

SEMESTER PROJECT
AUTUMN 2019



INNOVATION IN THE SUPPLY CHAIN
OF SAND TO TACKLE SHORTAGES
AND THE DETRIMENTAL EFFECTS OF
MINING



Authors
RICHARD Nicolas
BRAULT Victoire
OLSEN Nils
CAPRON Judith

Professor
Dimitrios Terzis

Contents

1	Introduction	1
1.1	Use of sand : A state of art	1
1.2	Key numbers and challenges	1
2	Supply-chain of sand	3
2.1	Extraction	3
2.2	Processing	4
2.2.1	Natural decomposition	5
2.2.2	Extraction	5
2.2.3	Sorting	5
2.2.4	Washing	5
2.2.5	Crushing	6
2.3	Trade	6
2.4	Construction	6
2.5	Demolition/recycling	7
3	Substitution, solution to the problem ?	8
3.1	Stone Ash	8
3.2	Plastic waste	8
3.3	Desert Sand	9
3.4	Recycling old concrete	10
4	Business model proposal : 3R! Reduce, Reuse and Recycle	12
4.1	Presentation, zone studied	12
4.2	Legal bases	13
4.2.1	Demolition and recycling	14
4.2.2	Strength and constructive requirements	16
4.3	Measures	16
4.4	Digital tools : Machine Learning and BIM, optimisation of the system	17
4.4.1	Aggregate Sorting with Artificial Intelligence	17
4.4.2	BIM used as a tool for a "just-in-time" production model	18
4.5	Going further with a new label	21
5	Discussion and conclusion	22
6	Annexes	24

List of Figures

1	Image of Dubai's Islands	2
2	Life cycle of sand, gravel and rock [1]	3
3	Impact of sand extraction on biodiversity	3
4	Production of sand and aggregates in Europe in 2016 [2]	4
5	Impact of sand extraction on biodiversity [3]	5
6	Pet Recycling in Switzerland in 2018 [4]	9
7	Sea sand vs. Sahara's sand [5]	10
8	Finite sand tests [6]	10
9	Links with others sectors for 3R : Reduce, Reuse and Recycle	12
10	Illustration of the central installed by Marti on the Champel working site	13
11	Flow of raw materials for the buildings, with or without 3R	16
12	Example of a digital marketplace of re-usable material	17
13	Convolutionnal Neural Network (CNN) - The technology used to detect the type of demolition waste	18
14	BIM level of maturity	19
15	Extract of the ArcGIS Platform [7]	19
16	Business Model Canvas	24
17	Lean Model Canvas	25

1 Introduction

1.1 Use of sand : A state of art

Sand is extracted world-wide and is mainly used in the construction industry. Sand is a non-renewable resource and is being over-exploited, around 50 billions of tonnes are mined every year (Steinberger et al., 2010).

Furthermore, sand mining has a very important impact on the environment. This issue is mostly unknown to the general public but also to specialists in the construction industry like us. For this reason, we decide to tackle this problem. Sand is almost everywhere, looking just around us: it is massively used to build the walls of a room we are in, as the well as the glass of our windows. It is also a key ingredient for the solar panel construction. Most of the sand is used in the construction and land reclamation. Numbers will be given in the case of Dubai and Singapore respectively.

This work focuses on sand used for construction. The main issue in this field is that not all the sand can be used to build concrete. Desert sand for example is not suitable as its shape is too round. Therefore, sand is often extracted from the sea as it is more angular hence more suitable for the construction industry.

The trade of sand extraction is not going to decrease and it is likely that in the future this resource will become an issue since world population increases and becomes more and more urban. Therefore, its need in the construction sector increases.

In the next section, key numbers are given and classified in order to have a general view point of the sand use in the construction sector.

1.2 Key numbers and challenges

Most of these numbers extracted from a UN environment program report from the GEAS [8].

- 50 billion tons of sands exploited every year¹.
- 3.7 billion tons of cement produced every year².
- 1 ton of cement need 6 to 7 tonnes of sand and gravel³.
- 45,000 tons of sand needed to build 1 mile of highway.
- Petrol : 1,8000 tons of sand for 1 single fracking site.
- 200 tons of sand for a house.
- 3 000 tons of sand for a hospital.
- 45 000 tons of sand per kilometer of highway.
- Palm Islands Dubai 150 million tons.
- Burj Khalifa 45700 tons od Sand from Australia.
- The world island in dubai 500 million tons of sand.

¹from UNEP-GEAS

²from UNEP-GEAS

³from UNEP-GEAS

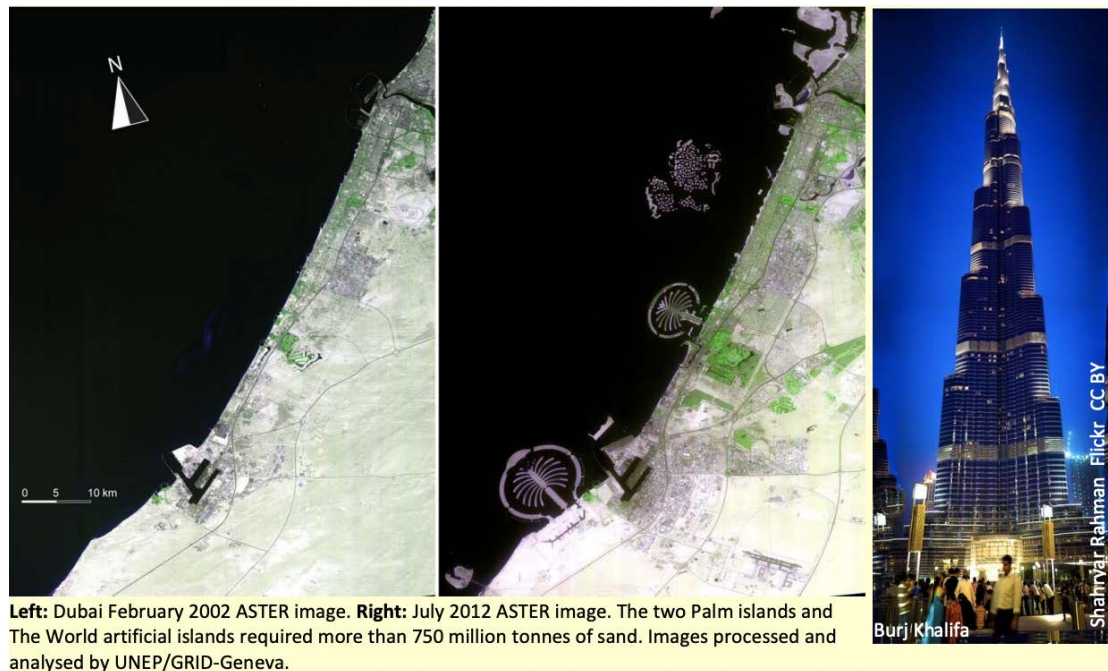


Figure 1: Image of Dubai's Islands

- Singapore 1/5 of the country is backfill.
- Dams prevent 25% of sand from reaching ocean.
- China 60% of global sand production⁴.

⁴from New York Times

2 Supply-chain of sand

As mentioned in the introduction, there are many environmental impacts due to the over consumption of sand, not only from the extraction that alters the landscape, but also from its entire life cycle, including processing, transportation, construction and demolition. In this section, we study each current process of the different stages of the life cycle and how we can modify them to improve the sand supply chain.

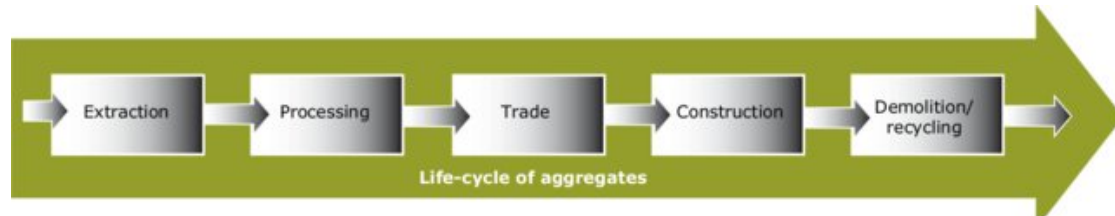


Figure 2: Life cycle of sand, gravel and rock [1]

2.1 Extraction

There are different ways to extract sand from the riverbank. One of them is by picking it up with a rubber-tired vehicle called "front loader". It can also be done by excavating it underwater with floating dredges that have a long boom with a rotating cutting head to clear sand deposits, and then using a suction line to suck up the sand.

However, this extraction is well known to destroy the environment. Indeed impacts could be mentioned as the following :

- Alters the landscape,
- Reduces gravel resources and water quality by increasing the turbidity, moving sediments...
- Impacts the ecosystem and more especially the seabed flora and fauna [9],

Tillin et al,2011.png

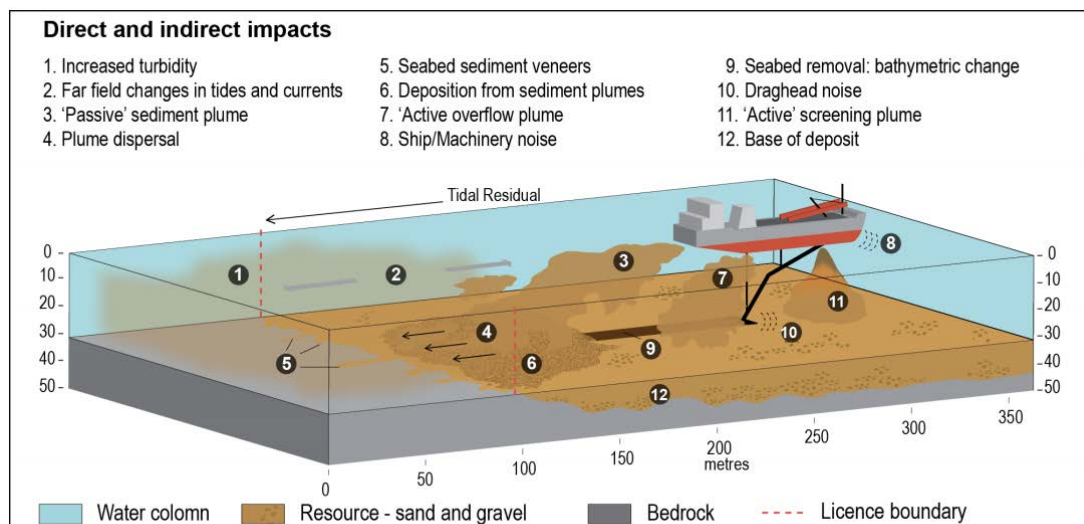


Figure 3. Direct and indirect consequences of aggregates dredging on the marine environment. Graph adapted from Tillin et al., 2011

Figure 3: Impact of sand extraction on biodiversity

- Increases the vulnerability of island and coastal lands. Indeed, by digging and extracting sand under the sea, near the coast, this creates slope instability that leads to soil erosion.

This erosion increases the impact of rising water levels and reduces natural barriers against natural events such as tsunamis,

- Impacts the marine currents because of density changes,
- Increases the salinity of coastal groundwater tables. Indeed, by digging close to coast, this collapses the ground level, brings it closer to the groundwater table and facilitates salt water infiltration.

Therefore, we can see that all of those risks are many detrimental impacts of sand extraction that must be reduced. At first glance we could imagine finding a substitute to sand. But, as we explained in first part, it is unreasonable to assume we can find a material able to replace entirely the sand needed nowadays.

The next section of this report propose two main solutions to reduce the consequences of extracting this raw material, which are the substitution of this raw material by another "clean" material or the use of recycled materials in the construction industry.

Regarding the geographic site of sand mining in Europe, they are mainly located in Germany and France (see figure 4 below).

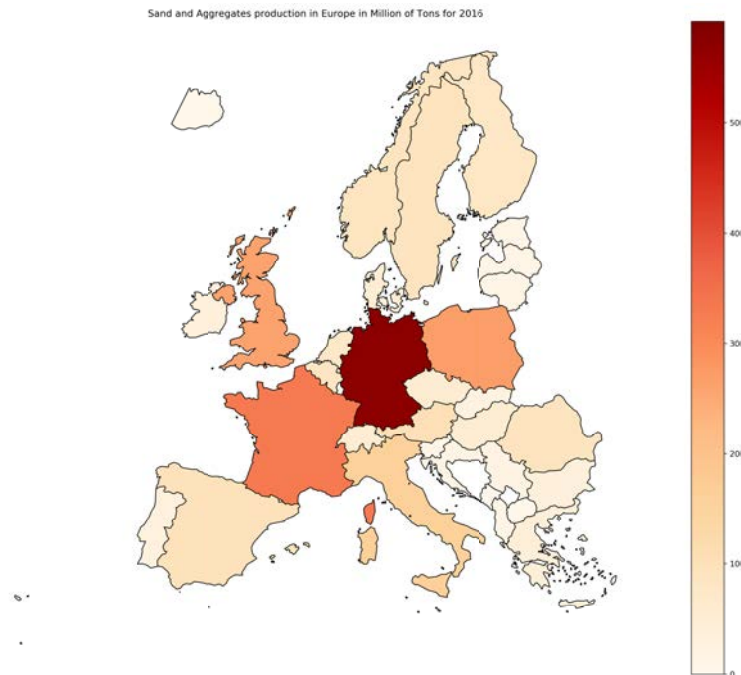


Figure 4: Production of sand and aggregates in Europe in 2016 [2]

2.2 Processing

From the raw extracted material to the material that can be used for construction, five main processes are required such as : natural decomposition (that takes millions of years), extraction, sorting, washing, and -in some cases- crushing [10].

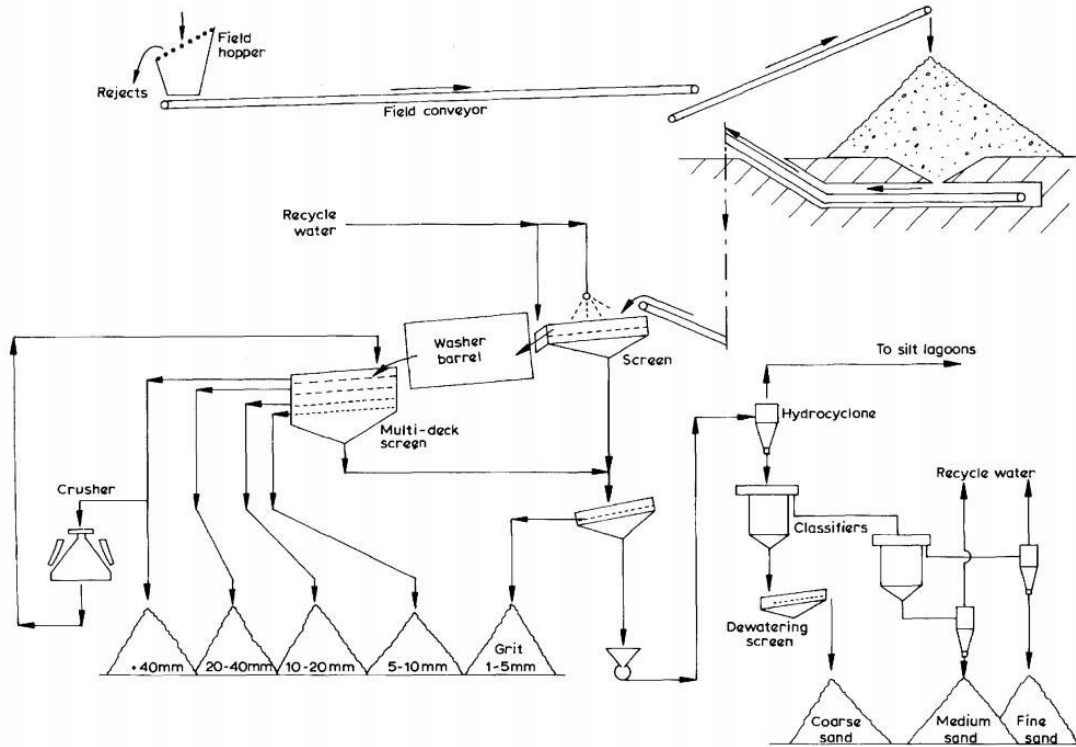


Figure 5: Impact of sand extraction on biodiversity [3]

2.2.1 Natural decomposition

Natural mechanical forces such as the movement of tectonic plate break solid rocks into chunks of rock that progressively disaggregate into smaller particles from chemical action, wind or water action. Those small particles are then carried into water before depositing into the bank and accumulating sediments.

2.2.2 Extraction

The extraction (explained in the first part above) could be summarized by using a huge front-loader that will excavate underwater and dig out the sand to the surface.

2.2.3 Sorting

When the sand is extracted in the ocean, it's therefore mixed with salty water. It's then necessary to separate out this water, as well as rocks and other foreign material.

Afterwards, it's then necessary to pass this material through several perforated plates with different hole size openings to sort the different particles depending on their sizes. As we can see in the figure 5, those plates also called "screens" are tilted at an angle up to 45 degrees from the horizontal. Then, those screens are vibrated in order to move all particles, unblocked them and to allow them to drop into the holes corresponding to their size. We can also see in the Figure 5 that the top screens correspond to the largest holes and therefore sort the largest aggregates first.

2.2.4 Washing

After the first coarsest screen, the material is washed by water rotating to add the scrubbing action, before going again through different screen sizes. Then, this dirty water, as well as the smallest material that pass through the finest screen, are pumped and a mechanism of settling is established to even separate the finest particles called "silt" that are really light and carried

off in the flow of water.

Moreover, if the sand was directly extracted from the ocean, it would still have a high silica content, making it impossible to use it directly on the working site after the sorting. Indeed, the steel beam would react with the silica and the durability of the reinforced concrete would be reduced.

2.2.5 Crushing

Finally, it's also possible, as we see on the left of the Figure 5 that some sand can be crushed to produce a specific shape or size that doesn't exist naturally.

Therefore, regarding the life-cycle of sand, processing is not the most environmentally damaging step, if, however, the sorting plant is located near the extraction sites and the water used to wash the materials is recycled.

2.3 Trade

Unlike the processing stage of the life-cycle, trade can be a key factor, both in terms of environmental impact and supply-chain optimization. Indeed, the trade implies the major following risks :

- Transport of the raw material which produces CO₂ for example,
- Price competition that can encourage the choice of one production site instead of another,
- Different companies with different environmental policies, often non-existent,
- Different taxes depending on the country...

Thus, there is a wide margin of manoeuvre regarding the measures to be implemented to limit the impact of trade on the environment. Indeed, we can imagine that if we find a replacement of raw material that can be produced closer to each site of construction, we'll reduce the damages of transportation. Same logic applies to the recycling of old concrete. We can also imagine increasing the price of the sand to encourage consumers to reduce their consumption, or apply a tax on transportation to encourage consumers to command sand as close as possible to their construction site.

The optimization of the supply-chain of sand would therefore be to rethink the transportation system. By combining the use of new hydrocarbons free transportation systems (trains for example) to close loop services, we may manage to reduce significantly the environmental impact.

An uniform law and regulations towards sand would also help to have a more respectful management of sand worldwide.

2.4 Construction

Once the raw material has been processed and transported, it can be used for construction. The two main needs of sand are :

- Sand without transformation for embankments
- Sand in combination with other materials to make concrete, asphalt...

As mentioned in the introduction of this report, 50 billions of tons of sands are exploited every year and for example, half of which are used to make cement for construction. It's therefore the

domain that requires the most amount of sand and that is mainly responsible of the environmental impact of sand mining.

Due to the population growth and more specifically the urban population, the risk associated with construction is constantly increasing hence the need for concrete sand too. Despite the fact that its availability does not seem critical, it is its extraction mode that is more worrying. The current risk is therefore to continue to extract sand in ever-increasing quantities, thinking that it is an almost unlimited material.

It is therefore important to find a way to change this mode of overuse of sand and prevent these risks of environmental impact.

Concerning the geographical distribution of the use of sand for construction, it would seem that it is mainly China.

In order to improve the supply chain of construction, we propose, for example, to use BIM models of buildings. Indeed, by receiving a BIM model, it is possible to calculate the volume requirements of concrete with their associated strength. Thus, we can then attribute to a wall requiring low strength, concrete offering lower strength because of recycled materials for example, as explained in the next section.

Therefore, for example, the demand for new sand could be reduced by submitting the BIM model of a new building before its construction phase, and a quotation could be proposed using as much recycled material as possible, depending on the volumes and strength required and using the minimum amount of "new" sand. It could also be proposed to produce as many recycled prefabricated elements as possible to facilitate and improve the installation phase.

2.5 Demolition/recycling

The demolition and recycling of the materials recovered as a result of this demolition is the key factor in reducing the risk of environmental impact from sand extraction. Indeed, if we could build only from recycled materials, it would allow us to reduce or even stop our demand for new materials.

On the other hand, the risk of recovering recycled materials is that they have already been used. They may therefore have been weakened, damaged, dirtied..., which could increase the uncertainties regarding resistance.

In addition, its availability seems limited. Indeed, despite the fact that a building has a limited lifespan of about 50 years, we are currently building far more buildings than we are destroying.

Thus, despite the fact that recycled sand is a rare commodity, even if it was more abundant, it also seems more expensive to build with concrete whose raw materials are recycled compared to new sand. Indeed, the price of new sand is so competitive that it seems difficult, if it is not taxed, to promote the use of recycled sand.

In order to improve the supply chain of demolition and recycling, we propose to use BIM models of buildings to create a database. Indeed, with this database it will be easy to predict which buildings will be demolished soon, how much sand and aggregate will be recoverable, in which region these materials will be recovered and therefore be able to optimize the use of these recycled materials.

3 Substitution, solution to the problem ?

As previously explained, the concrete is one of the main issues concerning sand use worldwide. We shall find new ways to produce cement or concrete in an efficient way (keeping its strength, permeability, properties) using less and less sand. We will in the following sections propose different ideas and researches done in that direction and present the outcome and the results of these studies.

Each solution may apply to one specific aspect of the construction field (cement, roads, etc ...) and we need to keep in mind that, sand may not be entirely replaced but, combining these alternatives and partial solutions may reduce significantly our needs.

3.1 Stone Ash

One of the partial solution we could propose is the stone ash. Stone ash is "the result of processing broken stones using stone crusher" [11]. Therefore, this resource is likely to be present in large quantities and could be considered as a good replacement. Once mixed into the cement, it would preserve the concrete strength as if sand was used.

Based on a report from the Indonesia Malaysia Research Consortium Seminar [11], we were able to find how stone ash would affect the strength of concrete once integrated in the cement production. The results of the study are shown below, in table (1).

Percentage of stone ash	Concrete compressive strength [MPa]	Strength reduction [%]
5%	39.37	0.63
10%	38.32	1.68
15%	37.38	2.62
20%	36.28	3.72

Table 1: Results from test of stone ash in cement for $f'_c = 40$ [MPa] concrete [11]

The results are giving a perspective of good alternative. With 20% of stone ash presence in the cement instead of sand, we "only" have 3.71% in reduction of the compressive strength after 40 days. Even though the need of sand will not be entirely covered by this solution, we could expect a good reduction in the cement production field with this alternative.

Stone ash percentage in cement could be managed for each type of wall : bearing walls require high compressive strength, in these cases the stone ash percentage is low whereas for less loaded walls we can increase the stone ash presence as to reduce the impact of sand.

3.2 Plastic waste

Another solution is based on the recycling of another overused material : plastic. As our consumption keeps growing, we encounter a higher and higher amount of plastic waste. PET especially could be a really good option in order to replace sand (until we manage to decrease our plastic consumption, in a more sustainable way).

Studies have shown that PET (polyethylene terephthalate) could be used in a very efficient way in roads construction. In the first place we will explain a bit more about road construction.

The first thing to know is the actual composition of roads and the percentage resulting from sand use. We know that the sand is used in the asphalt (around 95%, with stone and gravel, the 5% remaining being cement and petroleum product) [12]. Moreover the proportion of asphalt for most of the roads as it is done nowadays is 70% [13].

The idea behind replacing sand with PET would be to combine the effect of recycling, keeping the resistance and the properties and using less sand. It has been shown that using PET for concrete in roads (known as PC) in fact reinforce the material. Using PET reduces all the other matters in road construction, therefore sand.

"The test results clearly show that very good mechanical and durability properties can be obtained with PC using unsaturated polyester resins based on recycled PET plastic waste. The PC was compared to a standard mix of portland cement concrete using a water-to-cement ratio of 0.5. It can be observed that the PC material is much stronger and more durable than portland cement concrete. Most importantly, PC cures in matter of minutes or hours; conversely, it takes days or weeks for portland cement concrete to cure."[14]

PET recycling is already quite well developed in Switzerland (see figure (6)). As the chain is already existing, it could be very interesting to question this cycle and see how the road industry could take advantage if this situation.

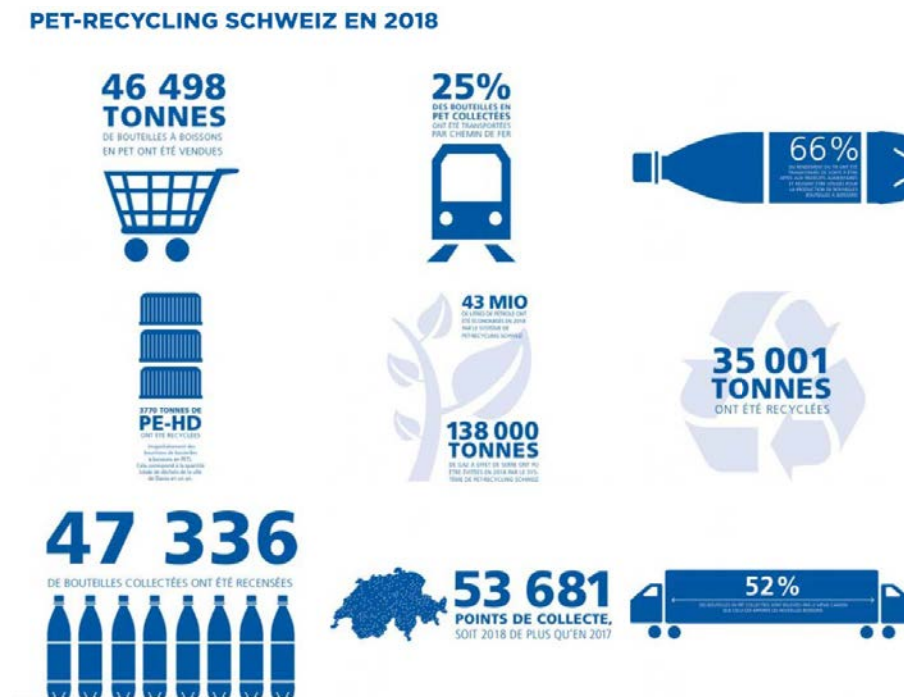


Figure 6: Pet Recycling in Switzerland in 2018 [4]

We shall nevertheless take into account the general behaviour concerning plastic use. As the concern for the environment grows bigger and bigger, laws about plastic regulation tends to emerge as well. We may observe a decrease in plastic (as the hydrocarbons tend to be less and less available as well). This solution is consequently more temporary than a long term solution, but still needs to be considered as we need to reduce the impact of plastic.

3.3 Desert Sand

We now know that sea sand (and river sand) is the preference choice when it comes to properties. Its coarse grains give better properties for cement like strength and permeability. On the other hand, desert sand is round and plain, shaped by the wind and displacement on a very plane area. We can observe these differences on the figure (7). If we could manage to use desert sand to cover a part of sand needs in construction, it could decrease the negative impacts of the extraction (destruction of rivers and coasts and all the resources that come with it).



Figure 7: Sea sand vs. Sahara's sand [5]

A recent enterprise called Finite developed a form of cement based on desert sand. As the study and technology is recent, we do not have access to the whole result. But we know that, for now, the technology is fairly practicable for temporary construction (for events). However, this solution is not yet ready to pass regulations for permanent construction. [15]



Figure 8: Finite sand tests [6]

Even though the idea of using desert sand seems a very good solution considering the actual consumption and its availability. We cannot entirely based our predictions on it, as we would need further information and studies. This is an idea to keep in mind though and to look forward in the following years.

3.4 Recycling old concrete

The last way we could possibly replace sand is again with ... sand. The same way glass is recycled into making new glasses and bottles, we could easily imagine recycling concrete into making

new one, needing less to no sand. An easy way to collect old concrete is directly on demolition sites. Demolition concrete could be then crushed into small pieces and re-injected in the supply chain (in cement, roads, building foundations, gravel, ...). This process is already controlled by governments in order to protect all the eventual dangerous matters in the demolition concrete. Landfills are also legislated so the maximum materials can be reused.

Multiple studies have been working on this subject and we will present some results under the following typology :

- RCA : recycled concrete aggregates
- CDW : construction and demolition waste
- NA : Natural aggregates

RCA produced by crushing of concrete CDW depends on crusher settings but in general, RCA is: 20 to 50% of fraction 0–4 mm, up to 65% of fraction 0–8 mm and the bigger fraction. As the EU standard does not allow usage of fine recycled concrete aggregates (F-RCA), those 20 to 50% have no further application. Fraction 0–4 mm can be used in a certain replacement ratio, mostly for non-structural concretes [16]. This means for now we cannot use this concrete for loaded walls or as important parts of the structural system.

Allowed replacement of coarse NA by coarse RCA vary from 20 up to 100%, but in case of F-RCA the allowed replacement ratio is more strict, and only several countries such as Brazil, Denmark, Japan, Russia, Switzerland,... permit its utilization.

The most significant characteristic and the difference between fine NA and F-RCA is water absorption, fines content and shape of the particles : a higher w/c ratio is needed to obtain same slump value as reference mix with only NA

A tendency of decreasing strength based on increasing replacement ratio is recorded throughout all reviewed articles and explained by lower strength of F-RCA itself. The replacement up to 50% was in most cases acceptable. All fractions are tested in the paper [16].

Results obtained from hardened mortar testing showed that F-RCA has no negative influence on compressive strength, on the contrary, it is increased. Favorable particle size distribution of FRCA might contribute to better workability and adjust overall particle size distribution of aggregates in the mortar/concrete mix, and lead towards better strength properties.

All mortar mixes with F-RCA gained slightly higher compressive strength than Ref mix which may indicate that strength of fine aggregates is not decisive. In the other hand, when fraction 4–8 mm was added compressive strength was acceptable up to 40% replacement ratio. Reduction of the density of mortar/concrete by F-RCA utilization was proven and can beneficially serve for non-structural concrete.

Overall it can be concluded that replacement ratio up to 40% has no negative influence on fresh nor hardened properties.

4 Business model proposal : 3R! Reduce, Reuse and Recycle

In Geneva, the UN asks for a worldwide organisation to manage the sand resources. The sand consumption is around 40 to 50 billions tons per year, so three times more than 20 years ago. We have seen the impact the sand extraction has on the beach disappearance, flooding and droughts. UN wants to work with Lafarge Holcim[17] a major actor in the cement industry, in order to improve the management of sand. Things are moving and that's why we want to intervene with 3R!.

4.1 Presentation, zone studied

The vision of our startup 3R! is incorporated in its name. Through the start up, the aim is to limit the sand consumption in the construction sector by using substitution materials coming from the demolition waste into the concrete using smart and innovative technologies.

The main market of 3R! will be in Europe where the housing market is aging and the urbanization is increasing. Therefore we tend to think that houses will be replaced with buildings in cities so that the demand matches the supply of housing. Moreover this process will prevent arable soil to be taken down (protecting resources).

For example in Switzerland, law on territorial planning : *"Art. 1 Aims : The Confederation, cantons and communes shall ensure that the land is used economically and that building areas are separate from the areas where building is not permitted. They shall coordinate their activities that have a spatial impact and implement a system of settlements that ensures the desired development of the country. They shall take account of the natural environment and of the needs of the population and the economy."*

This is precisely where we intervene. All the solid materials coming from the demolition of the house need to go somewhere. And in 3R! we want them to be sure that the best materials are used in a building again and not wasted in embankments or worse put into landfill.

Our method will be to take those materials coming from the demolition, crush and sort them with a machine and sell the sorted aggregates and sand to customers. It's main market will be to sell high quality recycled aggregates and sand that can be used in new buildings. There will be different quality of recycled materials :

- The aggregates with the best quality will be used in the bearing structure of the building
- The recycled materials with a lower quality will be used in the secondary structure
- The materials of poor quality or unusable will be send away to be used in embankments.

The following figure explains all the relations between the start-up and its customers, the technologies it uses and the laws. We'll explain in more details in the following sections.

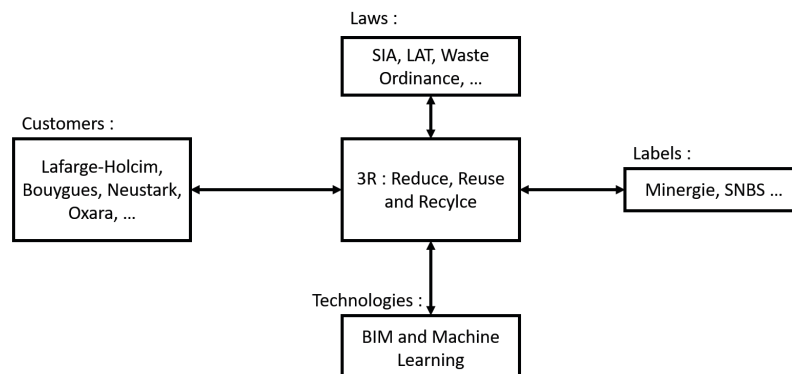


Figure 9: Links with others sectors for 3R : Reduce, Reuse and Recycle

4.2 Legal bases

As it was previously said, in order to be able to efficiently rethink the consumption of sand, one of the solution is the recycling of demolition materials. This is already wide spread in Switzerland and regulated. We will in this part discuss our legal bases and highlights the parts we need to have a closer look at.

A good starting point would be to look for examples and for cases where construction and demolition wastes were reused on site to produced recycled concrete. One example was found in Geneva, on one of the construction site where a tunnel was dug for the CEVA (Regional train in Geneva Area). The company Marti SA installed a centrale on the working site allowing an in-situ recycling of materials. The excavated materials when the tunnel is dug are crushed, washed and sorted before being used in the concrete. With this system[18] :

- 200'000 [m^3] of excavated materials were not put into landfill
- 270'000 [tons] of aggregates were produced on site
- 200'000 [km] were less traveled on the road to deliver the aggregates or removed the excavated materials



Figure 10: Illustration of the central installed by Marti on the Champel working site

What is also nice is that the station installed by Marti SA is reusable on other construction sites and can be transported with containers. The only drawback was that the company required to certify the aggregates, the concrete and respect some standards for construction site in urban area. Indeed even for "Eco-Concrete" standards have to be met. They need to fulfill the standard SN EN 206-1 which specifies the strength of the concrete, the maximum size of aggregates ... [19]. The SIA 430 standard 'Disposal of construction waste' entered into force in 1994 with the aim of making recycling and separate disposal of construction waste the norm.

Also when rocks or aggregates are extracted, crushed, the concrete mixed or construction waste recycled, standards has to be met on a working site [20] :

- ISO 9001:2015 Quality management system
- ISO 14001:2015 Environmental management system

We see that there are a lot of standards (non-extensive list presented above) which can slow down the adaptability of this new type of building material. An article [21] on the Swiss confederation website presents some guidelines regarding the objectives of the State on the topic of recycling CDW materials. The same article presents that in Switzerland besides excavation material, at over 15 million tons per year, mineral construction waste (concrete, sand, asphalt and masonry) is by far the biggest waste stream.

What we can keep from the directives are the following : (1) recovery of mineral construction waste to preserve natural raw materials; (2) remaining landfill space is scarce and it needs to be used more sparingly *source : David Hiltbrunner from the Waste and Resources Division at the*

Federal Office for the Environment (FOEN) in [21].

Also what is specific for the case of Switzerland is that each Canton has its own Waste Management Plan or Directives. Hence recycled construction materials will be used for different applications, depending on how and where they are processed. Some cantons have taken up the cause of promoting construction material recycling. The canton of Zurich, for example, is strongly committed to the processing of concrete rubble and supports the use of recycled construction materials, and the city of Zurich constructs a large number of its buildings using recycled concrete [21].

4.2.1 Demolition and recycling

The production of concrete in Switzerland today requires around 33 million tonnes of gravel annually – 2 million of this comes from recycling and the rest involves primary consumption. If we focus on how works recycling in Switzerland we need to have a look at the "Ordinance on the Avoidance and the Disposal of Waste" (Waste Ordinance, ADWO). This ordinance regulates waste management, meaning its recycling or/and destruction, one of its aim is to *"to encourage the sustainable use of natural raw materials through the environmentally sustainable recovery of waste."*[22].

Annex 4. especially gives information concerning the amount of each chemicals allowed for the recycling of concrete. It also lists the potential reuse we could see in those matters.

This following document [23] allows to see which companies are allowed by the Geneva canton to manage CDW. From what we can observe out of the 41 companies, 28 of them announce in their business plan to valorize concrete or other minerals materials coming from the CDW. 14 of them send the concrete in road embankments and 9 of them don't recycle the concrete but other material such as stone or glass. In the 5 remaining companies only one of them (Tecvia SA) properly recycle the CDW where the others (Serbeco SA, Transports Afonso SA, Jacquier Services SA and Ducret M. SA) only condition them.

In the Geneva canton, it is forecast that the need for the type A landfill (Unpolluted Excavation Materials) that will represent around 4 to 500'000 [m^3] per year for the following 10 to 12 years. It is in total from 5 to 6 mio of [m^3] [24].

What strategies can be implemented to handle sustainable those materials : it's possible to reuse in a better way, to valorize those materials and to reduce the amount put into landfill. The latest worked in the Vaud canton for other type of materials (concrete, bricks, old tarmac ...) and a recycling percentage of 80 % has been reached. However, objectives regarding excavation materials are far from optimal due to the fact that the price of natural aggregates are sold to a price really closed to recycled materials. An other solution could be to increase the available volume of landfill.

Example for the Vaud canton (2014) : [25]

- Construction Waste : 4'150'000 t
 1. Excavation Materials : 2'900'000 t
 2. Demolition Waste (Minerals): 1'035'000 t
 3. Other Demolition Waste : 215'000 t

The mineral demolition waste are the concrete obtained during the demolition or milling of reinforced or unenforced structures and pavements; the bituminous road demolition materials resulting from the milling or demolition of bituminous pavement; the non-bituminous road demolition materials resulting from the demolition of unbound base layers, free of substances such as concrete, bituminous materials, bricks or roof tiles. They are assimilated to natural gravel, provided that at least 95% of them are composed of it.

From the 830'000 [tonnes] recycled, 740'000 [tonnes] were taken by some specific companies who valorize the waste in some specific demolition waste management plant and only 90'000 [tonnes] were crushed and valorized on site.

Example for the Geneva canton (2013) : [26]

- Construction Waste : 3'454'794 t
- 1. Excavation Materials : 2'609'144 t
- 2. Demolition Waste (Minerals): 845'650 t

In the waste management plans of both cantons, one can observe their main interests for the following period and the positions they want to improve. The main points are quickly presented below : [26, 25]

- There will be an increase of the exported demolition waste because there will be less space in the landfills (Geneva)
- Each Canton aims to reduce the pollution from source (giving incentive/promoting valorization of excavated materials)
- Improve the sorting on small construction sites
- Promote the usage of recycled materials in construction.

From what we can observe at the level of the canton there is a market opportunity for 3R!. According to their waste management plan, each canton want to reduce the amount of materials put into landfill (which represent a cost for some agents) because it's a long and tedious process to open a new one. They also want to promote the recycling of those materials from the place they're created : the working site. However, the production of concrete with materials such as recycled concrete is not new. Some companies/start-ups are already on the market. Indeed recycling CDW directly impacts multiple sustainable development goals [27] (9 : Industry, innovation and infrastructure, 11 : Sustainable cities and communities, 12 : Responsible consumption and production). And we can say that those companies whom few examples are presented below have chosen a bold journey :

- Neustark [28] : Supported by the Climate-KIC grant, Neustark produce high strength recycled concrete aggregates and according to their website "unmatched compressive strength and ecological performance is achieved". Neustark vision is to reduce the sand and gravel consumption and the amount of construction waste put into landfill. They create a patented process to combine carbon dioxide and concrete waste into fresh concrete [29].
- Oxara [30] : Startup from ETH whose vision is to provide sustainable and affordable housing with a patent on a additive to produce cement free concrete. We liked their business model because even the company is only a start up for the moment, they propose multiple services : Additives supplier, products developer or contractor for affordable housing.
- Terrabloc [31] : produces earth brick with few percent of cement. The bricks obtained present really good compressive strength, durability and thermal inertia. They promote the fact that labels such as minergie p-eco can be obtained with using their component or with SIA 493.
- RE4 [32]: RE4 is a collaborative research project of 13 partner institutions from science and industry funded under the European Union's Horizon 2020 research and innovation program. Its main purpose is to develop a prefabricated energy-efficient building concept that can be easily assembled and disassembled for future reuse, containing up to 65% in weight of recycled materials from construction and demolition waste. The percentage of reusable structures/elements will range from 15-20% in existing buildings to 80-90% in "RE4 prefabricated building concept".
- GCM : Company in the Vaud Canton that sells concrete with recycled aggregates. Their price is economically attractive because it's from 3 CHF to 4 CHF cheaper per cubic meter than the concrete made from non recycled aggregate. Their EcoConcrete are composed of 25 % up to 40 % of aggregates made from recycled concrete.

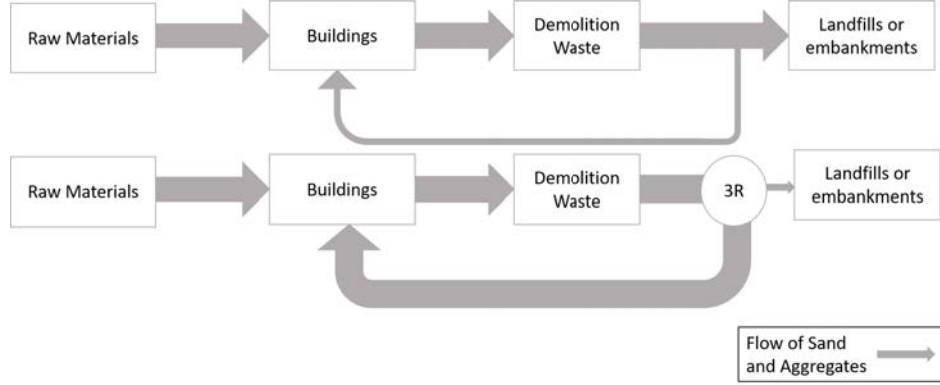


Figure 11: Flow of raw materials for the buildings, with or without 3R

4.2.2 Strength and constructive requirements

We also need to be sure of the characteristics of the new material we propose. Each new concrete for example would need to be tested to meet the requirements for construction.

This is regulated for the SIA norms in Switzerland and Eurocode (EN - European Norms) for the rest of Europe. Usually SIA requirements are higher than those asked by the Eurocode. We saw during the supply chain analysis (table (1)) that working with fly ash was providing concrete of similar structural strength. Can we obtain a concrete with the same structural strength but that contains recycled aggregates ?

- The production of sand from recycled concrete is working : In order to produce concrete we first need some aggregates and sand to a certain fraction. As cited in [33] we can produce recycled sand or aggregates from construction or demolition waste. The sand fraction originally present in crushed construction and demolition waste represents around 50% of the total waste. This paper presents a technology that permits the production of high quality recycled sand. The grain size analysis demonstrates that it is possible to produce sand from CD waste with similar grading of the original sand fraction present in the total waste. [33]
- Mechanical properties of recycled concrete : This paper [34] presents an experimental investigation on the effect of the replacement of natural coarse aggregate (NCA) with either recycled concrete aggregate (RCA) or recycled clay brick aggregate (RBA) on the compressive strengths of the hardened concrete. Two grades of concrete (C25 and C50) were investigated. In each grade concrete which was achieved by using different water-to-cement ratios, five different replacement rates of the NCA, 0%, 25%, 50%, 75% and 100% were considered. In order to improve the performance of the recycled aggregates in the concrete mixes, the RCA and RBA were carefully sieved by using the optimal degradation. The largest reduction obtained in the compressive strength obtained after a curing of 28-day was found to be only 7.2% and 9.6% for C25 and C50 recycled concrete when the NCA was replaced 100% by RCA. When the NCA were replaced by RBA the maximum reduction was 11% and 13% for C25 and C50 recycled concrete respectively. They conclude that in general, the concrete with RCA has better performance than the concrete with RBA.

4.3 Measures

The idea of this section is to end up with a business canvas of an innovative solution to reuse old concrete in order to minimize new sand excavation. A way we think this could be done is using the new digital tools to generate an adapted database of reusable material for the construction industry. For example, such a tool has been developed locally in the Netherlands and Belgium.

According to figure 12, it is possible to visualize a typical example of such an item available in the Amsterdam region of Netherlands. Information are well detailed, and the interface is user friendly. It is possible for instance to check number of pieces or the availability date, or the type of material.

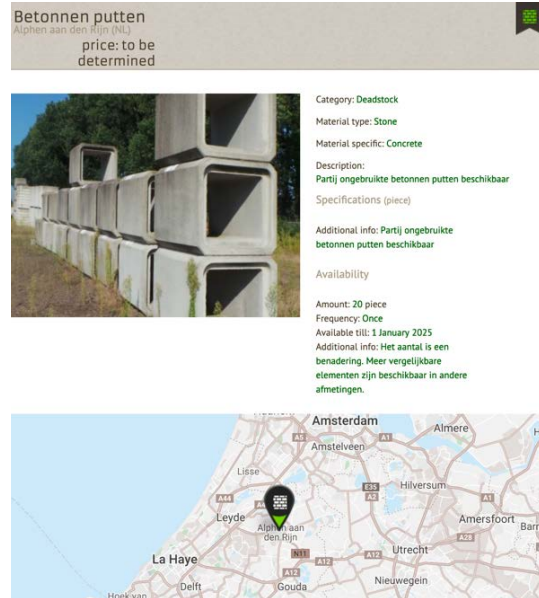


Figure 12: Example of a digital marketplace of re-usable material

The way used here to present the available materials is practical but not adapted to civil engineering sector. Indeed according to the figure 12 the chance that another civil industry is seeking for this specific dimensions of concrete block in the region of Amsterdam is extremely low. It is a main issue regarding reuse of concrete material in construction, most of building are designed from scratch with specific dimensions. The concrete structure are often recycle for the use of backfill in the road construction industry as an example.

Thanks to intelligent recycling concepts, it is possible not only to save costs with low energy consumption, but also and above all to conserve natural resources.

4.4 Digital tools : Machine Learning and BIM, optimisation of the system

4.4.1 Aggregate Sorting with Artificial Intelligence

the aggregates will be sorted on a conveyor belt created by 3R!. The conveyor belt will use machine learning and computer vision to detect and sort construction and demolition waste into different categories. All the aggregates, after being crushed will pass on the belt. They will be scanned and sorted. This system is already widely implemented in the agricultural sector to sort crops such as wheat, grapes, tomatoes. How can such a technology be developed for stones or aggregates ? Two articles can help us answer this question. In the first one called "Quantification of construction and demolition waste products that can be carbonated using a deep learning-based image analysis" [35], they focused on the development of a novel method to determine the composition of the CDW.

The composition of CDW is variable as it depends on the site from which it originates. They want to use the recycled concrete aggregates which contains a lot of cementitious material to uptake significant amounts of carbon dioxide with carbonation. In order to determine the precise composition of a batch of CDW, the NF EN 933-11 standard recommends manual sorting. However, this method is time-consuming and could become a bottleneck in the process of recycling larger quantities of CDW. To overcome this issue they focus their work on the development of a novel method to determine the composition of CDW with the use of deep learning and neural networks [35].

Their algorithm reached an accuracy of 92 % for this detailed classification task (Percent of the time an aggregate was correctly classified). They also state that further pixel-by-pixel identifi-

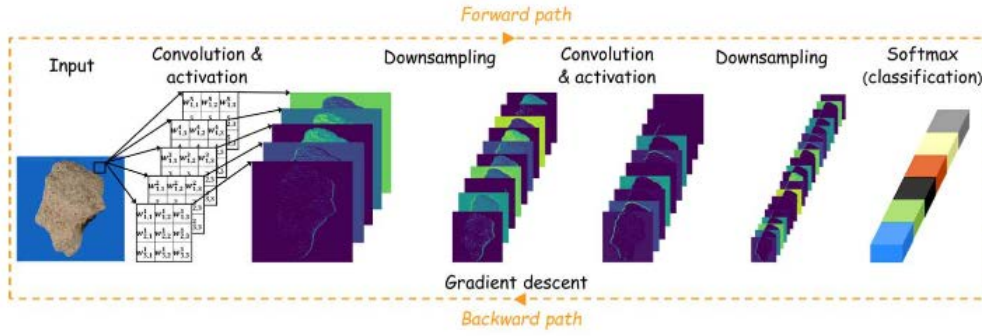


Figure 13: Convolutional Neural Network (CNN) - The technology used to detect the type of demolition waste

cation (semantic segmentation) of individual aggregates can be used to quantify the proportion of mortar available on each aggregate.

Where on the previous paper the grains were detected using a camera, in [36] numerical images are obtained with a simple optical microscope. The authors want to use those images to automate mineral grains recognition.

In [37] an approach was implemented to recognize relevant building material (concrete, lightweight concrete, brick, aerated concrete). Machine learning models such as random forest or support vector machines give the authors the best performance.

In conclusion, this type of problem is well known in the machine learning community, ie. classification of images. The only difficulty would be to sort rapidly and accurately aggregates and stones which looks alike a lot. The papers presented in that section showed promising results and show that it can be done for aggregates. The bottleneck factor would be the speed at which the sample are sorted.

4.4.2 BIM used as a tool for a "just-in-time" production model

Today Building information modeling is mainly used as a tool to manage construction sites. In fact Building information models (BIMs) is "*The process of creating and using digital models for design, construction and/or operations of projects*"[38]. Our idea here is to use these digital models to generate a strong database of available resources and future client. In a near future most of the building in Switzerland will be designed using building information modeling, it could then be possible to have a digital map of the actual buildings, the future ones and finally the ones that are going to be demolished. Our idea would be to buy BIM models from construction companies in order to produce the exact amount of recycle concrete they need. Today the building information modeling market is still not mature enough according to figure 14.

Les niveaux de maturité BIM

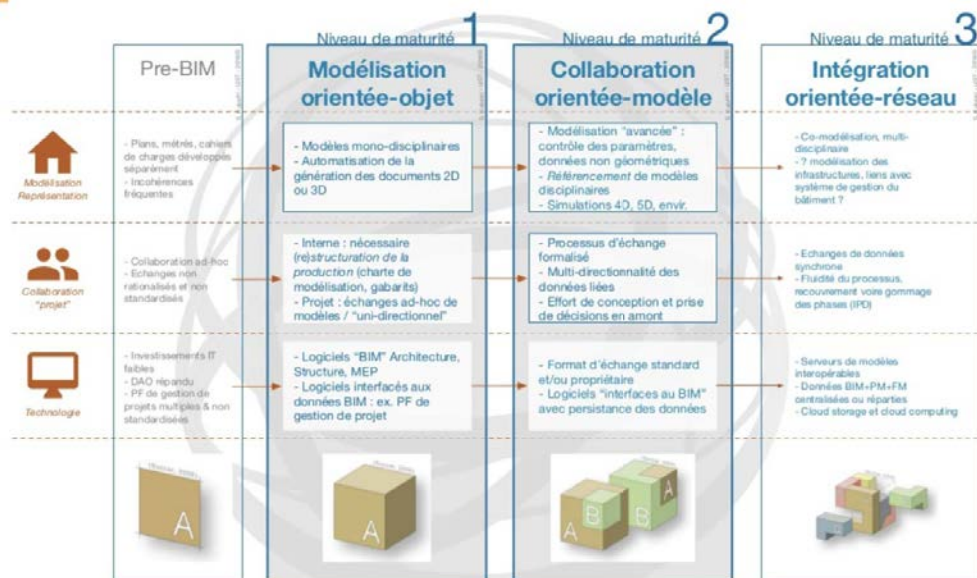


Figure 14: BIM level of maturity

If one day a so called BIM database server at the scale of a city, exist it would get much easier to manage waste of the construction industry. Furthermore our startup could have a "just-in-time" production model of recycle material. We would buy BIM model and optimize the needs of recycle material for the building according to available construction waste.

What already exists for the city of Geneva is a three-dimensional numerical map of existing buildings (grey) and those planned or under construction (purple). An extract from this platform is shown in figure 15.

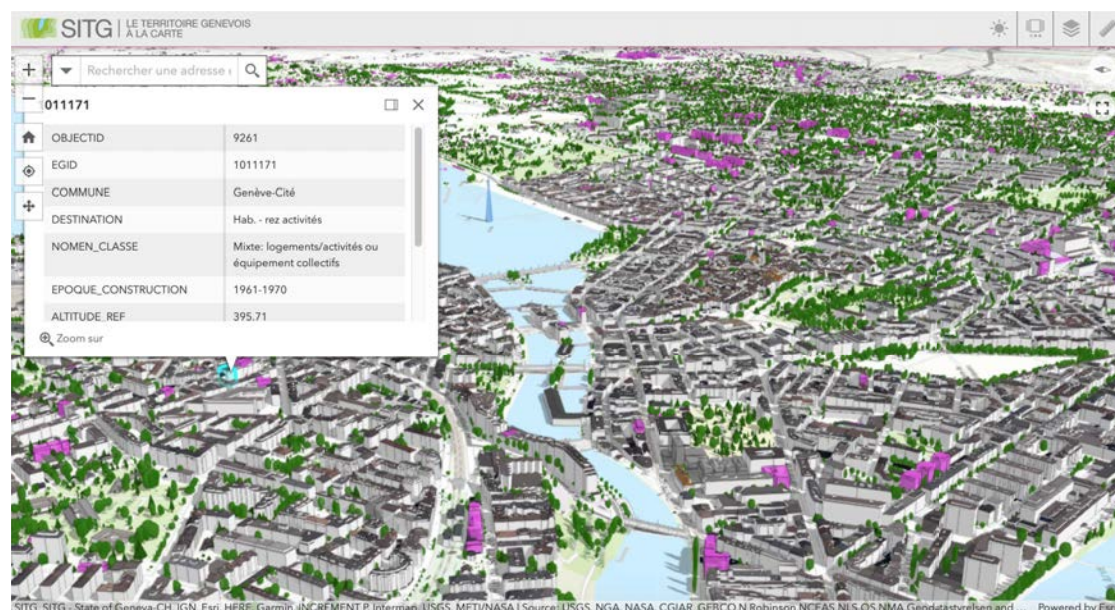


Figure 15: Extract of the ArcGIS Platform [7]

For example, it is possible to know the age of construction of a certain building and thus potentially determine the end of life date of the building, given that civil engineering works are generally designed for about 100 years. Therefore, when the third BIM level of maturity is oper-

ational and functional, we can group the material figures and know how much concrete we will be able to recover.

Of course this is still not in place today, in fact application of BIM incorporates different risks including technical risk, management risk, environmental risk, financial risk and legal risk [39]. Furthermore a dreamy world where BIM model would be shared is far from existing today. A BIM model is still an intellectual property of the ones that have created it. But the number one reasons why construction industry take so much time to include BIM is the lack of demand, cost and interoperability issues.[39]

The idea of the start-up is also to create economical value and application around a technology that struggle to rise up. If our idea of recycling material from BIM model works it could create value of BIM model. We strongly believe that there are plenty of incremental innovation around BIM that would make it even more legit. Such work already exist regarding recycle materials [40]. Members from the Hong Kong university have presented a "BIM based system" to estimate demolition and renovation wastes. They have written a script on revit that make it possible to add a "waste estimation and planning" tool. They studied the case of hong-kong and the main issue regarding recycling is that " When planning for recycling, contractors have to spend some time on identifying recyclables, selecting recyclers according to the identified information". The issue is that contractors have to spend time and thus money in identifying the quantity of waste and their category. If our start up wants to be useful and benefit to contractors, a waste management tool has to be implemented and a big part of the job will be to advise the contractors.

4.5 Going further with a new label

Labelling the whole process is a way to secure the future of our structure. By labelling, we intend to measure the ratio of recycled material from the site of destruction to the site of construction. Therefore there is a possibility to implement a criterion on the percentage of recycled materials for the building demolished AND a criterion for the percentage of recycled materials used for the construction of a new one.

The label would take into account the types of recycled materials, sites of recuperation and site of delivery. Consequently, we may also be able to have a full traceability of the materials. This is not to be taken lightly as it would make sure the laws are respected for the construction field.

We also want to ensure quality service and materials which is why we will add a quality criterion. The retrieved materials will be sorted by type and quality, which will then be helpful for the constructive part. Indeed, all aggregates cannot be used for every types of concrete. In order for our label to be efficient, we need to involve a good quality control in the materials we deliver to our customers.

We suggest the following plan as a sketch for our label :

I Recycling

A Percentage of retrieved materials

- 1 Percentage of good quality aggregates
- 2 Percentage of mid/lower quality aggregates
- 3 Other matters that can be recycled, but not as sand
- 4 Percentage of matters that cannot be recycled

B Percentage of materials used for construction

- 1 Recycled materials used for loaded parts
- 2 Recycled materials used for lighter parts
- 3 Percentage of construction materials not recycled (new)

II Origins of materials

A Sending recycled materials

- 1 Trajectory of the materials - Mileage
- 2 Crossing frontiers - taxes and laws
- 3 Landfills percentage - taxes and laws

B Buying recycled materials

- 1 From where do we import - taxes and laws
- 2 The closest the best, to be privileged
- 3 Quality of materials received

Our label is based values held by the actual labels concerning sustainability in construction in Switzerland and in the world. It could be applied following the taxes of Switzerland as well as the ones from other countries, needing an adaptation on the current law enforcement system. We may rely on other labels such as Minergie (and its derivation : Minergie-ECO, Minergie-P, Minergie-A) or the SNBS, especially the **criterion 303** which is oriented on the construction part and the revalorisation of materials (on the building's life cycle as well as the materials used in the construction), a construction standard following Switzerland norms (SIA).

If such a label would be implemented in the construction nowadays, we would be able to work on traceability and sustainability at the same time. We could make sure the laws and taxes on sand are respected and that the recycled materials we might sell and buy is respecting the strength requirements for construction. It would ensure security for the building industry as well as decreasing its impact on earth. The closest the materials comes from, the better it is. Our team look forward to such a structure to grow and develop worldwide.

5 Discussion and conclusion

During our case study, we went through a lot of different technologies, coming from different fields. We tried our best to propose a good alternatives from our researched and the table 2 below shows a quick summary of our discoveries. We hope to see new technologies develop in the following years and look forward to be part of it.

Technology	Field	Description	Reliability
Stone ash	Replacement	Using aggregate to be mixed with concrete without losing strength	✓
Sand desert	Replacement	Using desert sand for temporary events	X
Plastic waste	Replacement	Using recycled PET from households in roads construction	≈
Recycled concrete	Replacement	Using concrete from demolition site, crushing it to have new aggregates/sand	✓
BIM	Software	Technology allowing a whole building to be modelled and to assess its life-cycle	✓
Crusher	Machine	Used to create aggregate and crush parts of the demolished areas	✓
Conveyer belt	Machine	Treadmill to sort the demolished part in order to separate good and bad materials directly on the demolition site.	✓
Machine Learning	Software	To be adjusted with the crusher Technology to sort aggregate and crush parts generated by the crusher in different categories	≈

Table 2: Technologies treated during our case study

In conclusion, our innovation towards the actual situation of sand exploitation is mainly focused on recycling. Our recycling device aims to do a on-site treatment like Marti did and to specialise in it. This way, we could efficiently reduce transportation costs (to landfills or demolition, waste treatment sites) and help decrease the sand consumption.

We also propose a big data treatment and certification. This has two major goals. The first one focuses on the modelling of buildings. We could therefore have a good overview of the buildings life-cycle and foresee the recycling part at wished time. If we manage to globalise the system we would be able to have global data on all buildings of a city, to say Geneva, and we could assess in real time the resources. If a building is likely to be demolished soon, we could directly see were the resources need to be send. We would sell a service towards direct revalorisation of resources.

Our second main objective concerns a labelling of building. As many already exists, we can imagine have our own certification focusing on recycling. By proposing advantages for buildings in which recycled materials is used, we could change general opinions on recycling materials. We could implement deep changes in opinions thinking recycled materials is not safe.

"Italy and the Czech Republic have very low recycling rates, which is due, in part, to a strong consumer preference for virgin aggregate materials and the lack of any significant price difference between virgin and recycled materials within these countries" [1]

All this measures also need to work side by side with governmental institutions. If we want to protect sand extraction, we should also work on taxes, importation and exportation. This needs to be implemented in our label, as described previously.

"A number of wider policy factors influence extraction practices. It was recognised that a combination of policies was needed to stimulate a change in production methods and practices" [1]

Indeed, even with taxes, the results are not really significant in most countries. Positive results has been noticed in Sweden and seems to be achieved through a combination of measures rather

than attributing the full effect to the gravel tax.

"Co-ordination is relevant where countries have natural land borders and differences in tax rates can lead to perverse trade flows."[1]

As for now, we focus on Switzerland, but we could easily see further. Such changes may resonate on a wider scale, no to say worldwide. We are positive in saying that we need structures like the United Nations to take a further step towards the protection of limited resources. We would like to propose a better approach by also proposing a solution to this global crisis. Taxes and regulations can only be respected if an equivalent solution, if not better, is also available.

6 Annexes

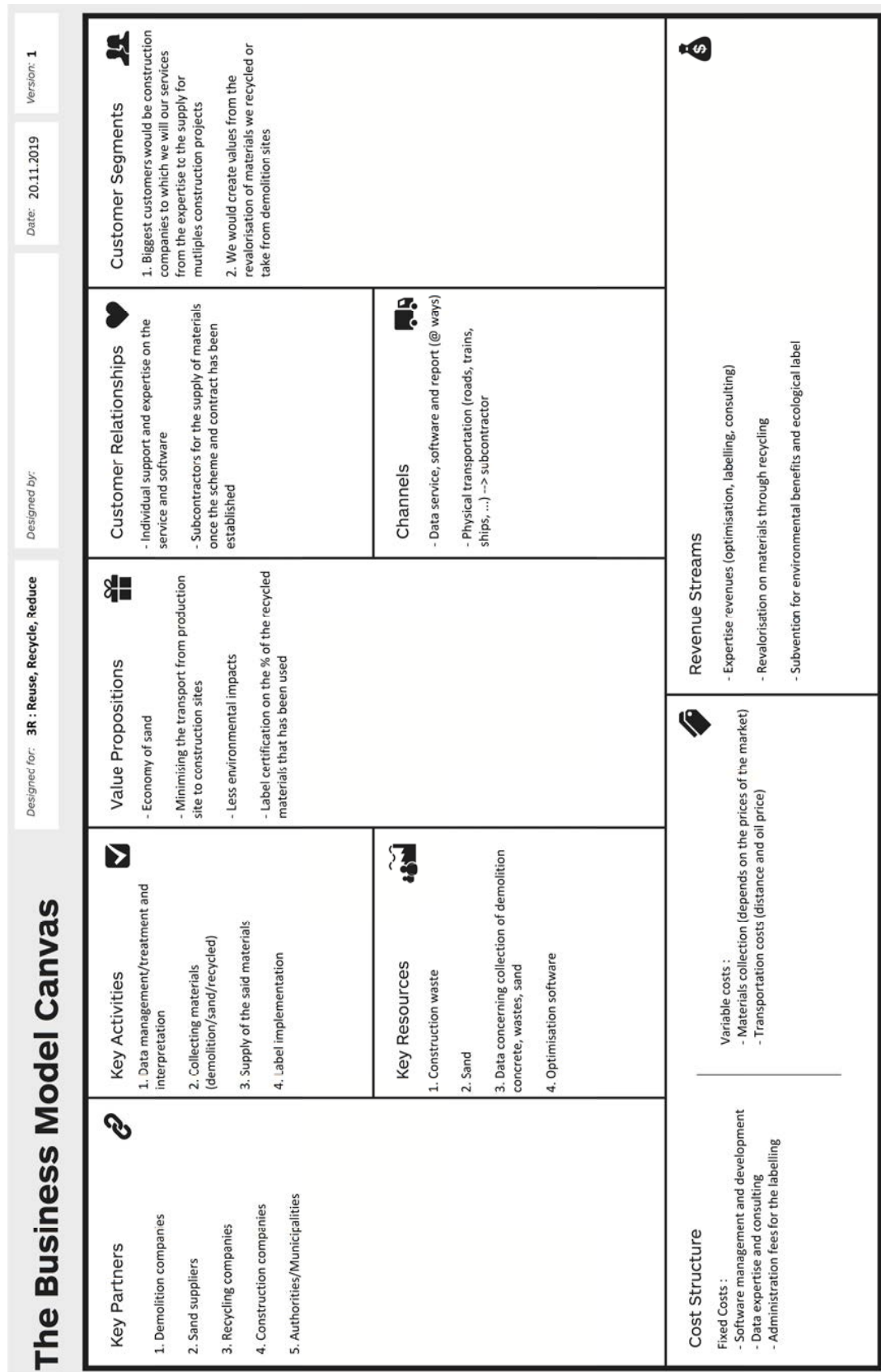


Figure 16: Business Model Canvas

PROBLEM <i>List your top 1-3 problems.</i> 1. Not enough sand for construction on earth 2. Environmental impacts of the sand supply-chain 3. Increasing demand of sand for less and less resources	SOLUTION <i>Outline a possible solution for each problem.</i> - Combining sand with other materials (decreasing sand quantity in building materials) - Recycling former construction materials into new ones - Supply and demand in a close (small) environment to reduce transportation - Label creation to implement permanent change	UNIQUE VALUE PROPOSITION <i>Single, clear, compelling message that states why you are different and worth paying attention.</i> 3R : Reuse, Recycle, Reduce Delivering live information on sand supply and its mixes (with substitution materials) in order to optimise the supply chain of sand, keeping in mind the environment.	UNFAIR ADVANTAGE <i>Something that cannot easily be bought or copied.</i> Using planning system such as BIM and machine learning and combine them with on field technologies in materials Label certification to add value to the construction	CUSTOMER SEGMENTS <i>List your target customers and users.</i> - Construction companies (with their own subcontractors) - Recycling companies - Demolition companies - Municipalities/authorities
EXISTING ALTERNATIVES <i>List how these problems are solved today.</i> No real alternatives for now	KEY METRICS <i>List the key numbers that tell you how your business is doing.</i>	HIGH-LEVEL CONCEPT <i>List your X for Y analogy e.g. YouTube = Flickr for videos.</i>	CHANNELS <i>List your path to customers (inbound or outbound).</i> 1. Direct contact through the software/system interface (optimisation of the project) 2. Subcontractor for the materials delivery	EARLY ADOPTERS <i>List the characteristics of your ideal customers.</i> Long term contract with construction companies and/or authorities
COST STRUCTURE <i>List your fixed and variable costs.</i> Fixed Cost : Expertise and software use Software development	Variable costs : Price of the materials (sand and demolition mixes subjective to the market prices) Delivery (depends on distance and oil)	REVENUE STREAMS <i>List your sources of revenue.</i> - Payments for the expertise and project optimisation towards the construction materials - Margin on the revalorisation of recycled materials		

Figure 17: Lean Model Canvas

References

- [1] Gorm Dige, David Legg, Henry Leveson-Gower, Roberto Zoboli, Marton Herczeg, Bettina Bahn-Walkowiak, Raimund Bleischwitz, Massimiliano Mazzanti, and Mette Skovgaard. *Ef-*

- fectiveness of environmental taxes and charges for managing sand, gravel and rock extraction in selected EU countries.* June 2008.
- [2] Uepg annual review 2017-2018. <http://www.uepg.eu/uploads/Modules/Publications/uepg-annual-review-2017-2018.pdf>, Seen on the 15.11.2019.
 - [3] Sflowers.be. Sand and gravel processing plant. https://sflowers.be/solution/9_09_39/sand-and-gravel-processing-plant-111.html, Seen on the 20.10.2019.
 - [4] PET recycling switzerland. <https://www.petrecycling.ch/fr/savoir/chiffres-et-faits/chiffres>, Seen on the 17.11.2019.
 - [5] Sand types. <https://www.sandatlas.org/sand-types/>, Seen on the 11.11.2019.
 - [6] Maccario Matteo Maruyama Saki Tam Carolyn, Oza Hamza. Finite. <http://www.materialfinite.com/>, 2019.
 - [7] Arcgis web application, sitg geneva. <https://sitg.maps.arcgis.com/apps/webappviewer3d/index.html?id=091fef0b3c9346188f63a72e960bdf0d>, Seen on the 09.12.2019.
 - [8] Global Environmental Alert Service (GEAS). Sand, rarer than one thinks. pages 1–15, 3 2014. https://wedocs.unep.org/bitstream/handle/20.500.11822/8665/GEAS_Mar2014_Sand_Mining.pdf?sequence=3.
 - [9] Diesing M. Arlt G. Krause, C. *The physical and biological impact of sand extraction: a case study of the western Baltic Sea.* Journal of Coastal Research, 2010.
 - [10] Madehow.com. Sand. <http://www.madehow.com/Volume-3/Sand.html>, Seen on the 20.10.2019.
 - [11] R Hidayata, Iswinarti, and Asnun Parwanti. Alternative of stone ash as a sand replacement in fc'40 mpa quality concrete mixture on pressure stress. *IOP Conference Series: Materials Science and Engineering*, 588:012045, aug 2019.
 - [12] NAPA National Asphalt Pavement Association. Engineering overview. https://www.asphalt pavement.org/index.php?option=com_content&view=article&id=14&Itemid=33, Seen on the 12.11.2019.
 - [13] Wikipedia. Asphalt. <https://en.wikipedia.org/wiki/Asphalt>, Seen on the 12.11.2019.
 - [14] Craft A. P. Rebeiz K. S. Plastic waste management in construction : technological and institutional issues. *Resources, conservation and recycling*, 15:1–13, JUn 1995.
 - [15] India Block. Desert sand could offer low-carbon concrete alternative. <https://www.dezeen.com/2018/03/24/desert-sand-could-offer-low-carbon-concrete-alternative/>, 2019.
 - [16] L. Boehme and A. Depoortere. Alternative sands as substitute for natural sand for the construction sector. In *IOP Conference Series: Earth and Environmental Science*, volume 290, 2019.
 - [17] Sand demand. <https://www.letemps.ch/monde/demande-sable-triple-20-ans-lonu-sinquiete>, Seen on the 24.11.2019.
 - [18] le Réseau de l'écologie industrielle dans le canton de Genève Genie.ch. La centrale de valorisation des matériaux d'excavation du tunnel de champel (projet ceva) par l'entreprise marte sa - genie.ch, le réseau de l'écologie industrielle dans le canton de Genève. <https://www.genie.ch/project/h/la-centrale-de-valorisation-des-materiaux-d-excavation-du-tunnel-de-champel-projet-ceva-par->html.
 - [19] Ecobétons bétons recyclés. <http://www.gcm.ch/betons-recycles-ecobetons/>.

- [20] Certificat iso 9001 and 14001. http://www.gcm.ch/wp-content/uploads/2018/02/certificat-iso-9001-et-14001-.pdf_2019, year=2019.
- [21] Green Economy Dialogue. Switzerland gets going with the recycling of construction waste. <https://www.gruenewirtschaft.admin.ch/grwi/en/home/green-economy-in-action/Resource-conservation-a-matter-of-quality.html>.
- [22] Swiss government. ADWO Ordinance on the Avoidance and the Disposal of Waste. <https://www.admin.ch/opc/en/classified-compilation/20141858/index.html>, Seen on the 17.11.2019.
- [23] Installations de traitement de déchets de chantiers autorisées par le canton de genève. <https://www.ge.ch/document/dechets-listes-transporteurs-recuperateurs-dechets/annexe/1>, Seen on the 09.12.2019.
- [24] Ge.ch, 2019.
- [25] Vd.ch. https://www.vd.ch/fileadmin/user_upload/themes/environnement/dechets/fichiers_pdf/DIRNA_GEODE_PGD__version_finale_novembre_2016.pdf, 2019.
- [26] Ge.ch. <https://www.ge.ch/document/dechets-plan-gestion-dechets-2014-2017/telecharger>, 2019.
- [27] <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>, 2019.
- [28] Neustark. <https://neustark.com/>.
- [29] Neustark - turning carbon dioxide into concrete. <https://www.cofoundme.org/project/10028>.
- [30] Oxara. <https://oxara.ch/>.
- [31] Terrabloc. <http://www.terrabloc.ch/#his>, 2019.
- [32] Reuse and recycling of cdw materials and structures in energy efficient prefabricated elements for building refurbishment and construction. <http://www.re4.eu/>.
- [33] C. Ulsen, H. Kahn, G. Hawlitschek, E.A. Masini, S.C. Angulo, and V.M. John. Production of recycled sand from construction and demolition waste. *Construction and Building Materials*, 40:1168 – 1173, 2013. Special Section on Recycling Wastes for Use as Construction Materials.
- [34] Chaocan Zheng, Cong Lou, Geng Du, Xiaozhen Li, Zhiwu Liu, and Liqin Li. Mechanical properties of recycled concrete with demolished waste concrete aggregate and clay brick aggregate. *Results in Physics*, 9:1317 – 1322, 2018.
- [35] Jean David Lau Hiu Hoong, Jérôme Lux, Pierre-Yves Mahieux, Philippe Turcry, and Abdelkarim Aït-Mokhtar. Quantification of construction and demolition waste products that can be carbonated using a deep learning-based image analysis. 06 2019.
- [36] Julien Maitre, Kévin Bouchard, and L. Paul Bédard. Mineral grains recognition using computer vision and machine learning. *Computers Geosciences*, 130:84 – 93, 2019.
- [37] Katharina Anding, Elske Linß, H. Träger, Matthias Rückwardt, and André Göpfert. Optical identification of construction and demolition waste by using image processing and machine learning methods. 01 2011.
- [38] Kristen Barlish and Kenneth Sullivan. How to measure the benefits of BIM — A case study approach. *Automation in Construction*, 24:149–159, July 2012.
- [39] Ali Ghaffarianhoseini, John Tookey, Amirhosein Ghaffarianhoseini, Nicola Naismith, Salman Azhar, Olia Efimova, and Kaamran Raahemifar. Building information modelling (bim) uptake: Clear benefits, understanding its implementation, risks and challenges. *Renewable and Sustainable Energy Reviews*, 75:1046 – 1053, 2017.
- [40] Jack C.P. Cheng and Lauren Y.H. Ma. A bim-based system for demolition and renovation waste estimation and planning. *Waste Management*, 33(6):1539 – 1551, 2013.