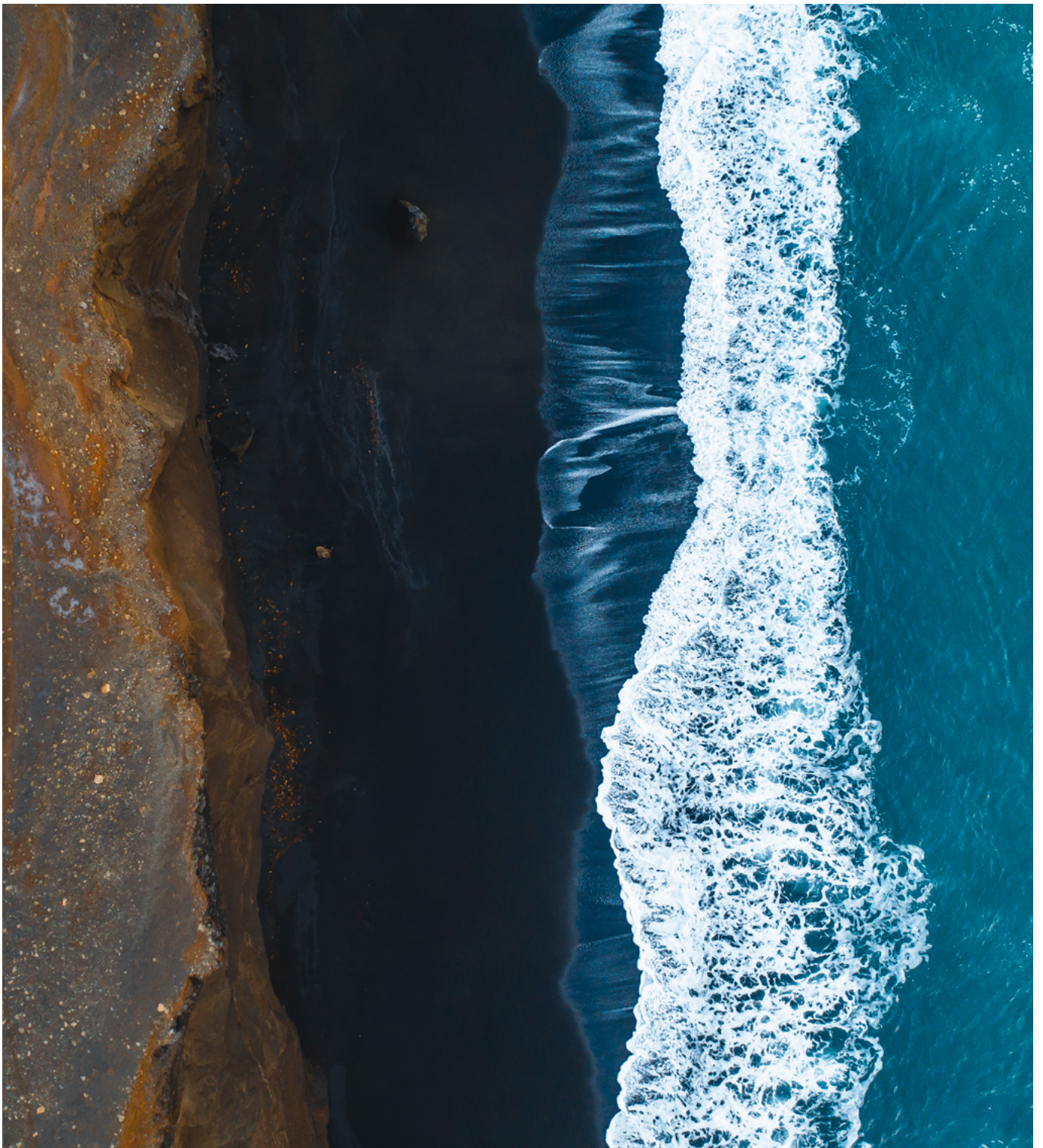




THINK GLOBAL, BUILD LOCAL

**Building Awareness of Environmental Preservation and
Sustainability of Housing in an Icelandic Fishing Village**

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Grindavik, January 2021

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Special thanks to André Ullal and Corentin Fivet for all their help in accomplishing this paper. I would also like to thank the EPFL community for their support in those complicated times and Thrainn Kolbeinsson for allowing me to use his beautiful pictures. Last, I would aslo like to thank my sister, Stephanie Bustion, for helping me design the layout of this report, and to my mother, Guðrún Bára Ingólfssdóttir, for always standing by my side.

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SUMMARY

The primary aim of this investigation is to apply global considerations regarding sustainable development in relation to building and construction - with an emphasis on environmental preservation - to the local context of the Icelandic fishing village, Grindavik. This application of global concepts to local conditions is undertaken in support for two specific objectives.

First, the investigation is sought to draw attention to implications of housing design and construction for environmental preservation and sustainable development in the local context by presenting them in a manner that can effectively engage all stakeholders in local housing development.

Second, the investigation is intended to serve as a basis for architectural strategies to guide a hypothetical local housing project that will perform better than current housing projects in Grindavik in terms of sustainable

development. In pursuit of these objectives, the investigation is divided in three parts:

1. Review the local culture, economy, nature, and construction customs in order to understand specific aspects of the context (i.e. the place) that are relevant to sustainable development.
2. Review the global concept of sustainable development, including specific dimensions of social development, economic development and environmental preservation – to establish specific themes that should be addressed, then use tools such as LCA to assess their status of current housing practices in relation to these themes.
3. Define strategies of action that adapt global considerations of sustainable development to the

local context the housing in the village of Grindavik.

This methodology is based on the principles of taking global concepts and ideas, establishing their relevance for local context, measuring them, and proposing actions to improve them. It highlights a need to consider architectural and construction projects at both a local and global scale – that is, to think global, build local.

The investigation draws on relevant precursor LCA studies in Iceland and, building on these, undertakes additional LCAs of four completed housing projects in the village of Grindavik. These studies support the identification of three areas of opportunity to achieve the goals of impact reduction, which, in-turn, underpin architectural strategies, namely:

1. Adapted housing typologies that accommodate both social/market preferences lower-density detached housing and lower environmental impacts associated with higher-density typologies
2. Implementing buildings better in their landscape to minimize

construction waste and improve connection to the surrounding nature.

3. Improving the use of reinforced concrete by improving the topology of structural elements, building with prefabricated and reusable elements, and using cements that have low environmental impact.

Analyzing how each proposal affects different stakeholders and predefined points of interest in sustainable development stresses the need to simultaneously use different strategies to address the issue of sustainable building in a thorough manner.

Applying well-designed solutions does not only contribute to a better built and natural environment. Well-designed housing can also contribute to job creation, development of knowledge, and enhanced social interactions to name a few benefits. Changes to support better housing and the various benefits it can yield should not only be instigated by policies of local authorities, but also, and more importantly, by the recognition of all stakeholders of the added common gains that sustainable development represents.

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INTRODUCTION

The place is Grindavik - a small village on the southwestern coast of Iceland with around 3'000 inhabitants whose livelihoods depend primarily on fishing and tourism. It is a place of personal importance - we call it *the village* - where my great-grandparents raised ten children - 3 girls and 7 boys including my grandfather. Their house remains and hasn't changed much in appearance, named Karlskáli - the hut of Karl - my great grandfather.

Karl's son, Ingólfur, my grandfather, was a fishing captain for a long time. After that, he became a contractor working mainly on earthworks. He and my grandmother built two houses, one of which they lived in until they died. My mother now lives in this house which, like Karlskáli, hasn't changed much. Most of my Icelandic family still live in Grindavik and work in the fishing industry.

The city where I was born and raised is quite different - Geneva, Switzerland. A city of around 200'000 inhabitants, extremely cosmopolitan and the home of the headquarters of some of the world's most influential multinational organisations and companies. Geneva is a melting pot of culture, knowledge and influence; a place that is well-connected to global networks in contrast with the village of Grindavik. I lived in Geneva until I was 19, then moved to Washington, D.C. for a year, then to Grindavik.

That was 8 years ago. At first, adapting to the village's smallness and lack of activity was difficult. It seemed to be a place stuck in time, 10 to 20 years behind the rest of Europe. Also, Icelanders, much like other Nordic people, can be cold and socially distant.



IMAGE 1 | The house named "Karlskáli" hasn't changed much since it was built in 1923



IMAGE 2 | A view of sheep grazing in the spring, with the old harbour in the background

IMAGE 3 | Krysuvik is an area 10min outside the village that offers beautiful hikes

IMAGE 4 | Kleifarvatn, a lake with beautiful surrounding scenery, close to Krysuvik

My perception of the village changed with time as I came to enjoy life there; the stillness, the surrounding nature, knowing everyone and meeting your friends and family whilst going to the store. The closeness, the strong-ties, the roots. A strong sense of belonging. Feelings I never experienced in Geneva.

Grindavik is a small town where every voice can be heard – a place where political and community leaders are closely connected with the people they serve, where one can implement change quite quickly.

This is the context of this work. The subject of the investigation stems from a simple, personal question - how can I use my experience and my access to knowledge at my school EPFL to contribute to the positive development of my community in Grindavik?

As we will see, a substantial increase in population is projected in Grindavik, requiring construction of new housing to accommodate new inhabitants. The question underpinning this investigation seems quite straight forward at first glance: how to make new housing in Grindavik more environmentally

friendly in accordance with sustainable development goals?

However, as we will see, addressing sustainable development of housing of a place in a comprehensive manner requires consideration of more than the environmental benefits induced by potential changes. Sustainable development contains other dimensions that are equally important. Focusing on only one dimension of sustainable development can potentially cause more harm than good for the local community.

Furthermore, it would be naïve to think this investigation alone could resolve current housing issues and determine sustainable development solutions. In that spirit, the outcome of this investigation is not a proposal that solves everything. Rather, this work provides a new understanding of sustainable development in relation to the local context, which will be used to support informed dialogue between local stakeholders.

This report will also provide a theoretical basis for an ensuing hypothetical housing project in the village.

Process

Sound proposals for sustainable housing require a thorough understanding of place. Therefore, first, this investigation considers the local culture, economy, nature, and construction customs.

Then, the concept of sustainable development will be explained in general and in relation to construction and buildings. In particular, the concept of sustainable development will be addressed through the framework of the three pillars of sustainable development: social development, economic development and environmental preservation.

After that, current housing types and construction arrangements in the village will be examined in relation to environmental preservation. Review

of precursor studies will establish a series of principles that define the boundaries and the focus of subsequent life cycle assessments (LCAs) of the four most prevalent housing typologies of Grindavik.

Finally, taking all this information into account, a series of opportunities will be defined for reducing environmental impact of housing in Grindavik whilst also contributing positively to the other goals of sustainable development.

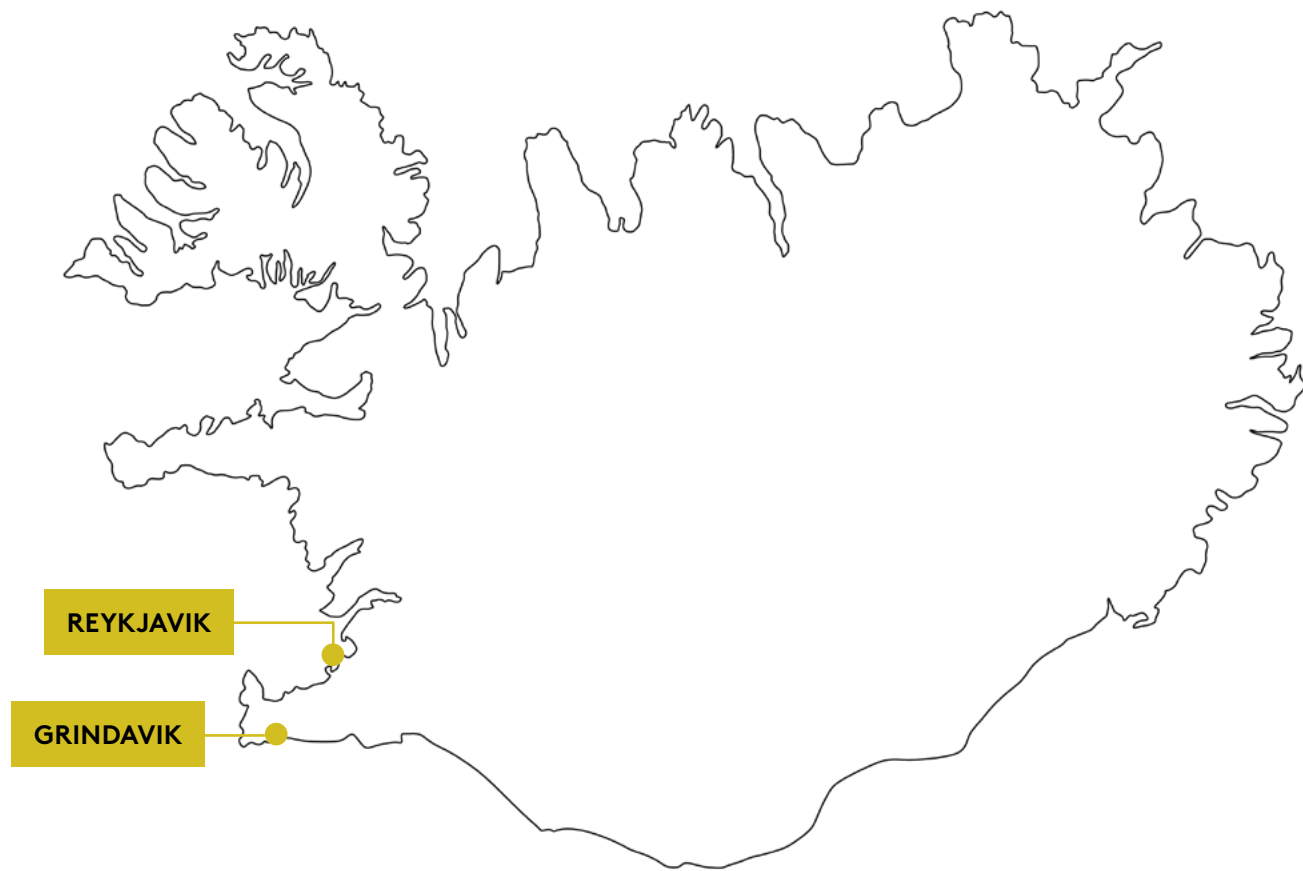


IMAGE 5 | A map of Iceland

IMAGE 6 | (next page) A small fishing boat from Grindavik



Grindavik

Grindavik is a village of around 3,300 inhabitants located on the south coast of the Reykjanes-peninsula. It is a family-friendly village that is close to the capital, Reykjavik, (45 minutes driving) and the international airport in Keflavik (20 minutes driving).

The village was first established around 934 A.D.¹ Since then, fishing has been the main activity of the village, with Grindavik being one of a few ports that survived a quota system put in place by the Icelandic government in 1990 that caused the merger of most smaller fishing ventures into conglomerates.² Today, the village maintains an important and active harborthat yields around

40% of Iceland’s salt fish.³ Speaking to villagers reveals their strong connection to the ocean and fishing. Many sailors have perished through the years, when fishing was a much more dangerous activity than it is today. Everyone in the village is well-aware of the perils of the ocean, but also of the great wealth that it has brought the community. Grindavik’s biggest fishing companies are leaders in the implementation of technology in the industry and collaborate with world-known food-process design firms such as Marel.

Grindavik has also embraced the growing tourism industry that provides considerable employment.⁴

1 "Grindavik", *in* Grindavik, 2018
2 "Grindavik: Fishing Town Near the Blue Lagoon", *in* Hit Iceland, 2020
3 ibid
4 "Grindavik: Fishing Town Near the Blue Lagoon", *in* Hit Iceland, 2020



IMAGE 7 | A map of Grindavik: The village will be expanded onto the red areas in the following years. The center of the village is in orange, where the town hall is located as well as most shops, restaurants and sporting facilities.



IMAGE 8 | Black sand beach just east of Grindavik

The most visited attraction in Iceland, the famous Blue Lagoon, is located about 10 km north of the village and is part of the municipality.

Grindavik is surrounded by a picturesque landscape of moss-covered lava, reminiscent of a moonscape. Vast fields of dark stone and sand are apparent, broken occasionally by a single, sinuous road crossing through it. Remnant of shipwrecks can be seen 50 meters inland; reminders of the force of the Atlantic ocean. There are many exceptional places to visit in proximity to the village and it is possible for tourists hike through the terrain or to rent all-terrain-vehicles and horses to explore.

The Village contains two kindergartens, one primary school and one middle school. Students who decide to continue to high school must travel either to the neighboring town of Keflavik or to the capital Reykjavik.

Sports are very important in Grindavik. The basketball and football teams are usually both in the top

division and have won national titles on several occasions. The municipality has invested heavily in sport facilities through the years, and it is quite striking to see such high quality and large size of sport-related buildings in such a small place.

As a result of this emphasis, most kids practice either basketball or football. In contrast, there is limited consideration given to other cultural activities such as performing and visual arts. This tendency has been criticized by children and adolescents that are less interested in traditional village sports and would like to practice other activities.

Grindavik is a popular town and has steadily been growing in recent years.¹ This popularity and expansion can be explained by the village's low-unemployment rate, its family-friendly environment and its proximity to Reykjavik and the airport while maintaining its closeness to nature. The local population is expected to grow by 13 to 21% in the next five years, which will require an increase of around 146 to 228 homes.²

1 ibid
2 HELGADOTTIR, Johanna, HALLGRIMSSON, Jonas Hlynur, *Husnaedisaaetlun Grindavikurbaejar*, 2018, p. 23

The most common housing type in Grindavik is detached housing, which represents around 52% of all housing units.¹ Pair- and row-houses are also popular, comprising around 27 % of housing stock.² In general, homes in the village are relatively large - 54% of housing units in the village are over 150 m² and 3.5% of them are less than 70 m².³ Those numbers reflect cultural values of the village. Most people aim at living in a detached house that are signs of social status and success. Furthermore, detached houses are relatively affordable in Grindavik and neighboring towns compared to the capital, Reykjavik.

The projected increase in population and new housing in Grinadvik presents an opportunity for authorities and the community to encourage construction projects and housing types that foster sustainable development. Current urban plans of expansion for the village include a greater proportion of smaller housing units in multi-storey apartment buildings or pair and row housing. This is in tune with the increasing demand for smaller more affordable housing.

1 HELGADOTTIR, Johanna, HALLGRIMSSON, Jonas Hlynur, *Husnaedisaaetlun Grindavikurbaejar*, 2018, p. 8
2 ibid
3 ibid

The local construction industry that is expected to build most of this new housing is comprised of a relatively small number of firms. Two large local contracting firms in Grindavik operate most often as developers in that they undertake construction themselves and sell the property directly to individuals. Typically, both of these large firms build with in-situ reinforced concrete, having invested in large funds in equipment and knowledge acquisition for this material.

In addition to these larger contracting firms, there are other smaller contractors which are most often employees of one of the two "bigger" contractors doing projects on the side of their jobs. There are also some out of town contractors that build projects in Grindavik sometimes. They have both built in-situ concrete and timber frame houses.

SUSTAINABLE DEVELOPMENT & LIFE CYCLE THINKING



While the concept of sustainability is approached from many different perspectives, a widely accepted definition of sustainability and its guiding principles were defined in the report "Our common future", published by the World Commission on Environment and Development in 1987.¹

The commission highlighted that there was deep concern for the environment globally, and established that new principles of politic and economic structures had to be created.²

It called for a new framework and strategy that would consider the **SOCIAL**, **ENVIRONMENTAL** and **ECONOMIC** dimensions. This concept of "sustainable development" was described as:

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs".³

1 "1987: Brundtland Report", in Federal Office for Spatial Development (ARE)
 2 WCED, *Our Common Future*, 1987, p. 26
 3 "1987: Brundtland Report", in Federal Office for Spatial Development (ARE)

This definition of sustainable development is widely accepted and has provided an umbrella under which other concepts and policies have been introduced.

Despite its widespread acceptance, this definition has also been criticized as being overly passive, encouraging action that would provide future generations with a world similar to ours or worse, rather than improving already-degraded current environmental conditions.¹

More active approaches to environmental preservation are

reflected in concepts of "restorative" and "regenerative" sustainability.² If the concept of sustainable development proposes not doing anything today that compromises future conditions, these two concepts propose restoring our societies, economies and environment to a better state and regenerating them to become extra positive sources.

These more-active approaches are interesting and important to consider as they push us to go beyond dealing with the negative impact we have and towards working on the positive impact we could have.

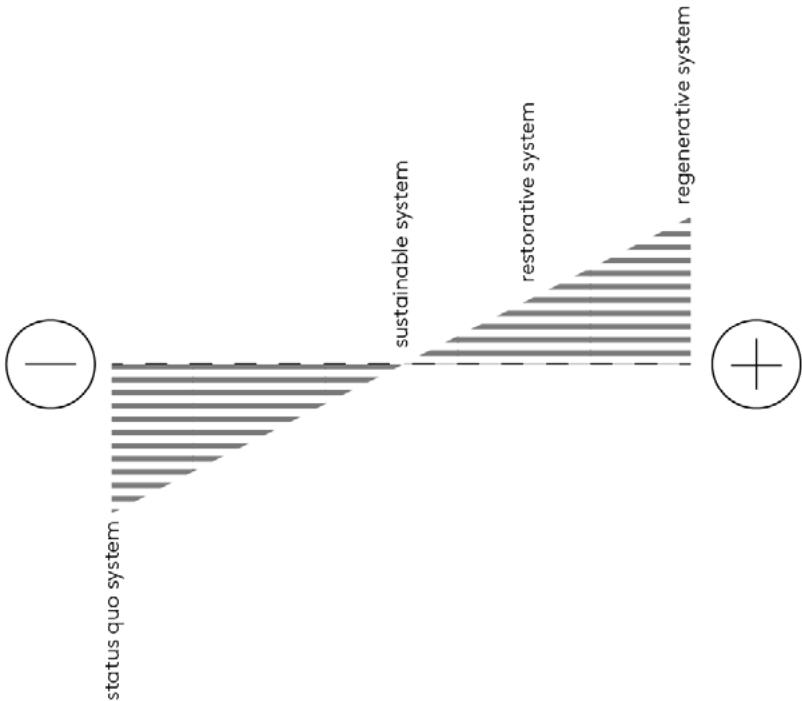


IMAGE 9

1 BROWN, Martin, et al., *Sustainability, Restorative To Regenerative: An Exploration In Progressing A Paradigm Shift In Built Environment Thinking, From Sustainability To Restorative Sustainability And On To Regenerative Sustainability*, 2020, p. 8
 2 ibid

"No single blueprint of sustainability will be found, as economic and social systems and ecological conditions differ widely among countries. Each nation will have to work out its own concrete policy implications. Yet irrespective of these differences, sustainable development should be seen as a global objective."

WCED, *Our Common Future*, 1987, p. 34

Recognition that personal actions have broader social, economic and environmental impacts at a global scale is difficult though necessary. Current development challenges affect all members of society (albeit some more than others). Every individual should be cognizant of recent changes in their environments as a result of increased pollution and human activities.

The concept of sustainable development presents an interesting relationship between the self and the world. The behavior of an individual will have social, economic and

environmental impacts throughout a community and beyond; in other countries, other continents and the world as a whole.

Clearly, the concept of sustainable development is complex, encompassing different fundamental objectives and different scales of action. In the following pages, an approach to sustainable development will focus on the three dimensions/pillars of social development, economic development and environmental preservation and the implications of these for building.

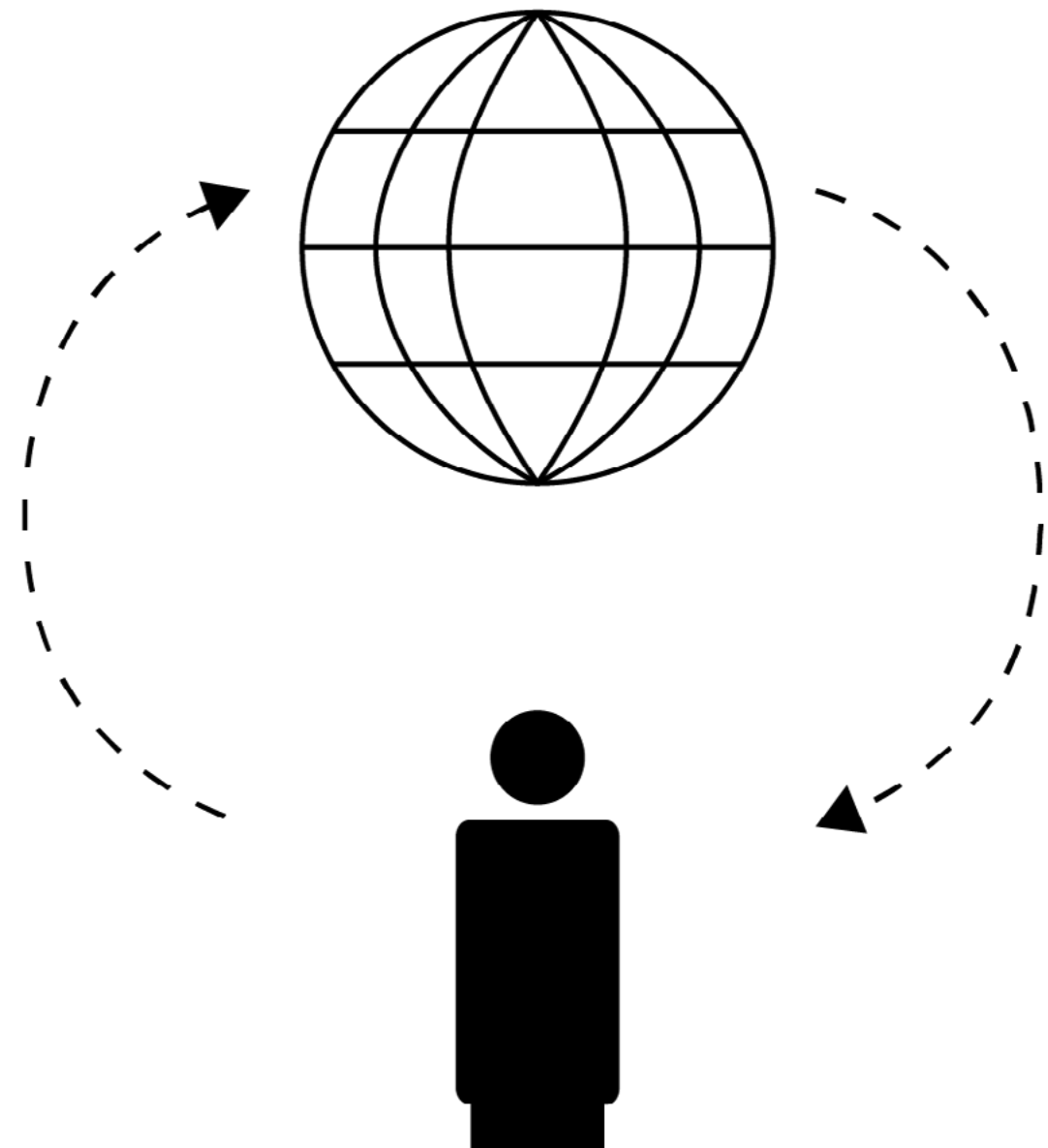


IMAGE 10 | The individual's actions have a global impact and can affect him/her directly and indirectly

How do we build for sustainable development?

To build for sustainable development – i.e. sustainable building - means systematically maximizing the usability and quality of building processes and products whilst minimizing its negative impacts in the three pillar areas of sustainability (society, economy & environment).¹ Considering the passive character of sustainable development compared to regenerative or restorative approaches, this description is somewhat problematic as it only aims at "minimizing" the negative impact and not changing them completely into positive impacts. Nevertheless, widespread recognition and acceptance of the concept of sustainability, particularly across various stakeholders of housing and construction in Grindavik,

make sustainable development an appropriate framework for this investigation.

Compared to the product of other industries, buildings are quite unique in that they are particularly durable - in developed countries, structures have an average life of 80-100 years. Thus, considering the potential effects of buildings across a long-term life span, it is important to consider the impacts of a construction from the very early stages of project planning and design. Conventional approaches to construction focus on cost, performance and quality issues; alongside these, sustainable building aims at performing positively in the three pillars of

¹ "Vistvaenar Byggingar: Kynningarrit", in Framkvaemdasysla Ríkisins, 2009, p. 2

sustainable development.¹ While construction encompasses a wide variety of structures, the goal of this investigation is to develop strategies for improved environmental implications of housing in Grindavik; hence the focus on sustainable building for housing.

I have learned about sustainable development from the beginning of my studies. Most often, all the attention was set on finding solutions with a better environmental impact, with less attention paid to economic or social impact. Nevertheless, as we will see, social and economic development considerations are often addressed implicitly in the architectural design processes without being explicitly assigned to sustainable development goals.

To understand what sustainable building means we will employ "life cycle thinking". This is a commonly used methodology to assess the environmental impact of a building that encourages designers and planners to consider a project on the long term.

¹ SEV, Aysin, "How Can the Construction Industry Contribute to Sustainable Development? A Conceptual Framework", 2009, p. 3

The "Life Cycle" is the development of a building product, from cradle - extraction of raw materials- to grave - demolition and disposal. The life cycle of a building is separated in four phases according to the European Standard EN 15978:

Phase A is the **production and construction process**.

The **production stage** encompasses all the energy and resources used to extract raw materials, transport them to the manufacturing facility and producing the final product.

The **construction process** stage encompasses all energy and resources used to transport the building materials to the construction site as well as for the construction process itself.

Phase B is the **use stage**. It encompasses all energy and resources used by occupying the building over its lifetime due to lighting, hearting and water usage. Materials used for maintenance, repair and replacement are also included in this stage.

Phase C is the **end-of-life** cycle stage. It encompasses all energy and resources used for demolition, disposal and waste processing.

Phase D is the **benefits stage**. It considers all the positive environmental impacts caused by various actions, such as re-using, recycling and recovering energy, materials or water from the project.¹

As we will see, there already exists well defined methods of assessing the environmental impact of buildings using life cycle assessments. There are also similar methods being developed to assess the other two pillars of sustainable development. These methods for assessing environmental, social and economic impacts are addressed in the following chapters.

IMAGE 11 | we can imagine the relationship of all life cycle phases to each pillar of sustainable development

1 HUANG, Monica, *Life Cycle Assessment of Buildings: A Practice Guide*, 2018, p.7

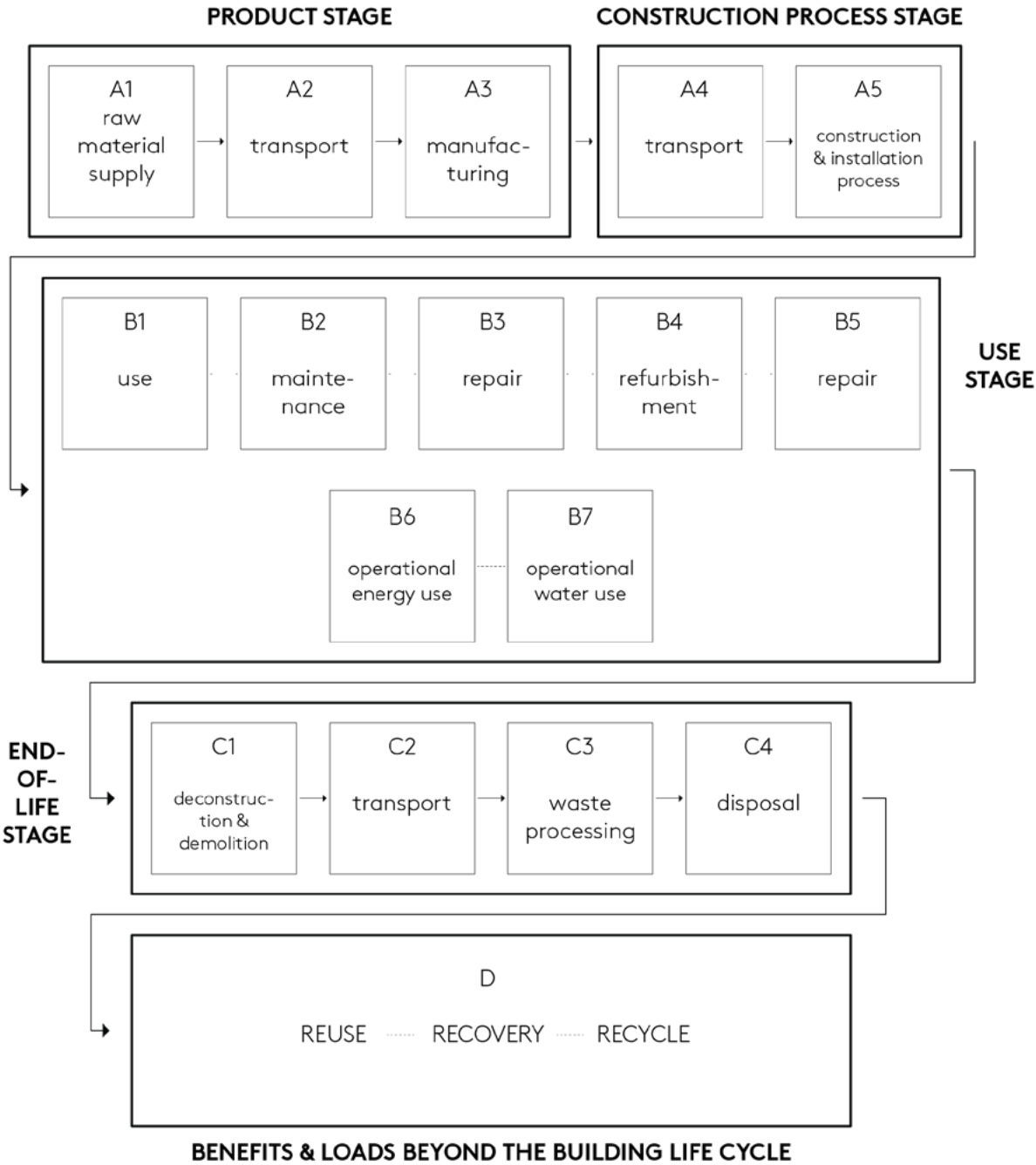
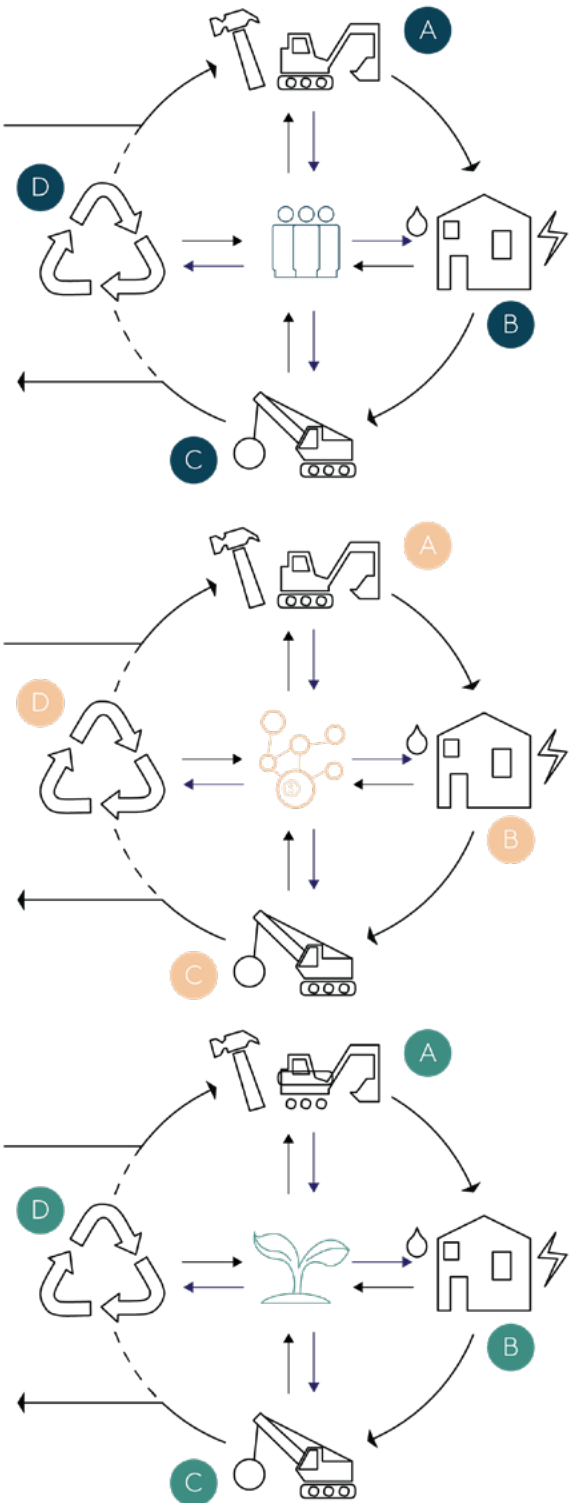
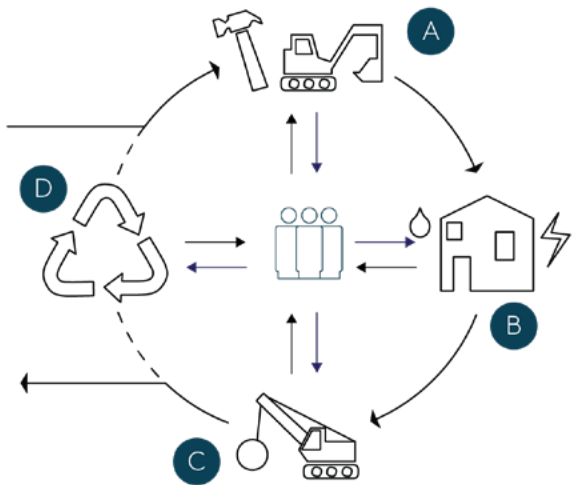


IMAGE 12 | All the sub-stages of the life cycle are shown on this diagram

Social development



In our increasingly dense cities, it is nearly impossible to escape the presence of man-made infrastructures. Moreover, on average, more than 70% of a person’s time is spent inside.¹Construction and buildings are complex activities that involve many stakeholders and inevitably have a wide variety of social impacts.

There doesn’t yet exist an established process to assess the social impact of buildings such as life cycle assessment for the environmental impact.² The International Association for Impact Assessment (IAIA) gives us a more

global definition of Social Impact Assessment (SIA) as all "processes of analyzing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, projects) and any social change processes invoked by those interventions".³

According to the IAIA the purpose of SIA is to create a more sustainable and equitable biophysical and human environment. It defines the areas which we can see on the following table as fields of interests to be considered when completing a SIA.

- Aesthetic impacts (landscape analysis)
- Archaeological and cultural heritage impact (both tangible and non-tangible)
- Community impacts
- Cultural impacts
- Demographic impacts
- Development impacts
- Economic and fiscal impacts
- Gender impacts
- Health and mental health impacts
- Impacts on indigenous rights
- Infrastructural impacts
- Institutional impacts
- Leisure and tourism impacts
- Political impacts (human rights, governance, democratization, etc.)
- Poverty
- Psychological impacts
- Resource issues (access and ownership of resources)
- Impacts on social and human capital
- Impacts on societies

Those subjects span a wide area of themes. They are not specifically designed for buildings and construction. As a result, comprehensive SIA are not meant to be undertaken by one person, but rather by a team of specialists coming from various backgrounds.¹

This raises an important question for us which we will also face when addressing other forms of impact

assessment: when dealing with an architectural project, is it realistic to aim at getting concrete data for all interest fields?

This depends a lot on the size of the project, the available funding and the existing data. We cannot expect to have the same degree of impact assessment for a detached house as for a new neighborhood or large government building. As

1 SEV, Aysin, "How Can the Construction Industry Contribute to Sustainable Development? A Conceptual Framework", 2009, p. 10
2 INGOLFSDOTTIR, Gyda Mjoll, BJARNADOTTIR, Helga, et al., *Vistferilsgreining fyrir vidbyggingu vid Sundholl Reykjavíkur*, 2018 , p.11
3 BRIDGET, "Social Impact Assessment", in IAIA

1 BRIDGET, "Social Impact Assessment", in IAIA

we will see in the next chapter on economic development, time and money are scarce resources and they must be well used to maximize their outputs. This applies of course to an architectural project, where decisions must be taken to define what dimensions of the project will receive more attention than others.

The architect can, therefore, be viewed as a stakeholder well informed of the various aspects of sustainable development, the project, and other stakeholders, whose role is to create a dialogue between stakeholders in order to decide democratically which areas should receive more attention. This issue is explored further later in this report.

In this investigation, specific appropriate themes have been identified for consideration when making proposals in relation to housing. As explained earlier, this process of choosing should be the result of a discussion between many stakeholders. However, this isn't possible in the scope of this work. For this reason, basing ourselves on the definition of SIA by the IAIA and a paper by Aysin Sev titled "How Can the Construction Industry Contribute to Sustainable Development?

A Conceptual Framework", we established five categories that are relevant to the social context of Grindavik.

Heritage

Awareness of their history helps strengthen the identity of communities. Buildings and man-made landscape play an important role in forming culture through time and it is important to consider past traditions and local culture when designing housing.

Connection to nature

The nature in Iceland is omnipresent and widely untouched. This is one of the main reasons the country is so popular for tourists.

Icelandic people have a tough relationship with nature. In the past, life on the island was quite rough. The sea would regularly over-flood towns and has taken the life of many sailors. In the summer months the sun barely sets, and in the winter, daylight is scarce.

Those extreme conditions have pushed Icelanders to attempt their best at protecting themselves from the forces of nature and somewhat isolate themselves from it. This can

be seen in most housing projects constructed in Grindavik. They are in very little connection to their surroundings. The rough lava field is completely covered by asphalt, aggregates and grass. The ocean and surrounding mountains are barely visible from the windows of houses.

Connection of the inhabitants to surrounding nature can help communities be aware of their local ecosystems. By designing to keep connection to nature, quality spaces can be achieved that offer good vistas and allow people to be outside more and help take full advantage of their surroundings.

Comfort & safety

Designers have to guarantee that buildings are safe for their users but also that they provide comfortable spaces in terms of natural light, heating, ventilation and acoustics. As explained earlier, the weather in Iceland is quite rough. In this context, designing for sustainable social development also means making sheltered outdoor spaces that allow people to be outside as often as possible.

Harmful mold in buildings is unfortunately common in Iceland. Houses should be properly designed and constructed to avoid any such issues. Designers must also select construction materials that aren't toxic.

Social interaction

Social isolation is becoming an important issue for our society. It can be found both in younger and older generations. Designers should plan for spaces that allow for and encourage social interaction between neighbors, regardless of social status or age.

Ownership

Ownership of housing is anchored in Icelandic culture. As of 2019, approximately 72% of residents lived in their self-owned house.¹ Sustainable social development of housing in Iceland must consider this and provide for housing solutions that are affordable to people. The state has recently launched a program of shared loans for people that have difficulty acquiring their own housing. The buyer will need to pay 5% of the total value and the state will loan him or her 20% of the total. The rest of the amount will have to be a traditional

1 *Husnaedisthing 2019: Stada og Throun Husnaedismala*, The Ministry of Social Affairs, 2019, p. 11

loan. This new path is only offered for housing in new buildings and adapted to the size of the family.¹

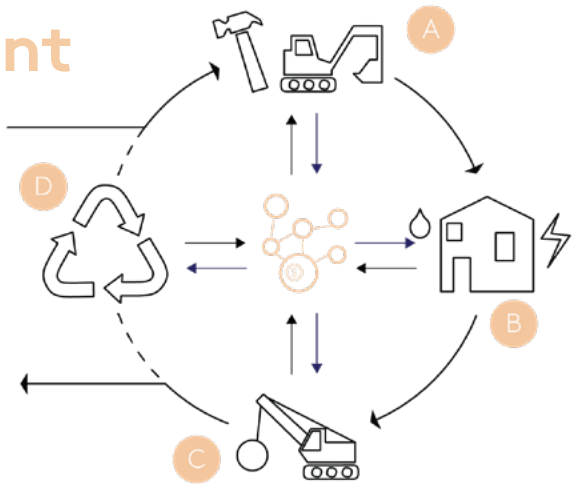
Those five categories provide us with a framework to consider the social impact of our proposals. We will now take a look at the economical pillar of sustainable development and attempt to understand its implications for our context.

1 Hlutdeildarlan, *Hlutdeildarlan*, 2020



IMAGE 13 | Two factory workers at the Visir (local fishing company) salting facility

Economic development



We live in a finite world, where resources are scarce - that is, they have a non-zero cost of consumption.¹ In other words, they are limited and will cost us something, whether it is time, energy, or money, if we wish to use them.

These resources include natural resources such as petrol, water, coal, as well as labour, including the time and work of architects and others contributing to building processes.²

An economy is all activities of production, consumption and exchange that assist in defining how scarce resources are allocated.³ Namely, how a society decides to

distribute limited resources with many different uses to fulfill the basic needs of its people and as many extra wishes as possible.⁴

What is economy?

Occidental economies are primarily market-based. They are governed by the laws of supply and demand, which are meant to define the price of goods and services and create balance between scarce resources and theoretically limitless want or demand. However, occidental economies are not solely market-based, the state interferes most often in the "free-market" by means of regulations, social security benefits and public education for example.⁵

1 "Scarcity", in Investopedia, 2019
2 ibid
3 KENTON, Will, "Economy", in Investopedia, 2020
4 "Scarcity", in Investopedia, 2019
5 KENTON, Will, "Economy", in Investopedia, 2020

At this stage it is important for us to speak of the difference between traditional economics and development economics. The first is primarily concerned with utility, profit maximization and market efficiency.¹ The second, in addition to being concerned with efficient allocation of scarce resources, aims at improving levels of living of people or "quality of life".²

Today's dominant economic models are closer to traditional economics than development economics. They are described by the United Nations Environment Programme (UNEP) as generators of widespread environmental and health risks, promoters of wasteful consumption and drivers of ecological and resource scarcities resulting in inequality.³ Consequently, it is safe to say that our current models do not contribute to environmental, social, or economic sustainable development.

What alternatives exist then? One presented by the UNEP is the model

of Inclusive Green Economy, which is "low carbon, efficient and clean in production, but also inclusive in consumption and outcomes, based on sharing, circularity, collaboration, solidarity, resilience, opportunity, and interdependence".⁴ An economic model that "must not only provide for jobs and income, but for our health, our environment, and our future" and deals with our common challenge of "creating the conditions for enhanced prosperity and growing social equity, within the contours of a finite and fragile planet".

Economy and the construction industry

The construction industry plays an important role in the world economy. Approximately 10 trillion \$ are spent each year on construction-related goods and services, making this sector one of the largest in the world.⁵ In 2018, the building and construction sector was responsible for 39% of final energy use in the world.⁶ Furthermore, as we will see in the next chapter on environment preservation, the construction industry is in large part

1 TODARO, Michael, SMITH, Stephen, *Economic Development*, 2015, p. 9
2 ibid, p. 10
3 "What is an Inclusive Green-Economy?", in UN Environment Programme
4 ibid
5 "In Brief: Reinventing Construction", in McKinsey Global Institute, p. 1
6 *2019 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and construction sector*, Global ABC, 2019, p. 9

responsible for the consumption of raw materials and natural resources. The significance of this sector for the economy is undeniable.

The primary function of the building and construction sector is "to create, repair and improve the built environment".¹ The scope of this industry can be defined in different ways.² We choose to consider it as encompassing all activity that concerns the four steps of the life cycle of buildings. As a result, there are six main actors working in this area:

- contracting firms
- consultancy firms
- building materials firms
- plant hire firms
- developers
- facility maintenance firms

The other important stakeholders of this sector are the owners and the end user of this industries' products. The people and organizations that will inhabit the buildings.

Most often, the purchase of an apartment or house is the biggest investment an individual or an organization will do in his or her life.

On one hand, poor design or construction of a building can lead to unnecessary costs and use of resources (both in building and in maintenance), which can then negatively impact the economy.

On the other hand, construction activity can have many benefits.³ It is seen by economists as one of the best ways to lift economic activity both in short and long term.⁴ We can witness this in our times of COVID where many governments, including the Icelandic one, have decided to invest large funds in construction projects.

There is room for low and high-skilled labor in construction. Its jobs provide people with little interest in academic life with the option of a strong career, with lots of room for progression.⁵ Moreover, this sector is said to provide for more social mobility than other industries.⁶ Meaning that lower-

1 GREEN, Brian, *The Real Face of Construction 2020: Socio-Economic Analysis of the True Value of the Built Environment*, 2020, p. 6
2 SUI PHENG, L., SHING HOU, L., *Construction Quality and the Economy: Management in the Built Environment*, 2019, p. 21
3 GREEN, Brian, *The Real Face of Construction: Socio-Economic Analysis of the True Value of the Built Environment*, p. 7
4 *ibid*, p. 9
5 *ibid*, p. 9
6 GREEN, Brian, *The Real Face of Construction 2020: Socio-Economic Analysis of the True Value*

income classes have better chances of progressing economically through construction jobs.

The economic interest of the construction industry's stakeholders must be considered when proposing ways forward for housing in the village of Grindavik.

Good proposals could offer opportunities for continued long-term and short-term employment for different levels of education and skills.

Local construction traditions which have been developed over many years could be encouraged and adapted to better fit sustainable development goals.

Just as for social impact assessment, there is a myriad of themes that can be considered for economical development. We will be focusing our attention on:

- **local employment for different skill and academic levels,**
- **knowledge creation and conservation.**

There exists a tool used to assess the economical impact of a building: Life Cycle Costing (LCC). It is a method used by designers to estimate the cost of a building during all of its life cycle phases.¹ Nonetheless, this does not come close to addressing all economical impacts of a project as we have exposed them. A simple example of this can be that a building that costs less to its owners might not participate in creating local employment.

For this reason, we will not be using this method, but instead will attempt to estimate the impact that our suggestions can have on the two categories previously mentioned.

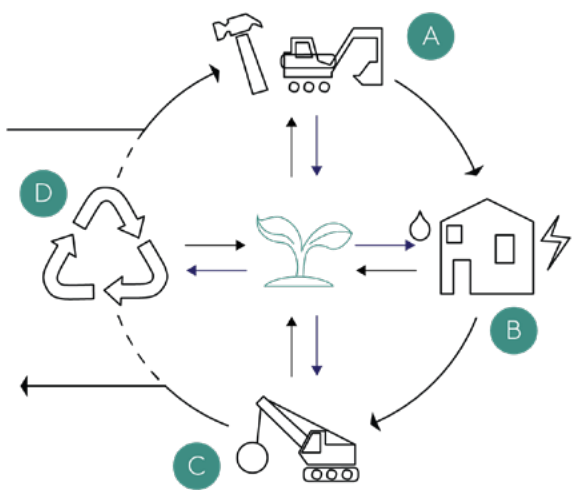
Let us now take a look at environmental preservation.

IMAGE 14 | (next page) Grindavik is surrounded by moss covered lava fields

1 of the Built Environment, 2020, p. 4
1 INGOLFSDOTTIR, Gyda Mjoll, BJARNADOTTIR, Helga, et al., *Vistferilsgreining fyrir vidbyggingu vid Sundholl Reykjavikur*, 2018 , p.11



Environmental preservation



Environmental preservation is a concept most of us should be familiar with. It speaks of the natural environment of our planet, its state and how it should be protected. It can be defined as "the prevention of unwanted changes to ecosystems and their constituent parts".¹

Ecosystems vary in scale. They can be tiny like a small pond or a tree trunk or huge like our planet. There are three main categories that describe their size.²

Micro: small scale eco-systems like the pond.

Meso: medium scale eco-systems like a forest or a river.

Biome: large ecosystems or a collection of ecosystems with similar characteristics.³

The importance of our globe's natural resources is unquestionable. Everything we consume finds its source in one way or another in nature.

One of the biggest threats to local and global ecosystems is climate change, which is caused by the steady increase of mean global temperatures. Its consequences

are various and range from shifting weather patterns that threaten food production to rising the sea level and thus increasing the risk of catastrophic flooding. It is a problem that already has a massive global impact and has been defined by the United Nations as the most crucial issue of our time.¹

Climate change is caused by the concentration of green-house-gases (GHG) in our atmosphere that has been steadily increasing since the industrial revolution. The most profuse GHG, accounting for about 2/3 of total GHG emissions, is carbon dioxide (CO₂). It is largely emitted by the burning of fossil fuels. The growth of economies, improved standard of living and increase in population has caused total GHG levels to reach levels that haven't been seen in three million years.²

Climate change is not the only threat to ecosystems. Various activities can have a negative impact on them, such as the release of toxic waste in

landfills, damming rivers, or natural resource extraction. Nonetheless, for the scope of this paper, we will focus our attention on carbon emission as they are an international standard that allows us to understand the impact that local activities have on our globe.

In 2016, Iceland had the highest per capita emissions of CO₂ from the economy within the EU and EFTA countries.³ The main emitters in the country are the air transportation sector and the basic metals production sector.⁴ Additionally, since 2008, Icelandic households are the highest emitters of CO₂ per capita within the Nordic countries.⁵

This is mainly explained by households' car usage.⁶ Iceland has a cold climate and sparse population. Cities and towns have in most cases been planned for automobile usage. The village of Grindavik has a radius of approximately 850m. The rule of thumb for walking distances is that one travels about 400m in 5 min. This

1 JORGENSEN, Sven, FATH, Brian, "Environmental Protection", 2008, p.1
2 "Scales of Ecosystems", in Eschooltoday
3 ibid

1 "Climate Change", in United Nations
2 ibid
3 «Iceland has the Highest Per Capita CO₂ Emissions from the Economy», in STATISTICS ICELAND, 2018
4 ibid
5 ibid
6 ibid

shows us that travelling in the village by foot takes little time. However, it is rare to see people walking if they own a car; and most people own at least one car.

As you might have noticed, we have compared Iceland to other countries in terms of emissions using per capita measure. This was done because Iceland has a very small population (340'000 people), and that the country has an extremely small impact when considering total emissions. Indeed, in 2018, Iceland was ranked 26th of 28 countries in Europe for total carbon emission.¹ Only Malta (440'000 inhabitants) and Liechtenstein (38'176 inhabitants) had less emissions.

We have established, firstly, that climate change, caused by GHG of which CO² is the most prolific, is a great threat to environmental preservation. Secondly, that Iceland has overall low carbon emissions compared to other countries, but that the per capita figures tell the opposite story. Thirdly, that households in Iceland have high per capita emissions rates, which are primarily

caused by the burning of fossil fuels for transportation.

Let us now look at how the construction industry contributes to carbon emissions and environmental degradation, first globally and then in Iceland.

In 2018, the building and construction sector was responsible for 39% of energy and process related CO² emissions globally, and 36% of final energy use.² As the world's population increases so will the number of buildings needed. In this manner, the building stock is expected to double. This means that if business goes on as usual, global consumption of raw materials could double by the middle of this century.³

Once again, just as for economic development, the impact of the building and construction sector on environmental protection is substantial.

Establishing where the Icelandic building and construction sector stands in terms of environmental impact is quite complex for one

specific reason. Iceland manufactures only two construction materials: isolation rockwool and the aggregates used in concrete.. All other materials are imported.

As we will see later, the life cycle step that has the worst environmental impact for buildings in Iceland is the manufacturing of the construction materials. This causes issues when attempting to establish the effects of the Icelandic building and construction sector because the environmental impact of the manufacturing of materials as well as their shipping is reported in the producing countries and, therefore, absent in Icelandic accounts.

In the National Inventory Report of 2020, we see that the manufacturing industries and construction account for 7.8% of the country's energy sector's GHG emissions. This sector is responsible for approximately 40% of Iceland's total GHG emissions. This means that the manufacturing and construction industry in Iceland is responsible for approximately 3% of the country's total GHG emissions. This is quite different than the global

impact of building and construction which is estimated at 39% of total GHG emissions.¹

The figure reported by the National Inventory of Iceland does not give a realistic view of the status quo. This lack of useful information was also observed by the Green Building Council of Iceland in an opinion letter on the government's proposals for dealing with climate change. The council expressed its disappointment that there isn't any focus set on their sector and that the emissions from the construction industry and built environment need to be better mapped.²

It is easy to see how this is problematic. If policy makers are not aware of the problems caused by the building and construction sector, they cannot propose solutions to help reduce the sector's environmental impact. Stakeholders of the industry might think that they are doing better than in other countries, when they are actually facing similar problems.

Let us now look at how environmental

1 "Air Emissions Accounts By Nace Rev. 2 Activity", in Eurostat, 2020
2 2019 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and construction sector, Global ABC, 2019, p. 9
3 Bringing Embodied Carbon Upfront, World GBC, 2019, p. 4

1 2019 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and construction sector, Global ABC, 2019, p. 3
2 KRISTJANSÐÓTTIR, Þorhildur Fjola, INGOLFSDÓTTIR, Gyða Mjoll, Umsagn Graenni Byggðar um Adgerdaraetlun í Loftslagmalum, 2019

impact of buildings is assessed.

Contrary to the economic and social development pillars, there exists a well-established way to define this impact: Life Cycle Assessment (LCA). LCA reports all substances released into the air, water, or soil during the various life cycles of a building. The substances are named emissions and are translated into environmental impacts across a specified number of environmental categories. Those categories represent measures of environmental change caused by the effects of various types of emissions. Commonly used impact categories to assess buildings include:

Global warming potential (GWP)

The potential changes in local, regional, or global surface temperatures caused by an increased concentration of greenhouse gas in the atmosphere.

Acidification potential

The acidifying effect of substances in water and soil. This category concerns the effect of acidification locally.

Eutrophication potential

the effect of adding nutrients to soil or water, which can compromise the survival of certain species in an ecosystem by favoring the growth of others.

Ozone depletion potential

The effect of substances weakening the ozone layer and preventing it to limit excessive ultraviolet radiation from reaching Earth’s surface.

The impact of each category over the life cycle is then obtained by multiplying the estimate of quantities of materials and process in buildings with the estimate of environmental impacts for each material and process.¹

According to the international standard ISO14040, there are four steps necessary to completing a LCA²:

Define goal and scope

This means defining why and how the LCA is made. More precisely, the scope specifies what the LCA includes and excludes. Functional description of the buildings, a reference study period, the boundaries of the system

which is what part of our buildings we are considering and over what life cycle phase, must be defined at this stage.¹ The scope helps focus the study and get more accurate results.

Collect inventory

The inventory can be likened to a "bill of activities and materials" of the subject buildings. It encompasses all materials and processes within the defined scope of the LCA.²

Perform impact assessment

The calculation of the environmental impacts of the building as described earlier.³

Interpret results

The objective of this step is to understand the result obtained and draw conclusions from them.⁴ The main impact of this report is to propose guiding principles for improving the environmental impact of housing in Grindavik whilst contributing positively to the other pillars of sustainable development. To this end, we will use the LCA method to assess the impact of the four most common housing typologies in the

village.

Making a LCA can be a quite demanding process for an individual. For this reason, we used precursor studies to determine what stages of the life cycle and what construction materials have the biggest impact. In the next chapter, we will see how those precursor studies were made, their results, how they allowed us to focus our scope of study, and the ensuing LCA of four different buildings.

1 INGOLFSDOTTIR, Gyda Mjoll, BJARNADOTTIR, Helga, et al., *Vistferilsgreining fyrir vidbyggingu vid Sundholl Reykjavíkur*, 2018, p. 7
2 "ISO 14040:2006", in ISO, 2006

1 HUANG, Monica, *Life Cycle Assessment of Buildings: A Practice Guide*, 2018, p. 16
2 ibid, p. 20
3 ibid, p. 22
4 ibid, p. 24

LCA GRINDAVIK

The goal of our LCA is to assess the global warming potential (GWP) of the most common types of housing in Grindavik. This will allow us to compare their performances and to establish strategies for housing that will a better impact on global warming than the current practice.

As explained earlier, GWP is an indicator of released green house gas emissions that are the main cause for global warming. We choose this measure because it represents a well-known phenomena understood by most people. It is also interesting because it informs us on both local and global impacts, thus demonstrating that buildings in Grindavik do not only have an impact locally but also on the global ecosystem.

The subjects of our study are four residential buildings located in the village. There is one detached house, one row-house, one two-storey building, and one four-storey building.

In order to establish the boundaries of our assessment and focus our scope, we performed preliminary studies. We analyzed a past LCA completed in Iceland, compared local data on energy production to that of other countries, and gathered information on the rate of house demolition in the village. This has allowed us to make five statements that resume the specificity of our context and allow us to focus our analysis and proposals.

The LCA we will be referring to is of the extension of the swimming-hall of Reykjavik completed in 2017.



IMAGE 15 | The entrance of the swimming pool extension
IMAGE 16 | The "reference house" (rendering)

The original building was opened in 1937. The new part is one and two storey high. It is made of concrete, isolated on the inside with a large glass facade on its north side.

This LCA only considered the new building containing the reception and women locker-rooms as well as the outside lockers and sauna. The new pool was excluded from the study. Therefore, the typology of this building does not differ too much from that of a residential unit. All building components were analyzed over all life stages.

Another LCA has been completed on a two-storey residential building in Reykjavik. This study was performed

by the same authors as the one for the swimming pool extension, the engineering firm EFLA. It was requested by the Icelandic Innovation Center and is named "Reference House LCA".

This building is nearly identical to some of our subjects of study. The results have not been published yet, but we have been allowed to consult them and they were very similar to the swimming pool extension's LCA.

For this reason, we can rely on the learnings that we take from the swimming pool extension to inform our research.

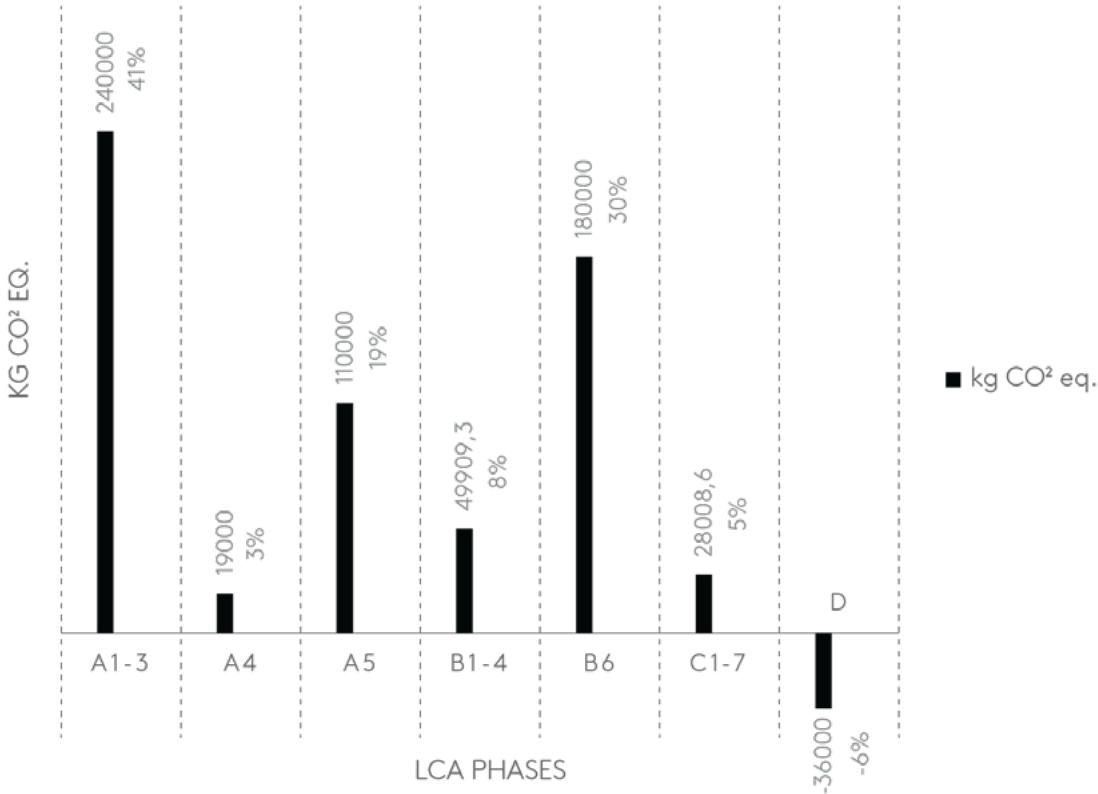
Precursor studies

OUR FIRST STATEMENT IS

Construction materials production (life cycle phases A1-3) have the highest environmental impact of all life cycle stages.

The production of construction materials accounts for approximately 40% of total GWP for the swimming-pool extension. In comparison, the operational energy and water use (phases B6-7) over 60 years account for about 30%.¹

¹ INGOLFSDOTTIR, Gyða Mjoll, BJARNADOTTIR, Helga, et al., *Vistferilsgreining fyrir vidbyggingu við Sundholl Reykjavíkur*, 2018, p. 50



GWP whole building - Swimming pool extension¹

OUR SECOND STATEMENT IS

The operational use phase of buildings in Iceland has a much lower environmental impact than in other European countries.

The phases B6 and B7 of the life cycle are the operational energy and water use of buildings. To date, most attention to reduce the impacts of buildings globally has been focused on those use stages.¹

In 2018, European households accounted for 26.1% of final energy consumption in the region. What EU households use energy for can be seen on the first graph.²

In Europe, 19.5% of the energy consumption of households is provided by renewable energy

sources.³ In Iceland, renewable energy accounts for 90% of households energy use for heating (geothermal energy) and 100% of household electricity needs (30% geothermal and 70% hydro-power).⁴ This information is visualized on the second graph.

In Grindavik, the electricity and heating needs of households are entirely covered by a local geothermal plant.⁵

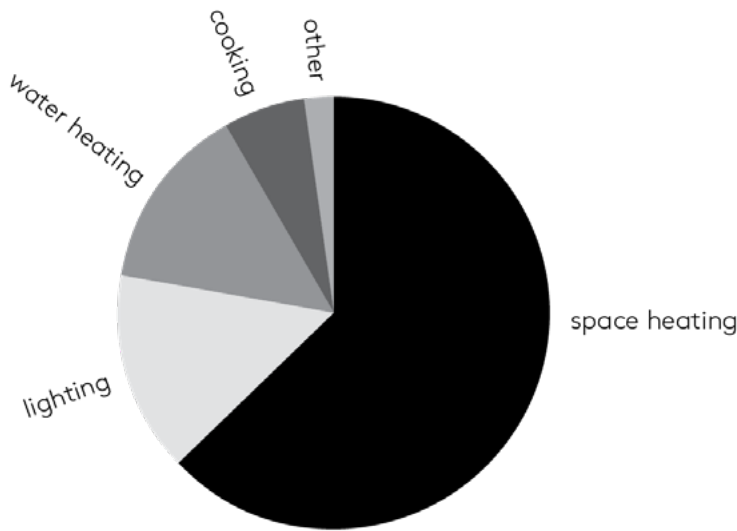
1 HOXHA, Endrit, FIVET, Corentin, "Environmental Benefits when Reusing Load-Bearing Components in Office Buildings: A Case Study", 2018, p. 11

2 "Energy Consumption and Use by Households", in EUROSTAT, 2020

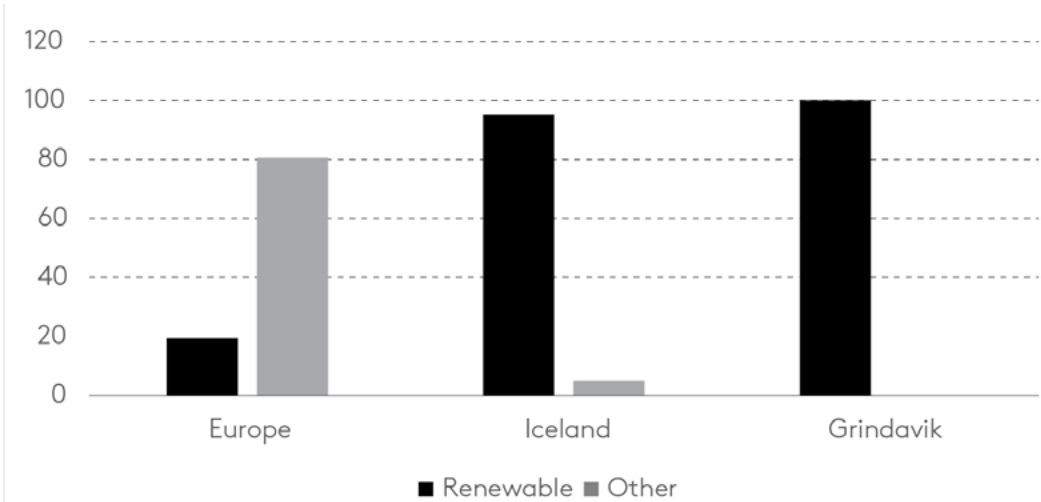
3 ibid

4 National Inventory Report: Emissions of Greenhouse gases in Iceland from 1990 to 2018, the Environment Agency of Iceland, 2020, p. 54

5 "Power Plants", in HS ORKA



Energy consumption in EU households by type of end-use²



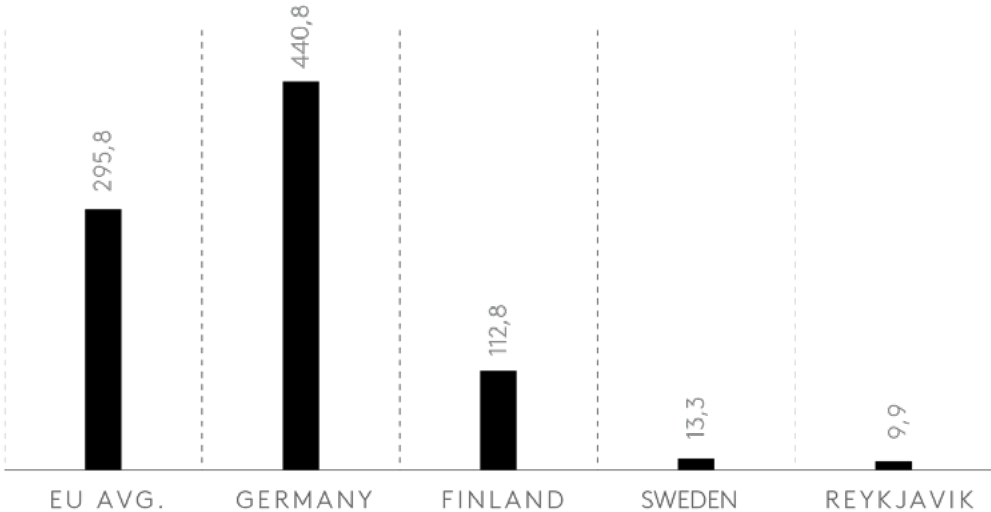
Renewable energy %^{3/4/5}

Carbon intensity indicates how much carbon dioxide is emitted to produce 1 kWh of electricity. It is useful to assess how carbon intensive the production of electricity is.

By comparing the 2016 carbon intensity figures from the EU and some of its member countries to those of Reykjavik, which produces its electricity in similar manner as Grindavik, we understand that producing electricity in Iceland has a much lower impact in terms of carbon emissions than in most other European countries.¹

Furthermore, the consumption of electricity per dwelling in Iceland is comparable to the European average. In 2017, the average was around 4'000 kWh for EU dwellings.² It was about 4'700 kWh in Iceland.³

1 "Environmental data - Reykjavik Energy Group 2015-2019", in Reykjavik Energy Group, 2019
2 Sectorial Profile - Households: Electricity Consumption per Dwelling, *in* Odyssee-Mure, 2020
3 "Rafmagn: Heimili", *in* Reykjavik Energy Group



Carbon Intensity Comparison (year: 2016)^{1/2}

OUR THIRD STATEMENT IS

The importation of construction materials from other countries does not have a high environmental impact compared to other steps of the life cycle.

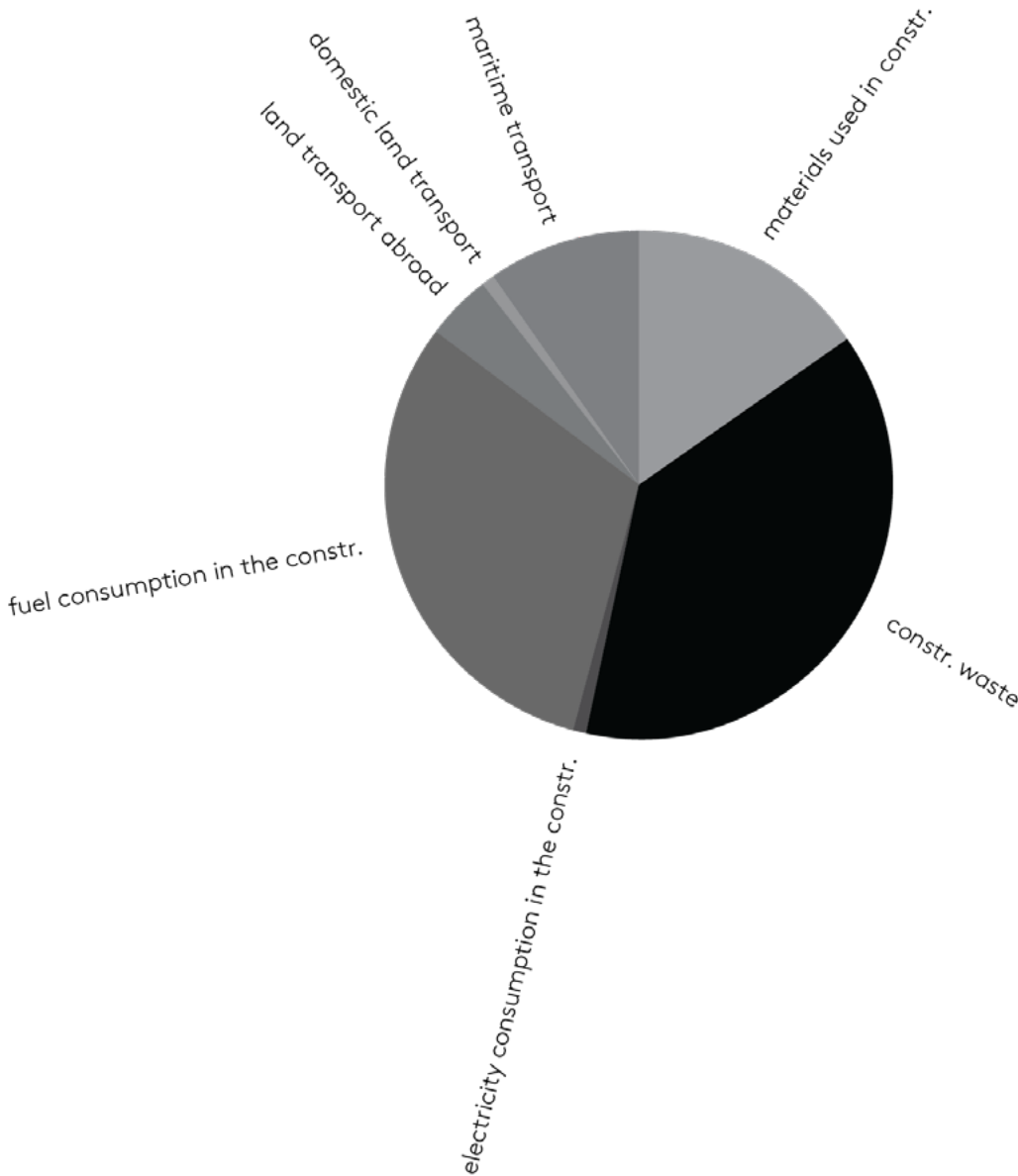
The only construction material manufactured in Iceland is stone-wool insulation, all other materials are imported. One could, therefore, think that the import of materials would have a large impact. However, marine transportation represents approximately 10% and land transportation 5% of the impact of phases A4-5, which accounts for 23% of total GWP for the building.

The subdivision of the GWP impacts of phases A4 (transport of construction materials to construction site) and A5 (operating equipment to install products and

construct the building) for the swimming pool extension can be seen on the following graph.

Maritime and land transportation account for just above 10% of the GWP. Fuel consumption during construction accounts for about 30% and construction waste 39%.¹ 95% of the construction waste produced for the construction of this building results from earthworks.² Furthermore, most of fuel consumption is also caused by earthwork, that is moving soil and aggregates to and from the construction site.

1 INGOLFSDOTTIR, Gyda Mjoll, BJARNADOTTIR, Helga, et al., *Vistferilsgreining fyrir vidbyggingu vid Sundholl Reykjavíkur*, 2018 , p. 44
2 ibid, p. 32



GWP for Phases A4-5 (construction process stages) - Swimming pool extension¹

OUR FOURTH STATEMENT IS

Structural elements have the highest impact on embodied carbon.

Embodied carbon is all carbon dioxide emissions caused by materials and construction processes over all life cycle phases of a building. It is the opposite of operation carbon, which is the emissions caused by energy use for operating a building.¹

The international design firm Arup investigated the embodied carbon of typical structural frames for non-residential building. This research describes that 50% and above of embodied carbon is contained in the structural elements of the buildings. The three types of buildings observed in that study where a hospital, an office building and a school.²

This can be explained by the relatively large proportion of structural materials - by weight - typically in buildings. In the swimming-pool

extension, the main construction material is reinforced concrete and accounts for 88% of the building's total mass.³ In that case, the structure most certainly accounts for more than 50% of total embodied carbon.

This observation demonstrates the importance for us to focus on the structural elements of our buildings for our LCA. Also, this might suggest different material use or construction processes as a strategy to reduce GWP. Timber, for example, has much lower embodied carbon than concrete. However, as we will see later on, a "greener" material does not necessarily mean less total embodied carbon. Other factors such as various structural design parameters are just as important as the choice of material.⁴

1 *Bringing Embodied Carbon Upfront*, World GBC, 2019, p. 56
2 KAETHNER, S.C., BURRIDGE, J.A., "Embodied CO2 of Structural Frames", 2012, p. 39
3 INGOLFSDOTTIR, Gyda Mjoll, BJARNADOTTIR, Helga, et al., *Vistferilsgreining fyrir vidbyggingu vid Sundholl Reykjavikur*, 2018 , p. 41
4 PURNELL, Phil, "Material Nature versus Structural Nurture: The Embodied Carbon of Fundamental Structural Elements", 2012, p. 454

OUR FIFTH STATEMENT IS

Buildings are rarely demolished in Grindavik.

There have been only ten applications for demolition of a building or part of a building since 2008 in the village.



IMAGE 17 | The streets of Grindavik do not change much with time as houses are rarely demolished

To sum up, by analyzing an existing LCA of a building in Reykjavik and gathering other information on the different life cycle stages of buildings in Iceland, we were able to make five statements:

- 1) the product stage (life cycle phases A1-3) has the highest environmental impact in terms of GWP of all life cycle stages,
- 2) the operational use phase of buildings in Iceland has much lower GWP impact than in other European countries,
- 3) the importation of construction materials from other countries does not have a high environmental impact compared to other steps of the life cycle,
- 4) structural elements have the highest impact on embodied carbon,
- 5) buildings are rarely demolished in Grindavik.

Using this information, we can establish which life cycle phases and what building components we will be considering.

In this way, our LCA will focus on the product stage of the life cycle (A1-3), and we will only consider structural building elements. Those are:

- foundations,
- structural walls,
- floors slabs,
- roof slabs (concrete),
- roof timber frame (timber).

Furthermore, we will also analyze the earthwork related to the construction of each buildings. This will give us an indication of construction waste as explained earlier, as well as introducing the theme of insertion in the landscape. We will speak more of this in our proposals.

We will now see descriptions of our four buildings. All information on material quantities was given by the local contractor who built those projects, except for the detached house. In that case, we had access to architectural and structural drawings of the project and were able to calculate all material quantities from them.



IMAGE 18 | Kids regularly jump in the ice cold water of Bjarnagja located west from Grindavik

Subjects of study



The location of each subject of study can be seen on the map above. Subjects 2,3 and 4 are in newer neighborhoods than subject 1.

Subject 1



TPOLOGY OF HOUSING

Detached house

SIZE

188 m²

ADDRESS

Badsvellir 16, 240 Grindavík

MAIN CONSTRUCTION MATERIAL

Concrete (in-situ)

ARCHITECT

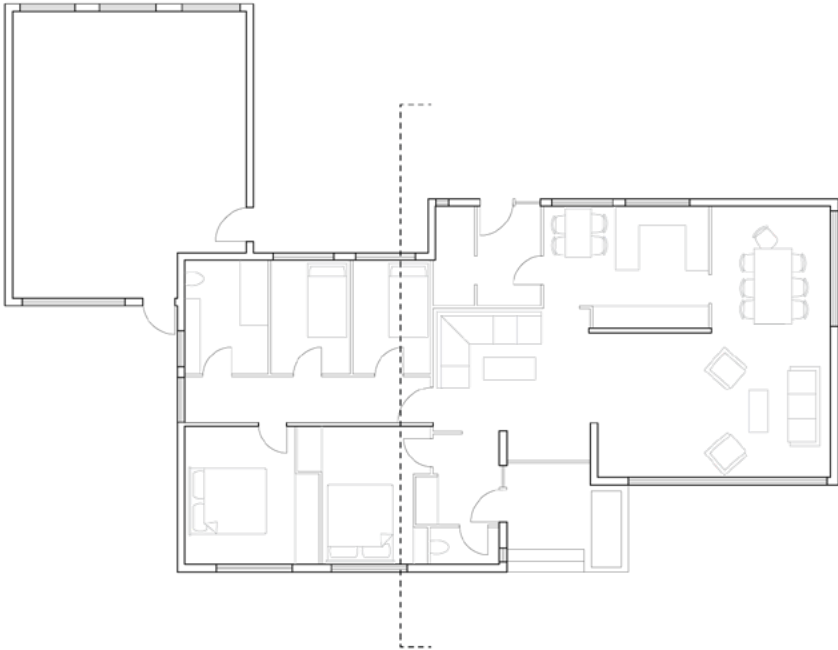
Kjartan Sveinsson

HOUSING UNITS

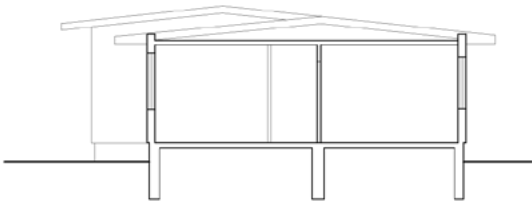
1

YEAR OF COMPLETION

1976



Plan 1:200



Section 1:200

Subject 2



TYPOLOGY OF HOUSING

Pair house

SIZE (avg.)

181 m²

ADDRESS

Vikurhop 9-11, 240 Grindavík

MAIN CONSTRUCTION MATERIAL

Concrete (in-situ)

ARCHITECT

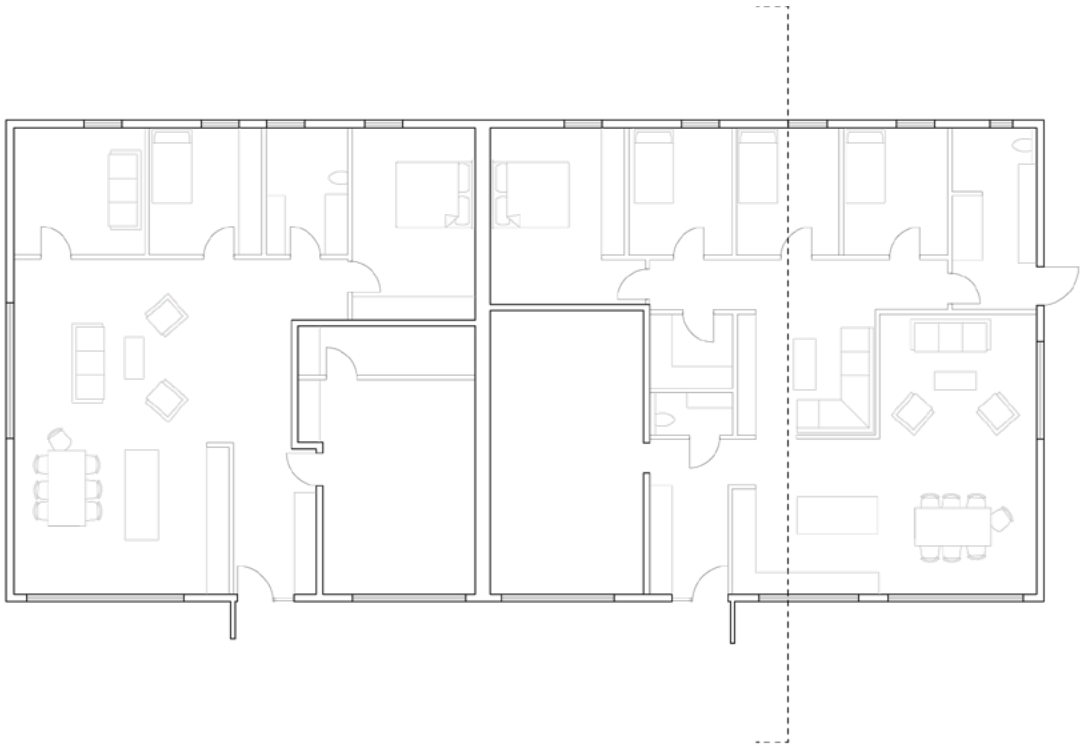
Jón Stefán Einarsson

HOUSING UNITS

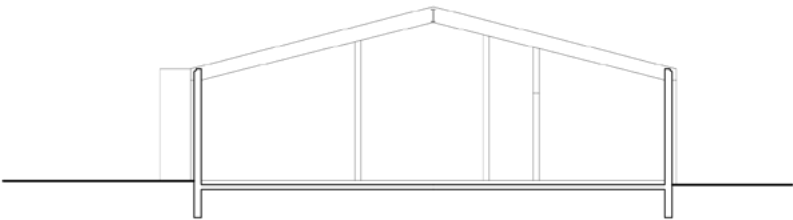
2

YEAR OF COMPLETION

2020



Plan 1:200



Section 1:200

Subject 3



TPOLOGY OF HOUSING

2 storey apartment building

ADDRESS

Vikurhop 32, 240 Grindavik

ARCHITECT

Jón Stefán Einarsson

YEAR OF COMPLETION

2020

SIZE (avg.)

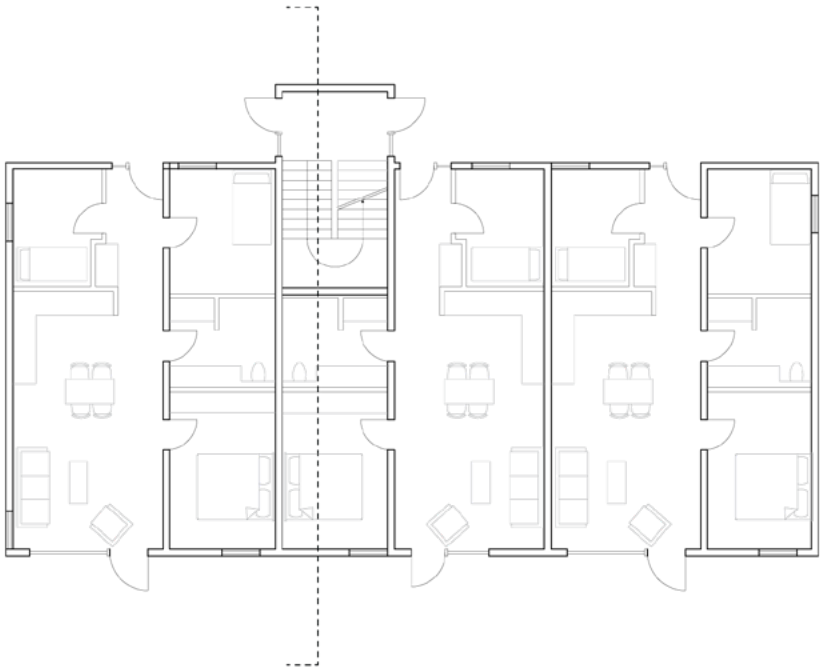
78m²

MAIN CONSTRUCTION MATERIAL

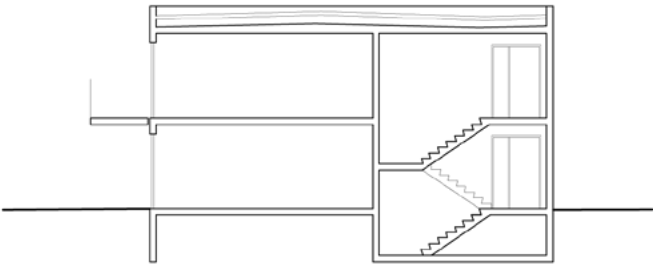
Concrete (in-situ & prefabricated)

HOUSING UNITS

6



Plan 1:200



Section 1:200

Subject 4



TYPOLOGY OF HOUSING
4 storey apartment building

ARCHITECT
Jón Stefán Einarsson

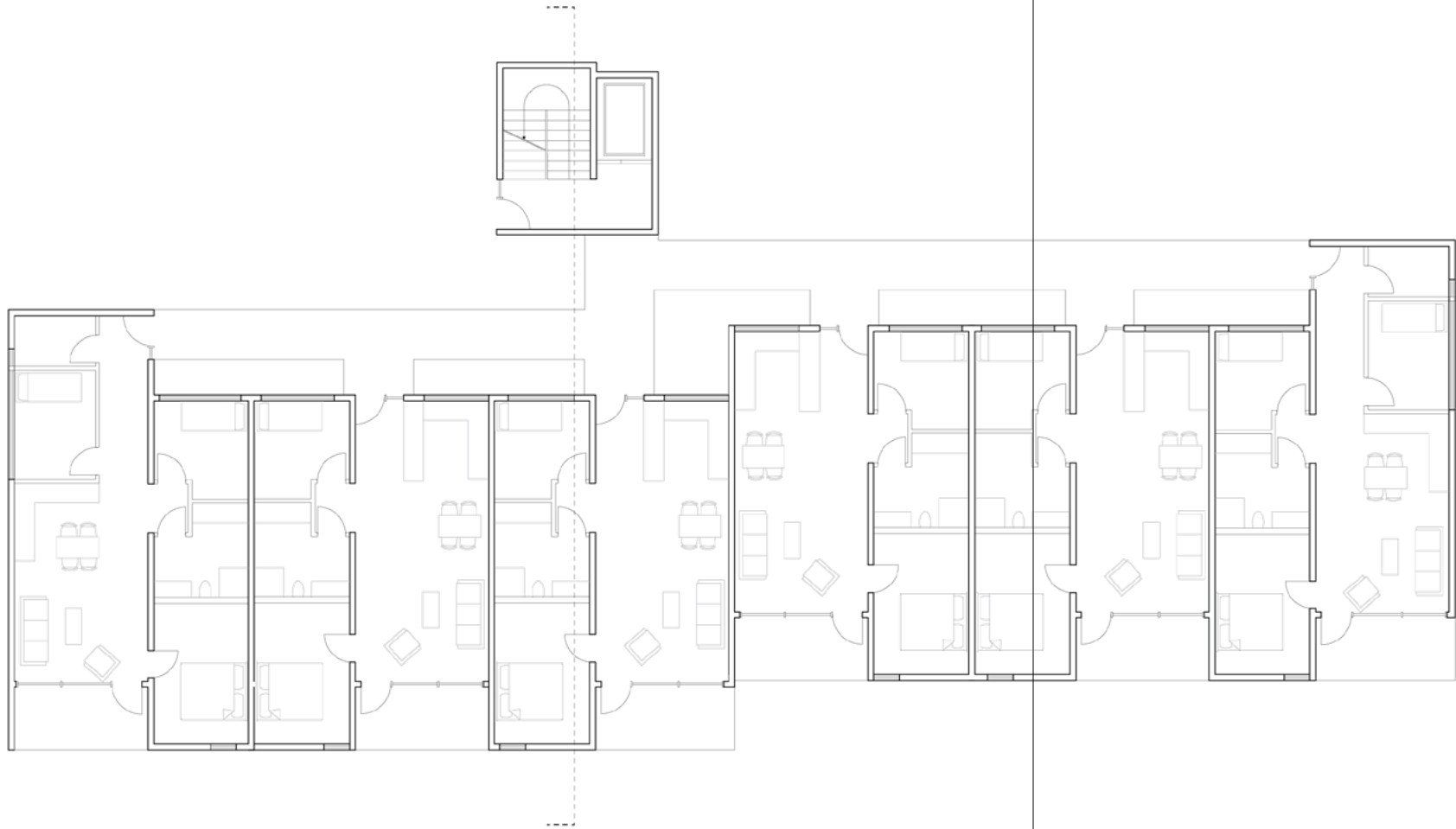
ADDRESS
Stampholsvegur 5, 240 Grindavík

YEAR OF COMPLETION
2018

SIZE (avg.)
79m²

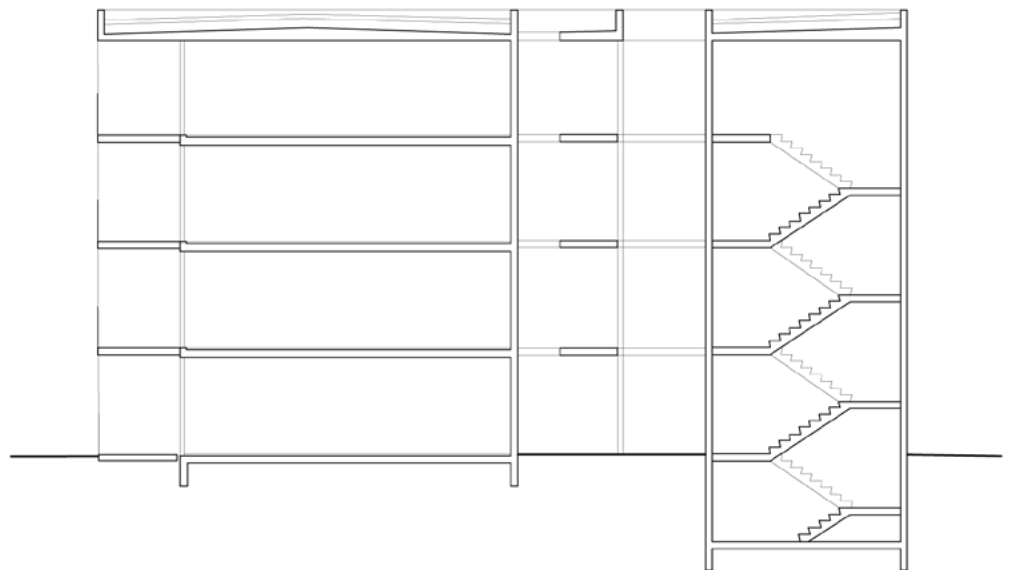
HOUSING UNITS
24

MAIN CONSTRUCTION MATERIAL
Concrete (in-situ & prefabricated)



Plan 1:200

P. 74 | 108

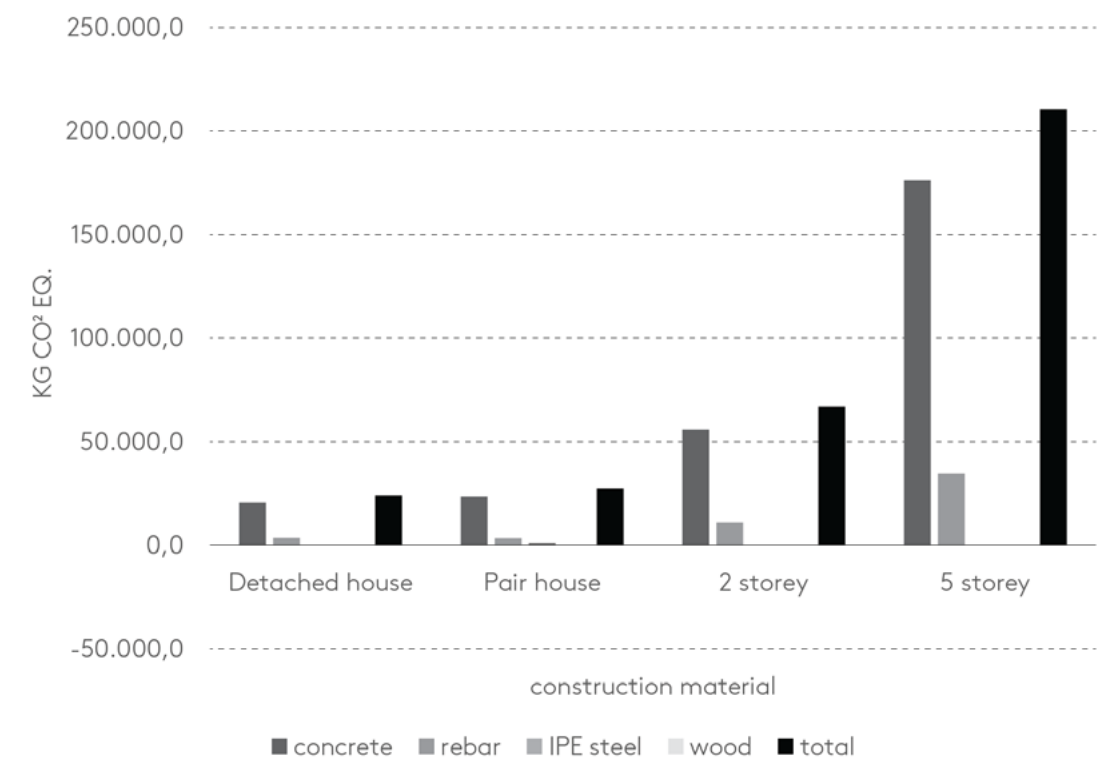


Section 1:200

P. 75 | 108

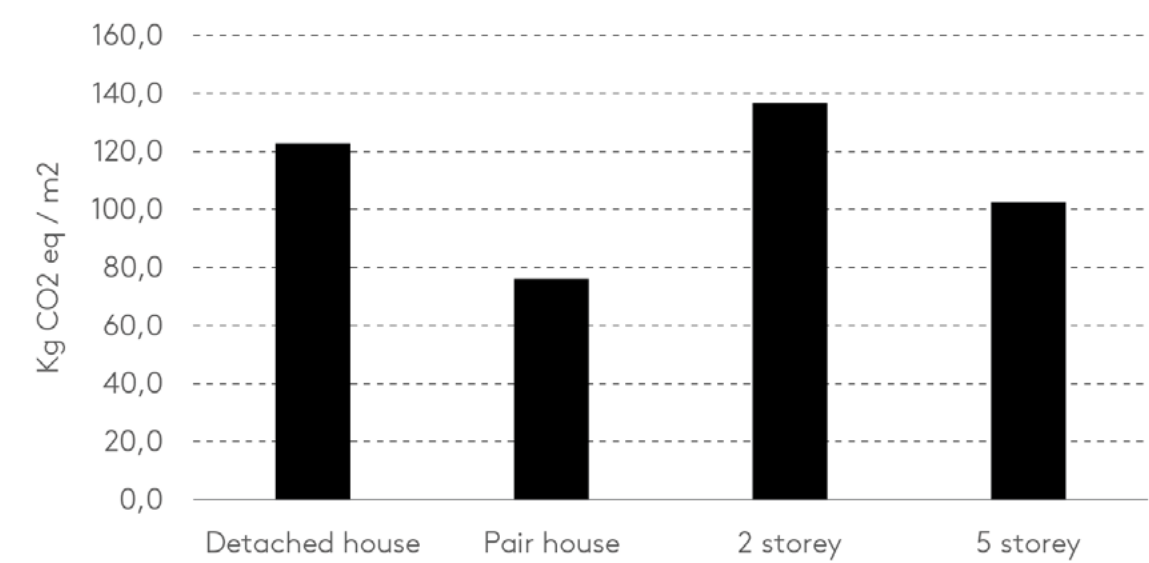
Results

GRAPH 1: GWP per materials



This graph shows the GWP in kg CO₂eq. for each material in each housing type as well as total GWP. This highlights the predominance of reinforced concrete.

GRAPH 2: GWP per sqm.



This graph shows the GWP in kg CO₂eq. per square meter (sqm.) for each housing type. We use the brutto sqm. count given by the architect of each project.

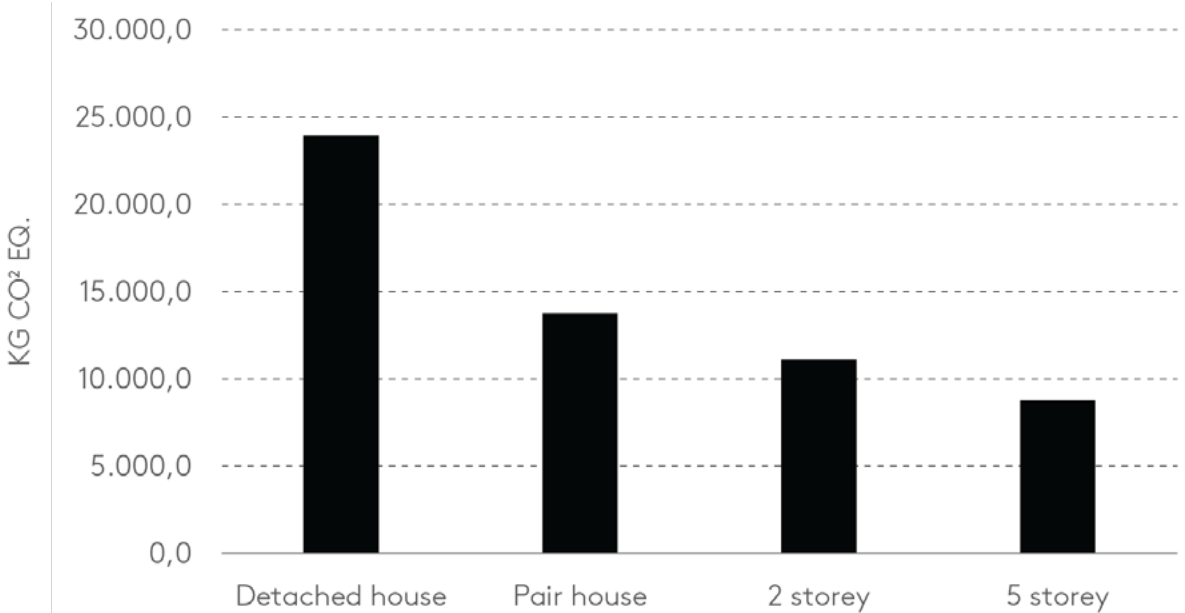
GRAPH 3: GWP per inhabitant



This graph shows the GWP in kg CO²eq. per inhabitant in each housing type. To define how many inhabitants there is in each scheme, we took the average number of persons living together in separate apartments in the village (3.16) and multiplied by the amount of departments in each scheme¹

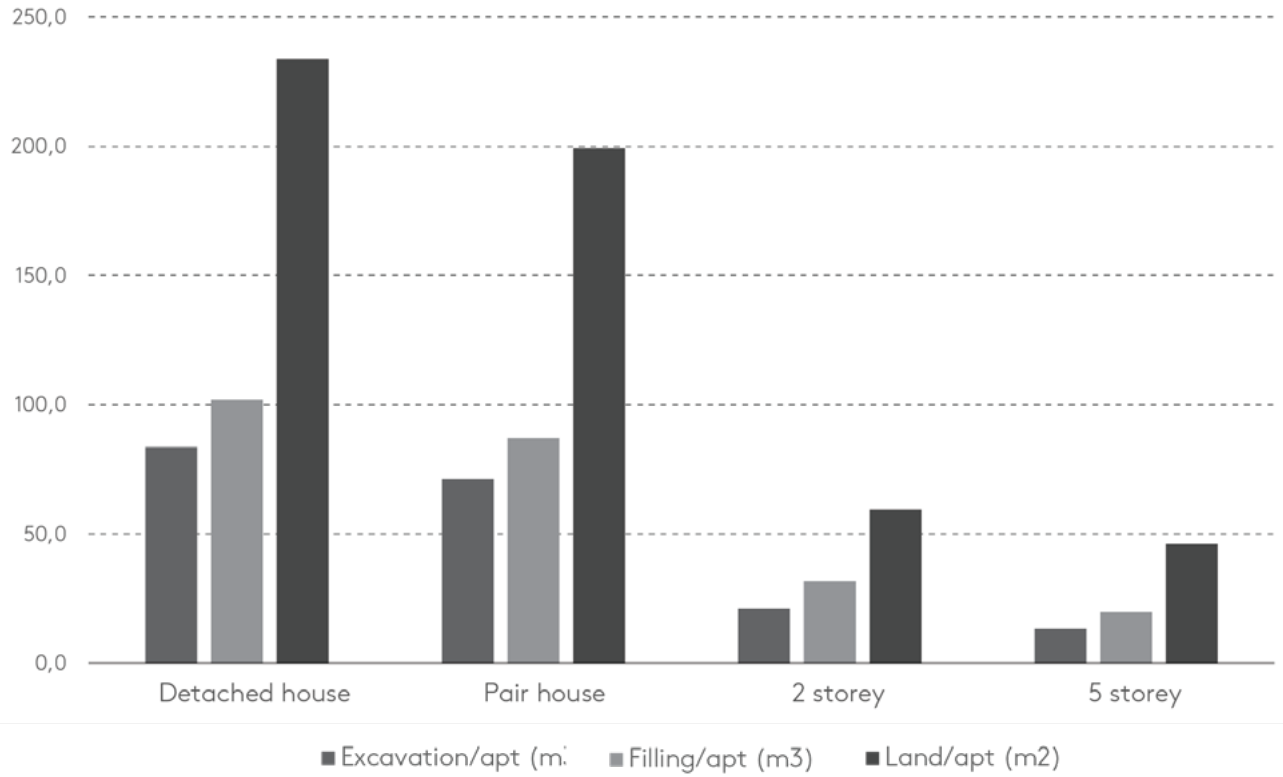
¹ E3, p.10

GRAPH 4: GWP per apartment



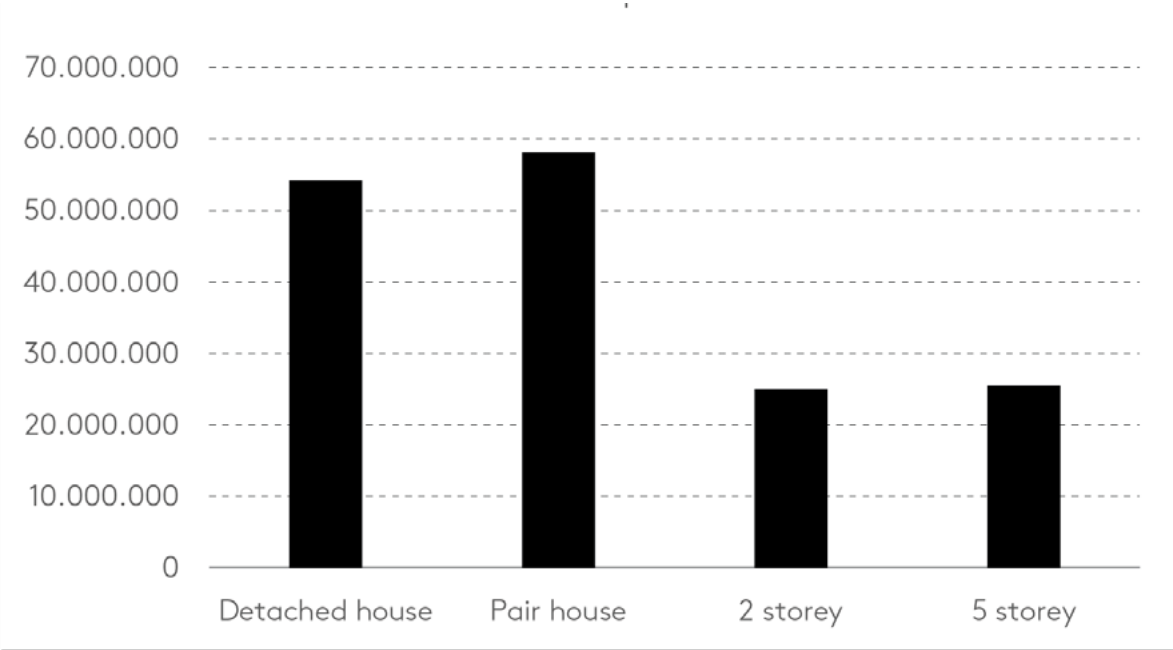
This graph shows the GWP in kg CO²eq. per apartment unit in each housing scheme.

GRAPH 5: landuse and earthwork



This graph shows firstly the amount of m³ of earth that had to be excavated for the construction of each project. Secondly it shows the amount of aggregates that had to be brought on-site to construct the foundation cushion of each building. Thirdly, it shows how much land each housing plot occupies.

GRAPH 6: price per apartment



This graph shows the price, or average price (for the multi-apartment schemes, of an apartment in each scheme. The figures are extracted from the Icelandic real-estate register.



Results Interpretation & Discussion

From the LCA addressing four completed housing projects in Grindavik, three groups of issue emerge relating to:

- 1) land-use,
- 2) architectural typologies,
- 3) construction techniques.

Regarding land-use, significant difference is apparent in the data between “grounded” apartment units (one storey housing for one housing unit), and multi-storey housing (at least two vertically stacked units). For land-use, there is a 14% difference between the detached house and the pair house, 70% difference between pair house and two storey, and, finally, 22% between two storey and five storey. Land-use reflects the production of carbon emissions for the construction and installation

phase of the life cycle (A5) and more precisely the production of construction waste.

Regarding architectural typologies, the LCA results highlight the principle that denser housing typologies have lesser environmental impacts per person and per housing unit. There is a 42% decrease between detached houses and pair houses, but a smaller gap between the ensuing categories: 19% from pair house to two storey and 21% from two storey to five storey. This is true both for GWP per person and per apartment and this information pertains to the carbon produced by the product stage of construction materials (phase A1-3).

Notably, the precursor LCA studies reviewed in this investigation highlight that the embodied carbon

of construction materials (i.e. LCA stages A1-3) has the highest environmental impact of all building life cycle stages. Therefore, measures for reducing GWP of housing that address changes in typologies will be more effective than those for land-use. Notwithstanding this greater impact of housing typology upon environmental impact, land-use remains an important aspects of sustainable development as we will explain later.

LCA results from this investigation and precursor studies indicate that detached housing has the highest environmental impact of the housing typologies addressed. Among the other three typologies addressed, the results suggest a comparable environmental impact per housing unit and per person.

Detached housing is, traditionally, the most esteemed housing typology for Icelanders. Living in that typology can be likened to the American dream for the villagers. In general, the denser a housing scheme, the less attractive it is for typical Icelanders. One can often hear people say: "Why live in a small apartment in Reykjavik, when you can have a detached house with your own garden in Grindavik (or

other neighboring villages/towns)". Thus, in comparing Grindavik with denser urban centres such as the nearby capital of Reykavik, it is a strong selling point for the village to have the option of less expensive detached housing. Such cultural and market preferences should be accounted for when developing sustainable building solutions to ensure widespread acceptance and effective impact.

Pair houses are well regarded, particularly designs of pair houses built in the village recently. This typology could be an appropriate compromise between different dimensions of sustainability – in particular, such semi-detached housing typologies can balance social development and environmental preservation considerations. Nonetheless, the data and graphs describing land-use and price per apartment, indicate that the pair-house typology performs quite poorly. This is due to the still-high square meter count both for the apartment units and land used in comparison to the two multi-storey housing schemes.

Considering these results, a potential strategy is to mix smaller pair

houses with multi-storey apartment buildings to achieve a denser scheme than the detached and pair-house. This typological strategy would retain social interest while reducing environmental impacts. The challenge is to find the right balance between density and appeal to maximize social and environmental implications.

Regarding construction techniques, LCA results from this investigation and precursor studies highlight the significance of construction material selection in building sustainability. In all case studies, steel reinforced concrete was selected as the main building component, highlighting that steel-reinforced concrete is the predominant structural material for housing in the village. This trend in Grindavik reflects broader preferences for structural concrete in Iceland generally. Alongside this general prevalence of structural concrete, recently many new projects of significant scale have used timber as the main structural material.

Reinforced concrete is commonly thought to be a material with a

higher environmental impact than wood. This assertion is sometimes justified in a simplistic manner by comparing the environmental impact per kilogram of reinforced concrete and timber in Iceland. For example, for lifecycle phases A1-A4, cross-laminated panels have an approximately three times lower GWP than reinforced concrete.

However, other factors than GWP per unit volume are more pertinent in determining environmental impact of materials such as timber and concrete.¹

The first factor is the topology of structural element – i.e. how well they are dimensioned and shaped to serve their purpose and make efficient use of material.²

The second factor is the choice of construction technique. Modular construction can shorten the construction time and reduce energy consumption during that phase, as well as facilitate the re-use of elements.³ Re-useable building components can have a longer

1 PURNELL, Phil, "Material Nature versus Structural Nurture: The Embodied Carbon of Fundamental Structural Elements", 2012, p. 454
2 ibid, p. 454
3 LEHNE, Johanna, PRESTON, Felix, *Making Concrete Change: Innovation in Low-carbon*

lifetime, therefore, considerably decreasing the embodied carbon of present and future buildings using them.¹

The third factor concerns other environmental impacts than GWP on ecosystems. Let us take the example of wood.² Some low-quality wood materials are dangerous to human health (contain toxic agents) and to ecosystems (acidification and eutrophication).³ Furthermore, forests' carbon storing properties should be guaranteed when producing wood.⁴ Converting high-capacity CO² storage forests to short rotation plantations to increase wood production could, in the long-term, lead to more CO² release in the atmosphere.⁵

There exist many different construction materials and it is impossible to say that one is better than another for all applications. Instead of focusing on material choice to reduce embodied carbon, emphasis

should be set on understanding the local environmental and economical context to propose adapted site-specific solutions.

Beyond these additional factors that affect the environmental impact of construction materials and beyond theoretical GWP data, other factors are relevant to broader sustainability of particular materials.

As explained earlier, there is already a strong local culture of using reinforced concrete in Grindavik. This current widespread use of concrete entails significant investments in skills and training, supply chains and production facilities for this material. This includes employment, skills and livelihoods associated with it. The considerable amounts of job connected to it should also not be forgotten. In this context, it is more appropriate for us to define ways of reducing the environmental impact of concrete rather than suggesting replacing it with another material.

Cement and Concrete, 2018, p. 73

1 HOXHA, Endrit, FIVET, Corentin, "Environmental Benefits when Reusing Load-Bearing Components in Office Buildings: A Case Study", 2018, p. 5

2 GUARDIGLI, Luca, "Assessing the Environmental Impact of Reinforced Concrete and Wood Building: A Case Study with LCA Application", 2014, p. 430

3 *ibid*

4 HARMON, Mark, "Have Product Substitution Carbon Benefits Been Overestimated? A Sensitivity Analysis of Key Assumptions", 2019, p. 7

5 *ibid*

Besides, any attempt at suddenly changing industrial norms would likely be rejected by industrial stakeholders and, thus, be ineffective.

To summarize, we identified three areas of opportunity for reducing the environmental impact of housing projects in Grindavik:

1. Adapted housing typologies
2. Better land-use
3. Better use of concrete

Our focus in the beginning of this chapter was on the environmental impact of housing, we will now consider how the paths we proposed fit from the perspective of the industry's stakeholders, as well as social and economic development. To accomplish this, we propose to use two graphs for each proposition. The first represents how relevant to each stakeholder each proposal is. The second shows the impact that each proposal could have in the various interest categories we established for the three pillars of sustainable development in Grindavik. The scale used is from 1 (insignificant impact) to 10 (important impact).

As a reminder, we established that the stakeholders of the building and construction industry are:

- building materials firms
- plant hire firms
- contracting firms
- consultancy firms
- developers
- facility maintenance firms
- building owners
- end-users

We determined the following interest areas for social development:

- Heritage
- Connection to nature
- Comfort and safety
- Social interaction
- Ownership

And for economic development:

- local employment for different skill and academical levels
- knowledge creation and conservation

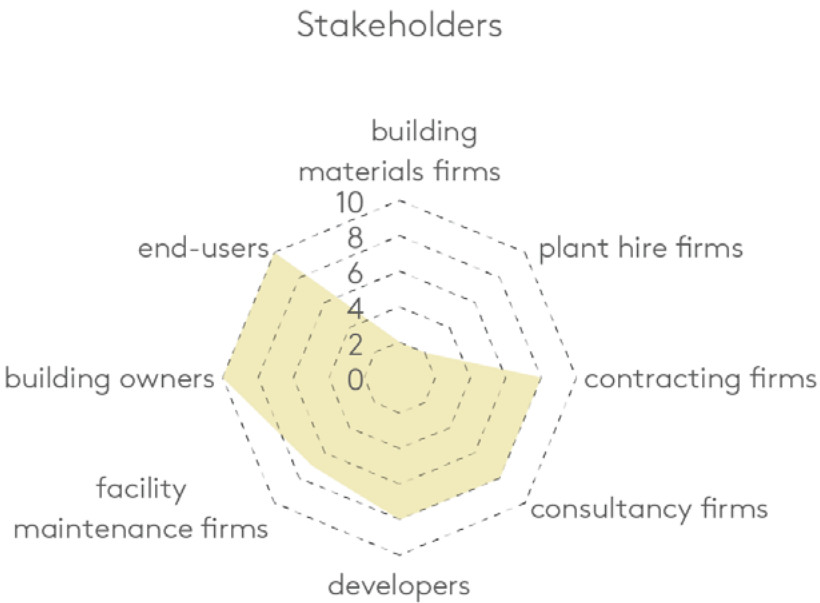
The first suggestion we made is to adapt housing typologies. The older parts of the village were planned for detached and pair or row housing with only a few multistorey housing units. The newest plan of expansion containing 382 units is considerably different. 71% of housing units will be in multi-storey apartment buildings, 19% in pair or row houses and 10% in detached houses. It can be said that this evolution is favorable to environmental preservation. However, it is not adapted to the culture of living and social standards in the village. It would have been preferable to have a better balance between multi-storey housing and pair or row housing, whilst keeping detached housing at a minimum.

Cultural preferences or simply put "culture" must always be considered in sustainable development. Culture is the "bedrock of society".¹ It comprises our values and ambitions and the way in which we develop, communicate, and receive those.² It is how we do things as a society. Every step taken in sustainable development must be taken in full awareness of the context and the "way of life" of local society.

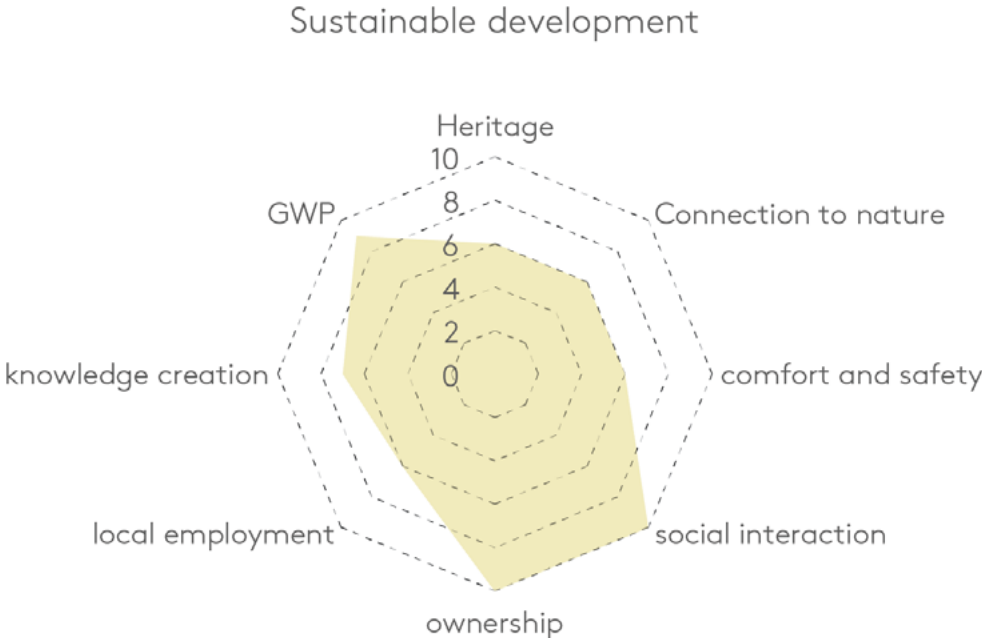
1 HAWKES, Jon, "The Fourth Pillar of Sustainability: Culture's Essential Role in Public Planning", 2001, p. 4
2 ibid

Not doing so, can simply render all actions useless for the simple reason that the local people/society will not connect to them. As explained, this should be used to establish relevant typologies for Grindavik, but also for all other proposals.

We also note that the different types of housing are rigorously separated in the new neighborhood proposal. Mixing up the different types of housing on the same plot could create more diversity in ownership, better social interaction, and culturally attractive housing.



Adapted housing typologies - how relevant the proposition is to stakeholders (above) and the potential impact of the proposition upon specific interest categories (below)



Our second suggestion is to make better use of land. This suggestion goes hand in hand with the types of typologies proposed. However, it also addresses how housing units are integrated in the landscape. In the past, the town was planned with little consideration for the natural landscape and topography it was taking over.

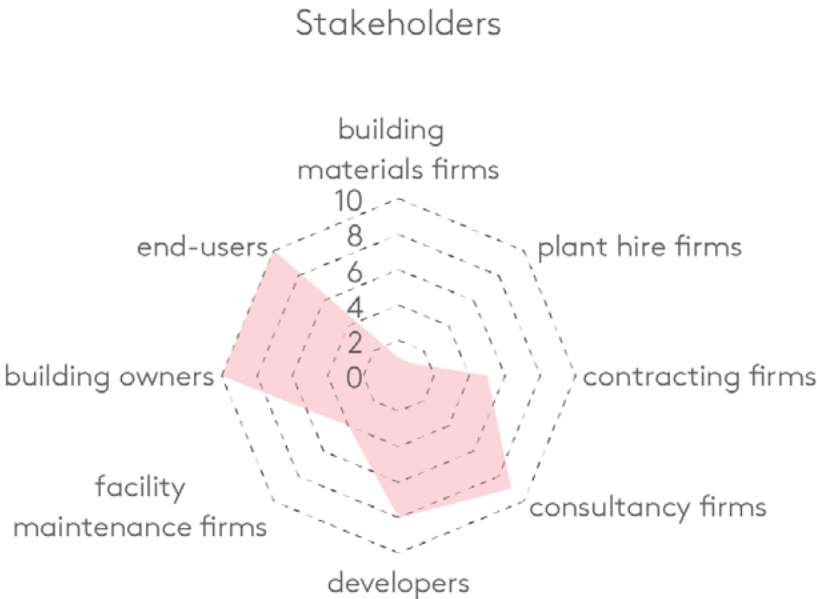
As a result, many construction plots have an aggregate cushion of between three and four meters to ensure that the houses are at the same level as the street. There are several disadvantages to such an approach.

The first being that connection to the surrounding environment is lost. There is no visual connection to the ocean, little connection to the surrounding mountains and hills, and no sign of the lava fields that are an icon of this part of Iceland.

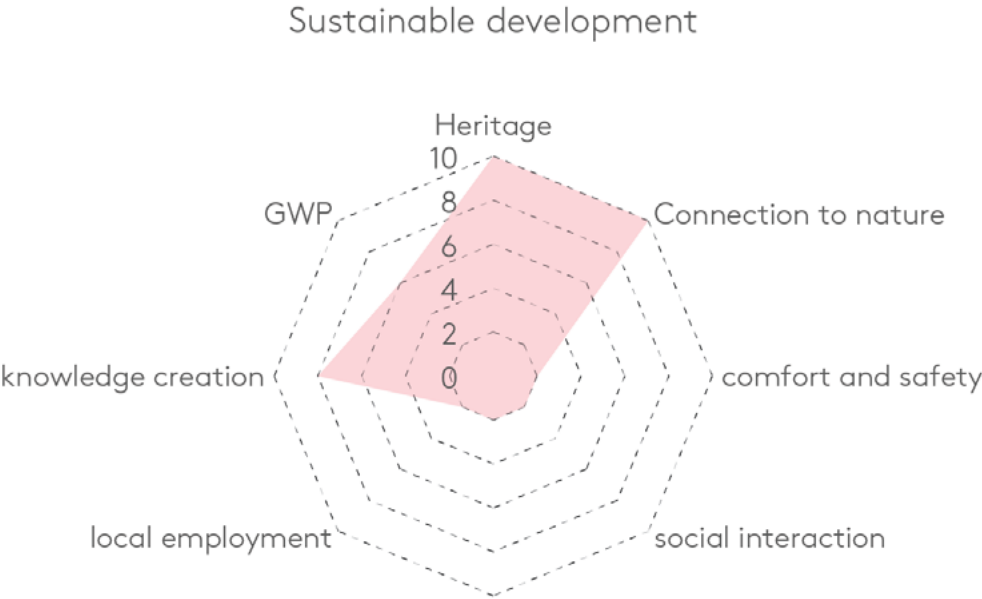
The second disadvantage is that bigger aggregate cushions means more expensive houses, more production carbon emissions, and more use of raw materials.

Instead of placing housing units in a "traditional" way using an

orthogonal grid, we suggest analyzing the topography and landscape and placing buildings in a way that minimizes land disturbance, raw material usage, and waste, but maximizes access to nature and view.



Better land use - how relevant the proposition is to stakeholders (above) and the potential impact of the proposition upon specific interest categories (below)



The third suggestion is to make better use of reinforced concrete. We mentioned optimizing the topology of structural elements, building with prefabricated and reusable elements. We will add here reducing the amount of Portland clinker in the concrete mix.

Clinker is the main component of cement and can be replaced by other more carbon efficient materials such as fly ash, granulated blast-furnace slag, limestone or pozzolans.¹ Such substitutions can potentially reduce carbon emissions from production of concrete by over 60%.² One of the biggest concrete companies in Iceland is already selling an environmentally friendlier concrete and plans on continuing research to provide "greener" concrete using local substitutes for Portland clinker.

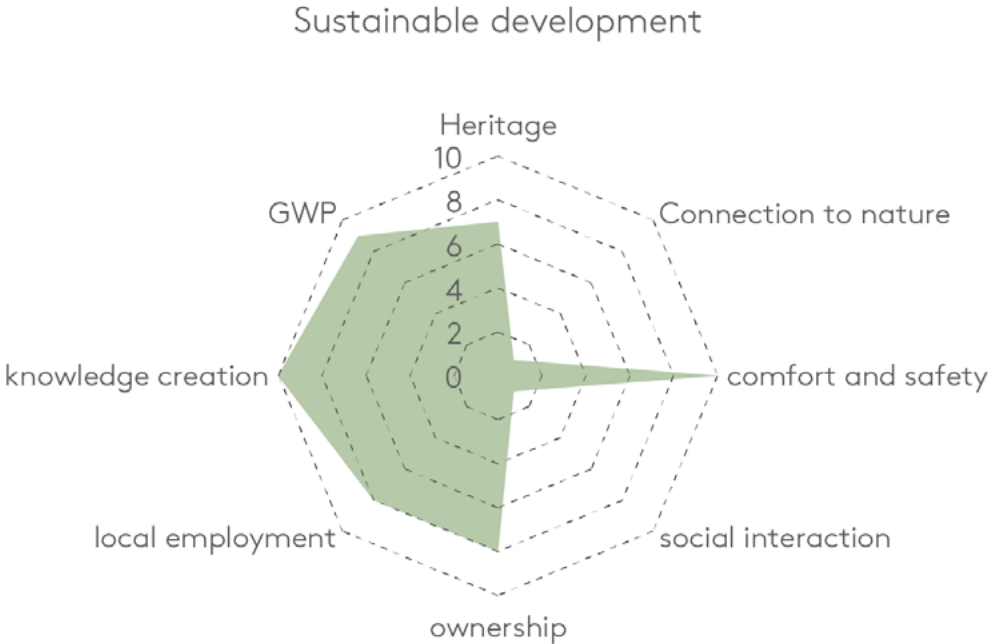
As explained earlier, buildings are rarely demolished in Grindavik. This reduces in some way the relevance of re-usable building components in the village. However, the village is projected to grow steadily in the upcoming years, and this could change current practices. We suggest

focusing proposals for improving the use of reinforced concrete on the optimization of topologies and structural parameters, whilst still offering the possibility for re-use by using prefabricated elements.

1 LEHNE, Johanna, PRESTON, Felix, *Making Concrete Change: Innovation in Low-carbon Cement and Concrete*, 2018, p. 8
2 *ibid*, p. 9



Better use of concrete - how relevant the proposition is to stakeholders (above) and the potential impact of the proposition upon specific interest categories (below)



This further analysis of our proposals highlights interconnections between different dimensions of sustainability and different stakeholders, and the ways in which global principles must be adapted to local conditions to develop effective solutions.

For example, typological strategies cannot be determined only by relative GWP, but rather, must account for cultural preferences. Material strategies must consider carbon emissions alongside local economic development considerations. It reveals the need to apply a comprehensive approach when addressing issues of sustainable development to avoid trade-offs.

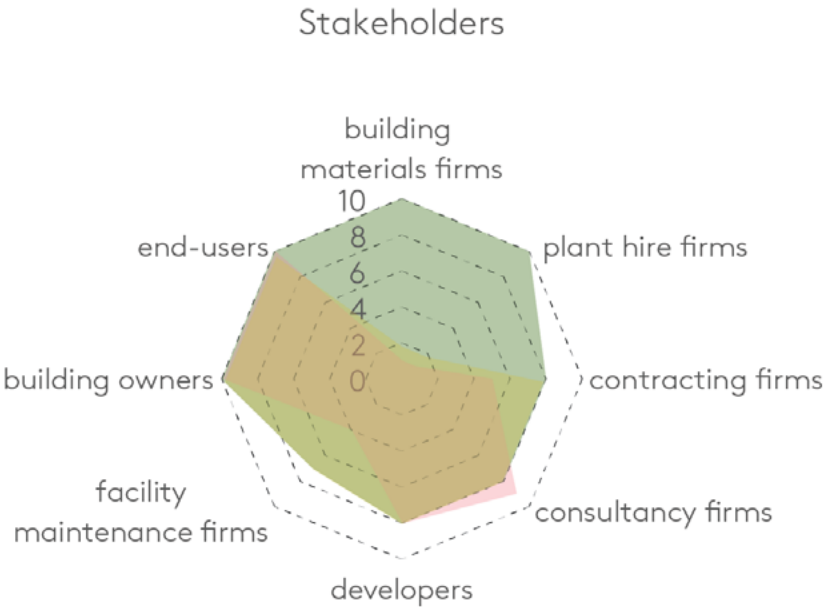
We see that each proposal succeeds at addressing only some aspects of sustainable development issues. In a similar fashion, different strategies affect different stakeholders in different ways. But, when superposing all our graphs, we see that the fusion of our three proposals touches all stakeholders and impacts on all defined fields of sustainable development.

Our proposals are an overview, or a direction, to use for further research and action. More work would be

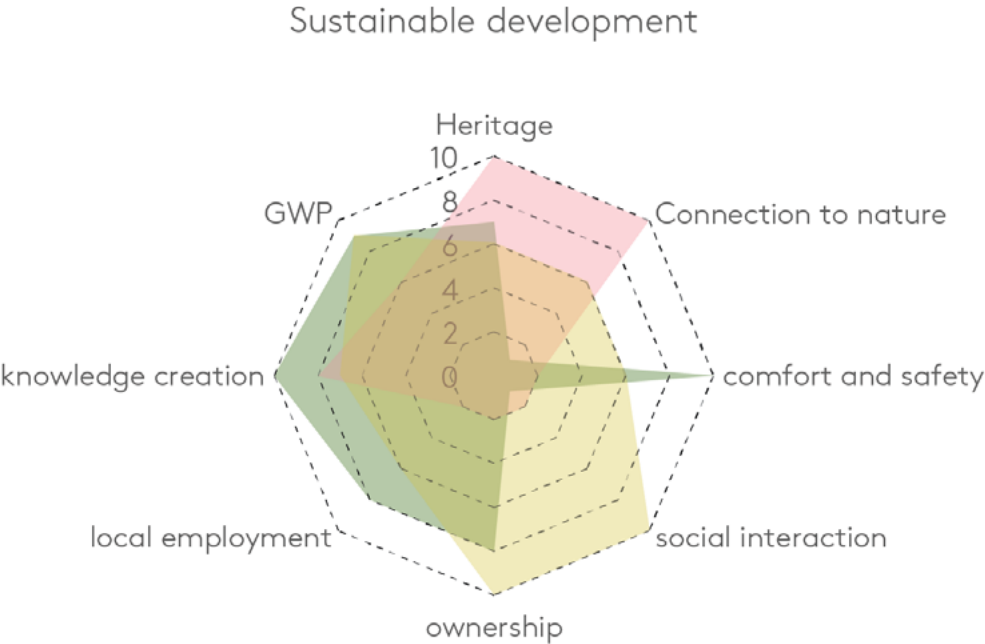
needed to define those issues more precisely and gather supplementary information on various impacts, but who should do this?

It is unreasonable to expect that one stakeholder can define all issues, understand the various interests at stake, represent each of them fairly, and reach conclusive and balanced solutions on his own. The interconnection of various aspects of building sustainability and their necessary modification to suit local contexts entails a collaboration between all involved parties to decide in consensus what the goal of a project should be and which areas should receive more attention than others. This discussion can be mediated by a stakeholder, well informed of the ins and outs of sustainable development.

The leading challenge for this role of "mediator" is to ensure that all parties are aware of the other parties' interests and that it is understood that when decisions are taken, there will potentially be trade-offs, but the main goal should always be to reach a well-balanced project in terms of sustainable development. The architect fits this role well because of the generalist



Mixture of all proposals - how relevant the proposition is to stakeholders (above) and the potential impact of the proposition upon specific interest categories (below)



nature of his/her profession. The function of architectural design is highly integrative, incorporating the knowledge, expertise and priorities of various building disciplines and other stakeholders in building development, including financiers, materials producers, etc. Considering the various interconnected dimension and implications of sustainable development, architects are well-placed to manage the process of sustainable building.

However, this role could most certainly be, and is already, filled by other stakeholders or a combination of stakeholders. In Iceland, this position is often shared by architectural and engineering firms. Sometimes there is only the engineering firm, depending on the size of the project and the owner's decisions. Other times, it is solely covered by the homeowner. Either way, a comprehensive approach as described above has, to our knowledge, never been applied to an architectural design in Iceland.

In our case, of a hypothetical housing project in Grindavik, the architect will endorse the role of "leader". The objectives of this new housing scheme will be to provide alternatives

to the current construction methods, and thus reduce the environmental impact of housing in a way that contributes to sustainable development in the village.

CONCLUSION

The primary aim of this investigation was to apply global considerations regarding sustainable development in relation to building and construction - with an emphasis on environmental preservation - to the local context of Grindavik. This application of global concepts to local conditions was undertaken in support for two specific objectives.

First, the investigation is sought to draw attention to implications of housing design and construction for environmental preservation and sustainable development in the local context by presenting them in a manner that can effectively engage all stakeholders in local housing development.

Second, the investigation is intended to serve as a basis for architectural

strategies to guide a hypothetical local housing project.

LCA of four completed housing projects in the village supported the identification of three areas of opportunity to achieve our goals of impact reduction, which, in-turn, underpin architectural strategies, namely:

1. Adapted housing typologies that accommodate both social/market preferences lower-density detached housing and lower environmental impacts associated with higher-density typologies
2. Implementing buildings better in their landscape to minimize construction waste and improve connection to the surrounding

nature.

3. Improving the use of reinforced concrete by improving the topology of structural elements, building with prefabricated and reusable elements, and using cements that have low environmental impact.

The implications of each of these strategies has been demonstrated in relation to the case of a housing project in Grindavik. We noted the highly interconnected nature of sustainable development and the need for a "mediator" that informs and facilitates a dialogue between all stakeholders with the aim of developing effective and comprehensive actions. This role can be endorsed by various actors of the industry, but we showed how architects' integrative approach to design is well adapted to lead projects of sustainable building.

Furthermore, analyzing how each proposal affects different stakeholders and predefined points of interest in sustainable development stressed the need to simultaneously use different strategies to address the issue of sustainable building in a thorough manner.

Another goal of this report was to develop a process that could be replicated in other villages or towns in Iceland to establish sustainable building strategies. The approach we propose can be divided in three parts:

1. Analyze the local culture, economy, nature, and construction customs.
2. Establish what themes in each dimension of sustainable development (social and economic development, environmental preservation) should be addressed and use tools such as LCA to assess their status.
3. Define strategies of actions that are adapted to the local context.

This methodology is based on the principles of taking global concepts and ideas, establishing their relevance for local context, measuring them, and proposing actions to improve them. It highlights the need of constantly zooming in and out of the location and considering the project in a local but also global scale. The title of our work

reflects this: Think global, build local.

As I reach the end of this report, it is clear to me that even though there already exists much literature on sustainable development, more work must be done to measure site-specific variables and propose realistic quantifiable solutions. My feeling is that too often, when speaking of sustainable development, architects only address a few issues of environmental preservation. All-encompassing approaches, like the one proposed in this report, are complex but necessary to guarantee well-informed decisions. I believe that this view of sustainable building will help stakeholders understand the true value and potential of this way forward.

Applying well-designed solutions does not only contribute to a better environment but can also create more jobs, knowledge, and social interactions to namebut a few benefits. I believe that change will not only be created by local authorities' policy making but also, and more importantly, by the recognition of all stakeholders of the added common gains that sustainable development represents.

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