. The initial design can use either traditional drawing methods that the algorithm can receive as an input or algorithmic design that can incorporate more design parameters. The result would be similar in either way, where the final design and activation of reusing the PVC pipes are enabled by the parametric generation of joints. Each joint informs the assembly process by slowly guiding the user to its final configuration. The assembly in itself requires little to no knowledge in building, resembling the processes of a 3D puzzle where each piece has its pre-defined position. As the joints are friction-based, the design retains its state of ‘temporary’. As shown in (Fig 109) the process is repeatable. Disassembly can occur, pipes can be added or removed, more designs can be generated and the nodes themselves can be recycled and reprinted. As long as the material is not damaged, this reuse of material at the end-of-life cycle can be extended for as long as material durability allows.

Lastly, in the same way, that designed waste objects require training on the designer part, so does utilize digital tools in the extension of end-of-life material cycles. Through the ability of architects to create their own tools, tedious design problems can be automated. Software tools that allow designers to focus on important aspects of design, but automate tedious and time-consuming repetitive tasks can completely change the range of solutions that designers will seek. The proposal of an emergency shelter that uses this method is interesting but needs to be explored further in detail on how the process would work in using waste material from the earthquake. While some products are given or designed a life cycle from the start, the possibility here is designing other life cycles after the product has turned into waste. Through a process of design that is strictly based on available stock of materials, and measurable material parameters, new designs can emerge that create new life cycles for products that we might have already considered as waste.

7.1.5 Collect, Transform, Make

Research in the thesis was based on two main pillars and discussions, that of waste as a resource and that of digital tools as a transformative instrument of waste through design and building. The thesis investigates different procedures of transforming waste material but decides to focus on end-of-life materials as a category that does not receive the required attention in normal procedures of recovering waste material. The thesis set out to identify procedures of recovering waste for reuse in new building procedures, creating a closed material loop, and delaying the inevitable return of the materials to a cycle that requires energy in order to reintroduce back the material in the production chain. The thesis argues strongly that the chain should be a loop that manages to feed resources back to itself. By detailing important steps in those procedures, we can create design methods based on local materials.

Collect

The collection process of waste is presented as an important part of the research as it allows for the stock of material to be created. It is during this process that waste can be put in the condition to become a valuable resource. Recycling guidelines have not managed to be successful everywhere, and countries, where this is never enforced, make this harder through non controlled waste management and collection. Through digital tools, a tedious process can be automated, documented, and become more efficient. This does not however remove responsibility from human users which still needs to be educated on the importance of reducing waste. The steps needed can be summarized in these points:

- User education through participation
- Urban Mining when needed for material collection
- Automated waste collection
- Categorization of waste based on chemical composition and/or geometry
- Waste archive/database creation and registration

Through these steps, we can make sure that waste is collected in a manner that facilitates future reuse. A large part of this is the proper categorization. As material reach their end-of-life cycle, they cannot be all thrown into the same container. If waste is properly categorized, someone’s waste becomes another person's treasure. However, these steps in waste collection require intervention and policy making in order to implement. As in the case of Peccioli (Salvini, et al., 2011), legislation for these new collection tools is unclear and needs to be defined.

Transform

Transformation refers to the act of changing the state of objects in one way or another. This procedure can happen in many ways, from the simple act of registering a product, which in itself shows value of the waste product, to the act of changing its configuration through physical manipulation. Transformation processes can happen even at the moment a designer or builder, select an object for a certain process. As discussed, design through waste requires a change in the design process where material stock is the starting point. In the case of digital tools, material stock serves as the digital bits that will make up the design. Automated processes of transformation shown such as mine the scrap do this automatically, through 3D scanning, while more practical projects read into the qualities of the material. These processes require an understanding of the possible set of goals to be successful. So the main points in transformation:

- Education in sustainable waste management practice and methods of reducing and reuse
- Digital archive of available waste material stock
- Education in new design tools
- Design for informed assembly and disassembly
- Allow material recollection and reuse from the design phase

Whether it's automated through algorithmic design or follows a more traditional design procedure, the stock material needs to be clearly defined by parameters in our tools. Also educating young designers in the tools, free’s creativity to find more relevant solutions to waste rather than be blocked in technicality. Although architects have the knowledge or should have from their university education, it is usually designers and makers that are courageous enough in material experimentation that can create meaningful artifacts.

Make

Production and the process of making is one of the main enablers of the ideas behind this thesis. As production has been democratized, the availability of advanced manufacturing tools is freed for general use. Rapidly expanding Digital Fabrication Laboratories in this case or Maker Spaces can become the enablers of the procedures in general. Through a specialized network of knowledge and sharing, spaces to allow communities to gather and learn, and the ability and knowledge to do and train interested groups. Designing with end-of-life material through open-source tools in the context where knowledge can build up through time and shared among networks can create processes that use waste in an efficient method. Maker spaces do not only enable easy fabrication and manufacturing but also offer a platform that can create a whole community of designers committed to seeing waste as a resource. With maker spaces taking a central role in the discourse there are some key issues that the process needs to take into account while making new artifacts with end-of-life materials.

- The process should have an informed assembly to allow any user to follow
- Disassembly should be easy and allow total or partial material recovery
- Joinery and connection are important for the last two points, and tools that create them should be automated for non-professionals
- Fabrication needs to happen with local and recyclable materials. Fabrication waste should be optimized as much as possible.
- Successful design and solutions should be open-source and shared with the community

By creating communities that are based on common goals, maker spaces can become the drivers in the creation of prototypes where end-of-life materials are explored. The ability to share knowledge from anywhere in the world can lead to global knowledge applied to local solutions and resources.

These three main categories in the procedure look similar to the linear process we usually follow, with the main distinction that once a material enters the process it continuous to be part of the loop until the material integrity allows. The outcome of making would be directly fed to the income of collection thus cutting manufacturing costs and CO_2 of new materials.

7.1.6 UN's Sustainable Development Goals

The time and location of the idea of sustainability emerged are difficult to ascertain, however, the idea of sustainability was established as an action plan, a blueprint for steps toward a planning approach (Filho, 2000). The SD[38] paradigm provides conceptual tools to explore how to analyze the transition of the system from its present growth-oriented direction to a more growth-oriented sustainable one. As a

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[38] Sustainable development paradigm: https://sustainabledevelopment.un.org/partnerships/goal12/

logical metaphor, SD is suggested as a novel way of interpreting the development of the structure and stimulating the discussion on possible solutions. The first concept of waste management is that the volume of waste is decreased by one, generating less in the first place by consuming less. The imperative of "reduce" is not to interrupt all new development and related development. Innovation opportunities, but to reconsider the growth-oriented, market-like approach; consent to safeguard institutional opportunities. The Policy Statement, analogous to the argument for responsible use of the global regulatory space is the argument footprinting for carbon. The reduction of footprints and pollution offsetting will help for future generations, ensure a stable climate. The second concept of waste management is to "reuse" materials instead of throwing them away or moving such materials on to others in their original form, that will use them too. This is where sustainable development goals meet alternative concepts, new practices, and bold methods (Papa, 2015). Recycling refers to putting old products that are unusable through a process that converts them into new products.

Through the drafted procedures we can create correlation to many other Sustainable Development Goals. The correct management of waste directly correlates to climate actions (13), a better quality of life below water (14) as well as life on land(15). Through sustainable methods that enable the reuse and reduction of waste the impact on the environment can be greatly reduced while opening new processes. Processes of building from this resource can prove to be cheap while also launching a new businesses based on transforming waste into value, promoting economic growth (8) and sustainable communities (11). Users on the other hand are able to learn new methods of production through digital tools, proving education and most importantly creating a range of individuals educated (4) in working with digital fabrication tools. Through maker spaces, industry innovation can happen as trained individuals in the digital tools can transfer their knowledge in other areas of production bringing innovation to other local industries (9).

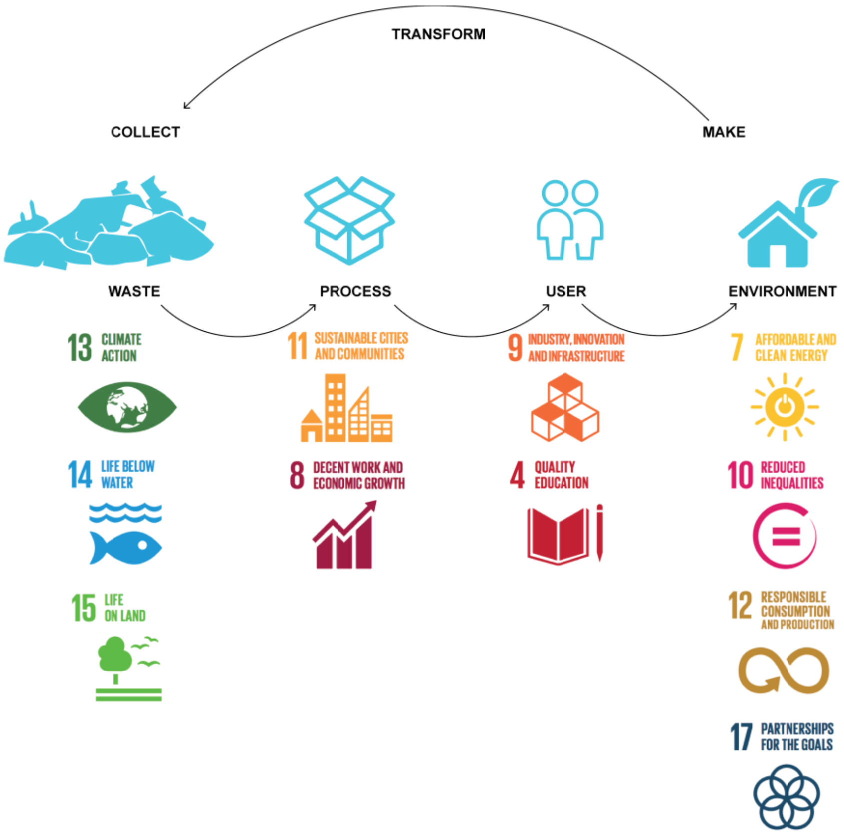

Figure 117 Collect, Transform, Make procedure in relation to Sustainable Development Goals. Source: Author

Lastly the environment that we can make through this procedure not only promotes a responsible consumption and production (12) as the tools themselves used that, but can also reduce inequalities (10) as different communities and professionals from different fields of life come together. Affordable and clean energy can be a by-product of the whole process, as materials unable to be reused can be properly recycled and used to create clean energy (7). As many actors have interests in the many goals listed, partnerships will come naturally in achieving the goals.

8. CONCLUSIONS AND RECOMMANDATIONS

8.1 Conclusions

This thesis set out with the aim of *finding digital design and fabrication procedures that can extend the end-of-life cycle of materials.* This research aim was investigated by trying to understand the two main pillars of this research. The first, ‘waste’ through the current methods of transforming waste into a desirable building material used for building and understanding the value and potential that it can have. The second, digital tools, by exploring the current practices and new implications that these digital tools can have. While digital design and fabrication have become an important part of today’s architectural practice, the effect they have had on the large market of applicable products is still taking shape. Processes of design and fabrication, that were exclusive to certain industries before, have become more common for anyone interested enough to explore them.

Innovative practices of dealing with waste that uses digital tools are showing that they can change the process of how waste is perceived, given back to us, and used. Through the change of perception and understanding of the value that waste can have, new procedures that take advantage of it, become very interesting. These procedures have even more impact in countries (like Albania) that largely fail and managing and recycling their goods. If waste is seen as a resource, new uses of it will become second nature to everyone. As this perception can gradually happen and change, especially communities in need will see the economic benefits of it. The impact that current waste management methods have on the environment has proven to be catastrophic. Reuse and recovery in this sense can automatically remove a good portion of materials that would become part of landfills, most of them unable to be recycled. Cataloging waste is a process where digital tools can thrive, both in applicability but also in scope and results. This is also in line with the UN’s goals for sustainable development on responsible production and consumption. As the building industry is still one of the main culprits in the generation of urban solid waste, strategies of reducing or avoiding it completely can change the impact that building processes have on our environment.

The procedure discussed above of Collect, Transform and Make serves as a set of steps that a design process involving reusing waste materials needs to take. Most importantly it emphasizes the ability to make tools and procedures as easy to use for non-professionals. These tools need to incorporate some principles of design, made as easy as possible for individuals that want to make with waste but lack experience and knowledge. MakerSpaces offer that experience and knowledge in the form of local professionals and global networks of knowledge sharing and design resources. Open-source design cuts costs for the average person that is interested in fast, sustainable, and cheap design solutions. And while the tools themselves can have these principles embedded into the design goals, it is up to maker space which can always stand at the center of the process to oversee that these procedures have the desired outcome.

New materials and technologies that use waste in order to create new building components certainly help in the quest of reducing waste. Although the long implementation time of these materials for countries that still face the problem of how to manage waste is proving shows a different reality. Some start-ups that experimented with waste in the creation of construction elements are now companies. The unavailability of those materials worldwide makes this research even more relevant. End-of-life material is a state that almost everything human manufactured has to go through. Procedures defined during this thesis on the usage can impact greatly the amount of waste material that we send back to our environment while reintroducing for as long as possible into new processes of construction and deconstruction materials that have been considered part of a linear process with a dead end.

Architecture in this thesis, or better the aim of making architecture, is controlled by the digital tools created by the designers. By embedding design information in our tools, we can inform building processes that allow a wide array of applications, especially when dealing with unusual materials. The process can be automated either through fabrication tools or by embedding assembly information into the fabricated pieces themselves. Architects and designers have shown to be open to experimenting with unconventional materials and as building and architecture, at the larger part already happens without architects, this can be a way in informing and giving quality to the process. Through the transformation of waste into a desirable resource, new possibilities are open that are more focused on local production and resources than before. The democratization of production and design allows almost anyone with the right tools to design and make on its own. These tools need to be specifically directed at these audiences while built by architects and designers that understand the implication of a circular product lifecycle. Waste or future waste in this case becomes a resource through design and digital tools.

8.2 Recommendations

This thesis does not deal at all with one of the more interesting advancements in digital design tools in the last 3 years, namely machine learning and Artificial Intelligence (AI). While these tools do fall into the digital design tools category, they are still under development in their applicability in the building industry. Research in the field shows very interesting results with terms of Artificial-Intelligence-Aided-Computer-Design (Cudzik & Radziszeweski, 2018) already being touted as methods that we will be using soon. The premise in this case is having an artificial intelligence as a design assistant. While in no way should we think that AI is capable of designing on its own, exactly the opposite is true in fact. Modern AI is based on machine learning techniques which as the name implying, is a method that allows machines to learn from past experiences. In the sense of design, machines can be fed a range of design solutions with certain parameters and goals to measure in order to learn from experiences. This could be revolutionary as a tool at the disposal of MakerSpaces, where an AI assistant that has knowledge from other architects and projects can suggest solutions to complex problems such as designing from materials at the end-of-life.

Project credits

Ur Re 2.0

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Parametric Bamboo Spatial Structure

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