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Urban-farm eco-communities

a proposal for a new human settlement typology for resolving the global environmental crisis

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Urban-farm eco-communities - a proposal for a new human settlement typology for resolving the global environmental crisis by Tom Becker

Abstract

In this thesis project I try to envision what could and, in my mind, should become the future path for contemporary architecture in the 21st century. From the study of the environmental issues which humanity is facing and which will become ever more serious and urgent to resolve, it is becoming clear that humanity should undergo a fundamental structural revolution in the ways it procures and produces it's food and goods and in the way it shares them (i.e. economic activity).
This fundamental revolution will be made possible by the application of different ecological practices and by the adoption of a new design philosophy for society. This new design philosophy will encourage the creation of new holistic human settlement typology, that is urban-farm eco-communities. This new typology will integrate the three prevalent settlement typologies of the 20th century, i.e. cities, suburubs and countryside, each with its own associated function: business, living and food cultivation, into a one holistic identity which merges all these functions together. This integration is necessary for the optimal application of solutions based on ecological principles, as well as for the increase of resilience and the reduction of waste and energy consumed for unnecessary transports. This new typology will change the functioning of society as well as the role of architecture from a discipline concentrated largely on responding to the functional and aesthetic needs of the real-estate market (creation of marketable buildings which respond to specific functions and attractive images) into a discipline concentrated more on the design of natural systems adapted to human needs without disturbing ecological systems both in the local and in the global scale.
The first chapter of the thesis analyses in depth the different environmental threats and their implications, and tries to point out how each of the major human activities, i.e. industrial agriculture, industry, transport and construction, are responsible for the environmental crisis we are experiencing. In the first section, the topic of fossil fuels is explored. I try to show how the amazing technological, social and economic achievements of 20th century modern society would not have been made possible if not for the discovery of fossil fuels, which are a 'once-in-a-lifetime' gift of an extremely efficient and cheap energy resource. This resource is running out at an increasing speed, and it's consumption is also causing large parts of the environmental problems we are witnessing today (such as pollution and climate change). The first chapter tries to show how currently available renewable energy resources would not be able to supply the same amounts of energy of fossil fuels due to their low efficiency and therefore high costs. Therefore, along with the shift to renewable and clean energy resources, the need for a drastic reduction of the energy demand of contemporary society is paramount. In the second section of the first chapter, the negative environmental impacts of each of the main human activities, i.e. industrial agriculture, industry, transports and construction, are analysed to depth. In this section i demonstrate how the mixture of unsustainable practices, an utter dependence on fossil fuels and chemicals, and the sharp division into sectors of each activity made these activities extremely harmful for the environment and therefore for the future of the planet. From this section the need for integrated holistic systems which utilize practices based on the ecological and cyclical principals of nature becomes evident.
The second chapter of the thesis explores the different solutions for the environmental crisis and the different alternatives for the harmful human activities presented above. A part from specific sustainable practices which our society will have to adopt in the different activity areas, from the study of the different solutions a new way of building society emerges which is greatly influenced by the ecological design philosophy of Permaculture and by the ecological principles which permeate sustainable agricultural practices such as Aquaponics. In this chapter, I try to show how by the adoption of the principles of ecology, and by their application into the design of our living environment and agricultural economic activities (basically the strategies of Permaculture and other organic farming methods) we can create new human settlements which can function without the use of fossil fuels and with minimal negative impacts on the natural environment. From the study of these new sustainable practices and of the ecological approach to design, a vision emerges of a new holistic human settlement typology which could become prevalent in the 21st century, and whose application on a large-scale could constitute a major contribution to the ecological revolution we will have to undergo.
The final chapter of the thesis depicts an example project i elaborated to be situated in the area of the ex Innse Lambretta factory in the eastern periphery of Milan. The idea is to integrate the different solutions explored in the thesis into an architectonic example of a self-sufficient urban-farm eco-community which makes use of the landscape, as well as of the disused warehouses of the abandoned factory for intensive biological agricultural production as well as for other green industries and commercial activities.

Communità agricole ecologiche urbane - una proposta per una nuova tipologia di insediamenti per la risoluzione della crisi ambientale. Tom Becker

Abstract

In questa tesi ho cercato di concepire un nuovo modo ecologico di insediarsi che potrebbe diventare protagonista del percorso futuro dell'architettura contemporanea nel 21esimo secolo. Dallo studio delle problematiche ambientali che l'umanità sta affrontando, la cui risoluzione diventerà sempre più urgente, si raggiunge alla conclusione che l'umanità dovrà subire una rivoluzione strutturale nel modo in cui procura e produce il cibo e i suoi beni e nel modo in cui li distribuisce (attività economica).
Questa rivoluzione fondamentale sarebbe garantita dall'applicazione di diverse pratiche ecologiche e dall'adozione di una nuova filosofia di progettazione insediativa. Questa nuova filosofia di progettazione conduce alla creazione di una nuova tipologia di insediamenti olistici - le comunità agricole ecologiche urbane. Questa tipologia integrerà le tre principali tipologie insediative del 900', cioè la città, il suburbano, e la campagna, ciascuna con la propria funzione associata ad essa: il lavoro, l'abitare e la coltivazione di cibo. Le tre tipologie saranno integrate in una tipologia olistica che fonde le diverse funzioni in un sistema unico. Questa integrazione è necessaria per l'ottimale applicazione delle soluzioni basate sui principi dell'ecologia, che esploro nel secondo capitolo di questa tesi, e per l'aumento della resilienza che costituisce anche la riduzione degli sprechi eccessivi nei trasporti evitabili tra le origini della produzione agricola e industriale (campagna) e i punti del consumo (città).Questa nuova tipologia cambierà il funzionamento della società e del ruolo dell'architettura. L'accento dell'architettura passerà dalle esigenze del mercato immobiliare (funzioni specifiche e esigenze estetiche di commerciabilità) alla progettazione di sistemi ecologici in grado di rispondere alle esigenze umane senza compromettere la salute dell'ambiente e del pianeta.
Il primo capitolo si occupa dell'analisi approfondita delle diverse minacce ambientali e delle loro implicazioni future, e cerca di dimostrare come ciascuna delle principali attività umane (agricoltura industriale, industrie, trasporti, ed edilizia) è altamente responsabile della crisi ambientale che stiamo subendo.
La prima sezione del primo capitolo si occupa della tematica dei combustibili fossili. Cerco di dimostrare come le incredibili conquiste tecnologiche, economiche e sociali del 20esimo secolo non sarebbero state possibili senza la scoperta dei combustibili fossili - un 'regalo' di una fonte di energia estremamente abbondante, efficiente e perciò economica, che non si ripeterà più. Queste risorse si stanno esaurendo con un ritmo crescente e, inoltre, il loro consumo genera gran parte degli altri problemi ambientali principali che stiamo affrontando, quali il cambiamento climatico e l'inquinamento della terra. Nel primo capitolo cerco di dimostrare come le fonti di energia rinnovabile oggigiorno disponibili non saranno in grado di fornire le stesse quantità di energia colossali forniteci dai combustibili fossili, a causa della loro bassa efficienza e alti costi (gli alti costi derivano dalla bassa efficienza e bassa densità energetica). Perciò, insieme al cambio di fonti di energia derivanti dai combustibili fossili in fonti di energia rinnovabile e 'pulita', ci sarà un ulteriore bisogno di ridurre drasticamente la domanda energetica della nostra società.
La seconda sezione del primo capitolo si occupa dell'analisi dei negativi impatti ambientali di ciascuna delle principali attività umane: agricoltura industriale, industria, trasporti, ed edilizia. In questa sezione cerco di dimostrare come la combinazione di pratiche non sostenibili, la dipendenza assoluta dai combustibili fossili e chimici, e la settorializzazione delle attività umane ha reso queste attività estremamente dannose per l'ambiente e per la salute del pianeta. La conclusione di questa sezione è il crescente bisogno di sistemi olistici integrati che utilizzino pratiche basate sui principi ciclici della natura.
Il secondo capitolo esplora le diverse soluzioni per la crisi ambientale e diverse alternative alle attività umane non sostenibili. Oltre a specifiche pratiche sostenibili che la nostra società dovrà adottare nelle diverse aree di attività umane (agricoltura, industria, trasporti e edilizia), lo studio delle diverse soluzioni ecologiche fa nascere una visione per un nuovo modo sistemico di fare società, altamente influenzato dalla filosofia di progettazione della Permacultura e dai principi ecologici che permeano le diverse soluzioni sistemici quali i sistemi di giardinaggio aquaponico. Questa filosofia di progettazione ecologica fa nascere l'idea di una nuova tipologia insediativa architettonica, che secondo me, potrà costituire una parte consistente del cambiamento ecologico che la nostra società dovrà subire nel 21esimo secolo.
L'ultimo capitolo della tesi descrive un progetto esemplificativo elaborato dall'autore nell'area della ex-fabbrica Innse (Lambretta) a Lambrate, Milano. L'idea è quella di integrare le diverse soluzioni esplorate precedentemente in un esempio di una nuova architettura insediativa di una comunità autosufficiente di eco-agricoltori urbani che fa uso del paesaggio agricolo tipico della periferia est milanese e dei preesistenti capannoni industriali per la creazione di un centro residenziale-produttivo che integri produzione bioagricola intensiva, industrie verdi a piccola scala e attività commerciali.

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Introduction

The 21st century will present to architects the a myriad of interesting challenges, more than ever before in history. It will be a time in history which could permit architects to regain their lost role of social leaders they once were due to the variety of problems which humanity will confront; problems that should be dealt with largely through architectural means.
The 20th century was the age of technological and social innovation, economic global expansion and of the advent of instant global communication. In the 20th century humanity witnessed the greatest revolutions and technological miracles in its history, as well as the greatest and most horrifying wars.
Democracy and western liberal values (human rights, freedom of speech, etc.) prevailed over the religious, fascist, monarchic and oligarchic governmental systems of earlier times and brought the global society (mainly the western part but not solely) to it's noblest and most enlightened state in history.
The progresses in science, engineering and medicine extended life expectancy to unprecedented levels and improved the quality of life for people around the globe significantly (together with the social revolutions that accompanied them).
All these technological miracles and social changes were made possible by the industrial revolution, which liberated people from manual labor and paved the way to the advent of the capitalist consumer society.

However, global industrialization brought with it all of the negative phenomenons which humanity will have to confront in the 21st century in order to survive and to prevent colossal disasters.
In the first place, the technological industrial revolution wouldn't have been made possible without the discovery of fossil fuels (mainly oil and gas) which supplied humanity with unprecedented amounts of extremely cheap energy. These non-renewable energy resources are depleting in an increasing rate and currently there is no other apparent viable energy alternative which will be able to supply the same quantities of energy consumed by contemporary industrial society once we'll run out of them. Additionaly, the industrialization of the planet brings with it the destruction of the natural environment and puts at risk its ability to sustain life in the future.
Never before in history have humanity witnessed so much destruction of the natural environment, so much so that scientists consider our time period as one of the great mass extinctions of living species in our planet's history.[1] The threats of climate change and the disappearance of the natural resources that sustain us (water, forests, minerals, etc,.) constitute further manifestations of the ecological damage done by our actions and impose further challenges with which humanity will have to deal in the current century.

Even though most of the civilised world is aware of the environmental destruction caused by modern society and the dangers it embodies for our planet's future (and hence for our children's future), it seems that the changes done are too slow and too few in order to make a significant shift in the major tendencies observed globally.
The global economy, that functions according to the dictates of the capitalist economic ideology, doesn't seem to be able to address the environmental problems we are facing, and as if that was not enough, recent decades have shown an increasing and worrying gap between the rich and the poor within the western countries as well as between the richer and poorer countries across the globe.[2] The proliferation and the propagation of monetary debt across the global economy as well as the increasing demand for goods and energy (due to population growth and development of former third world economies such as China and India) puts further strain on natural resources and on the planet in general and prevents governments, organizations and individuals, who are too busy with their financial struggles, from having the adequate economic resources for combating and resolving the environmental crisis.
Nevertheless, in recent decades countless solutions have been developed in different fields (agriculture, economy, ecological building materials and practices, renewable energy technologies, etc.) for combating the environmental crisis. Numerous communities around the globe have adopted sustainable lifestyles and developed sustainable solutions for food, energy and shelter.
The study of those different solutions and practices, which are all based on the principles of ecology, reveals a deep necessity, not only for a change in the way modern society grows its food, manufectures its products, harvests its energy and natural resources and distributes its wealth, but also for a change in the way society functions as a whole.
In the 21st century, modern society will have to scale down it's operations, shifting from an urban consumer society reliant on heavy industries and global markets into a more rural and holistic society that integrates urban and rural life together and that is more reliant on locally produced food and goods, local markets, local self-sufficient economies and lo-tech intermediate technologies.
21st century contemporary society will have to adapt to a world of scarse energy and will have to redirect its knowledge

and creativity towards smaller scale lo-tech green solutions (high tech solutions will probably be too energy expensive and costly) in order to survive and thrive in the future.
Here is where, in my opinion, the role of the architect as a social leader comes back into play. Architects, rather than operating as mere desigers of good looking buildings, should aspire to become major protagonists in the transition our society will undergo. Architects, as built environment planners, will dictate the forms and the functioning of the cities and settlements of the future.
The building industry is one of the main contributors to the problems of climate change and one of the main consumers of non-renewable energy - an additional reason for architects to become one of the leading figures in the changes of 21st century contemporary society.

In this thesis work i will develop a new project for the renovation and restucturing of the former Lambretta factories in the eastern periphery of Milan. The goal is to create a sustainable community of urban farmers, using the existing massive abandoned structures of the factories for the creation of a new hub and production center of biointensive agriculture and to design the residential neighborhood of the community, integrating it with the milanese context and making use of the specific geographical and natural features of the site in order to create a new example of a sustainable human settlement for the future.

Before describing the project i will firstly begin with an investigation of the major and most critical environmental and economic problems contemporary society is facing, and the most important solutions, in my mind, for these problems which could be integrated in the project.

The first chapter will discuss, in the first section, the main ecological problems our society is facing, i.e. climate change, peak oil and resource depletion, and will try to elaborate on their main causes and on the steps needed to be taken in the future in order to resolve these issues.
In the second section, I will try to show how two of the major human enterprises, that is the food industry and the building industry, are responsible for most of the ecological damage being done throughout the world and then try to explain what will probably be the steps our society will have to take in order to correct these issues.

The second chapter will attend to various solutions from different fields for the problems described above.
I will shortly describe two agricultural methods and philosophies, employed by organic farmers around the world, that could provide the answer for the agricultural crisis contemporary society is affronting. That is, Permaculture, a design philosophy for sustainable self-sufficient human settlements developed in Australia in the 1970s and successfully used throughout the world by organic farmers, as well as Acquaponics which is a method of sustainably combining cultivation of fish with container gardening.
I will briefly discuss some of the main renewable energy resources available nowdays and i will mainly focus on the systems which could be integrated into the project.
Lastly, i will draw a brief overview of existing sustainable building materials, practices and methods with a focus on those employed in the urban-farm community project.

The first part of the third chapter will attend to the project's site. I will try to give a concise description of the site's urban history, main geographical features and importance in terms of its strategic position within milans peripherys urban network. I will focus on the sites previous functions and on the processes which lead it to its current state and try to present its inherent potentialities in terms of contribution to milans peripherys urban texture, connectivity and spatiality.

The second part of the third chapter will present the verbal description of the project. I will start with the explanation of the project's intents and the vision that guides it. Subsequently, i will list the main agricultural and energy production systems that will be integrated into the project. I will describe the intended different functions and their interrelations and try to show how this project attempts to respond to the various challenges presented in previous chapters.

My hope is to establish an example for a new kind of urban development typology which breaks from the traditional city-suburban-rural division of 20th century modern society and which will succeed in creating the right environment for a transition into a low energy sustainable future. This chapter will try to explain how this project works to reach this goal.
Finally, the last part of the thesis will contain the projects graphic elaborations.

Chapter 1 - The Environmental Crisis and Peak Oil - causes and implications

As mentioned earlier (and as we all know), in the 20th century humanity underwent the biggest technological and social revolutions in its history. Industrialisation brought with it mass production of goods which increasingly liberated large parts of the population from manual labour and drudgery, initially througout the western countries and subsequently extending to the rest of the world. The process of manufacturing consumption goods in factories extended afterwards to agriculture as well, around the middle of the 20th century, giving birth to industrial agriculture which utilizes machinery, in order to replace man and horse power, and chemicals for fertility and pest control.
During the second half of the 20th century, due to the triumph of democrary and liberal values, the capitalist economic ideology spread across the world. One of the main consequences of this fundamental change was the creation of an economy driven by the consumption of goods and accumulation of private property and wealth. Ownership of cars for transportation became prevalent around the world in parallel with the expansion and development of other forms of transportation fueled by large quantities of energy (aeroplanes, trains, etc.) and of other infrastructures such as electricity grids, telephone lines, etc. Mass production in factories and the industrialisation of agriculture and of the building industry were made possible, as mentioned earlier, by the huge quantities of energy supplied by fossil fuels and in turn created a new demand for huge quantities of energy. Therefore, a new cycle of energy consumption has been created: huge quantities of energy permitted the development of new technologies that in turn increased the demand for more energy.
On top of that, the capitalist economic model is based on competition and economic growth which is a further reason for the constant increasing demand in energy we have been seeing ever since.
During the second half of the 20th century, most of the world's largest economies went through a fundamnental paradigmatic shift from a keynesian economic model to neoliberalism as the main economic model for society. This shift entailed a change in the way governments intervened with and regulated the economy and the financial institutions and resulted in the stregthening of the financial sector and of its influence on the worlds economy. A shift that has led to the increasing gaps between the rich and the poor we are now witnessing created through the propagation of monetary debt througout the world economy.

All in all, the 20th century witnessed the creation of a new capitalist global society nurtured by high technologies which permit the creation of the infrastructures needed to sustain it (physical infrastructures and instant comunication systems). This society is reliant on non-renewable energy resources ,which are disappearing in an increasing rate, and on technologies and practices which destroy the natural environment and the possibility of our planet to sustain life in the future. The changes that are being done are too few and too slow mainly due to the global economic system which functions in contrast with the steps needed to be taken in order to solve the environmental and the energy crises.

In this chapter i will try to explain in detail the phenomenons, processes and mechanisms described above with references to the data and the facts behind them.

1.1. The energy crisis and oil depletion

Global energy consumption

A non-renewable resource (also called a finite resource) is a resource that does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time-frames. An example is carbon-based, organically-derived fuel. The original organic material, with the aid of heat and pressure, becomes a fuel such as oil or gas. Earth minerals and metal ores, fossil fuels (such as coal, petroleum, and natural gas), nuclear fuels, and groundwater in certain aquifers are all non-renewable resources.
Natural resources such as coal, petroleum (crude oil) and natural gas take thousands of years to form naturally and cannot be replaced as fast as they are being consumed.
The vast majority of the energy supplied and consumed in the world today comes from non-renewable resources, mainly fossil fuels. As we can see from the graph below (figure 1.1), created by the International Energy Agency, around a third of the energy consumed globally in 2008 came from oil, around a quarter of the energy came from coal, and around a fifth came from gas. In total, 81.2% of the energy consumed in 2008 came from these three resources, all of which are non-renewable and in risk of depletion in the next decades as i will show further ahead.
On top of that, the world's energy consumption is constantly increasing, with the biggest increase documented in the period between the years 2000 - 2008. The graph below (figure 1.2) shows the worlds energy consumption by resource from 1970 to 2010. In the graph the increase in the consumption of energy resources, and in particular of non-renewable resources, is evident.

Power source	TWh	%
Oil	48,204	33.5%
Coal	38,497	26.8%
Gas	30,134	20.9%
Nuclear	8,283	5.8%
Hydro	3,208	2.2%
Other RE*	15,284	10.6%
Others	241	0.2%
Total	**143,851**	**100%**

Source: IEA
* = solar, wind, geothermal and biofuels

Figure 1.1: World energy consumption by power source 2008[1]

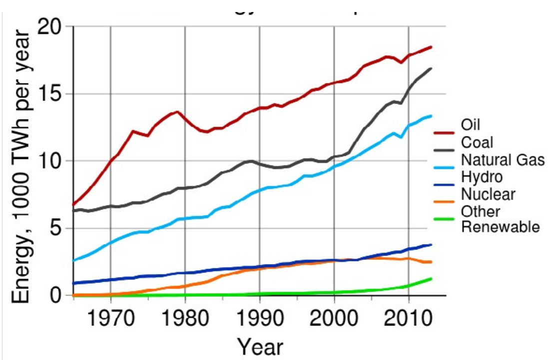

Figure 1.2: World energy consumption between 1970 and 2010 by source[2]

Depletion of non-renewable energy resources

Peak oil, an event based on M. King Hubbert's theory, is the point in time when the maximum rate of extraction of petroleum is reached, after which the rate of production is expected to enter terminal decline. Peak oil theory is based on the observed rise, peak, fall, and depletion of aggregate production rate in oil fields over time. Hubbert predicted that world oil production will peak sometime between 1993 - 2000 but, mostly due to the development of new production techniques and the exploitation of unconventional supplies, Hubbert's original predictions proved premature.[3]
Hubbert's original prediction that US Peak Oil would be in about 1970 was accurate though, as US average annual production peaked in 1970 at 9.6 million barrels per day.[4]

Some observers, such as petroleum industry experts Kenneth S. Deffeyes and Matthew Simmons, predict negative global economy implications following a post-peak production decline and oil price increase because of the high dependence of most modern industrial transport, agricultural, and industrial systems on the low cost and high availability of oil. Predictions vary greatly as to what exactly these negative effects would be.

Optimistic[3] estimations of peak production forecast the global decline will begin after 2020, and assume major investments in alternatives will occur before a crisis, without requiring major changes in the lifestyle of heavily oil-consuming nations. These models show the price of oil at first escalating and then retreating as other types of fuel and energy sources are used. Pessimistic predictions of future oil production made after 2007 stated either that the peak had already occurred[5][6]

[7][8], that oil production was on the cusp of the peak, or that it would occur shortly.[9][10]

The predictions for the peak production of gas also vary considerably. In 2002, R.W. Bentley (p. 189) predicted a global “decline in conventional gas production from about 2020.” [11]
In their March 2013 report, ‘Fossil and Nuclear Fuels - The Supply Outlook’, the Energy Watch Group predict global natural gas production ‘will peak around or even before the year 2020’. [12]
However, the US Energy Information Administration predicts that world gas production will continue to increase through 2030, with a total increase of almost 50%, and an average annual rate of increase of 1.6% per year, for the 2006-2030 period[13], largely due to the extraction of shale gas, one of the most polluting processes in the extraction of natural resources.[13]

The estimates for global peak coal extraction vary wildly. Many coal associations suggest the peak could occur in 200 years or more, while scholarly estimates predict the peak to occur as soon as the immediate future. Research in 2009 by the University of Newcastle in Australia concluded that global coal extraction could peak sometime between the present and 2048.[14] Collective projections generally predict that global peak coal extraction may occur sometime around 2025 at 30 percent above current extraction.[15][16]

As we can see from the data presented above, during the 21st century it is extremely likely that the worlds most important energy resources will deplete at some point.
From these findings two other major problems emerge: the extraction of fossil fuels is one of the most damaging activities for the environment and one of the main causes of climate change, as i will discuss further ahead. The second problem which emerges is the lack of any viable and renewable energy resource that is capable of supplying for the colossal energy demand created by fossil fuels as cheaply and as efficiently.
I will discuss this topic in the next paragraph.

Energy Returned on Energy Invested (EROEI) of different energy resources and the inefficiency of renewable energy resources in comparison with fossil fuels

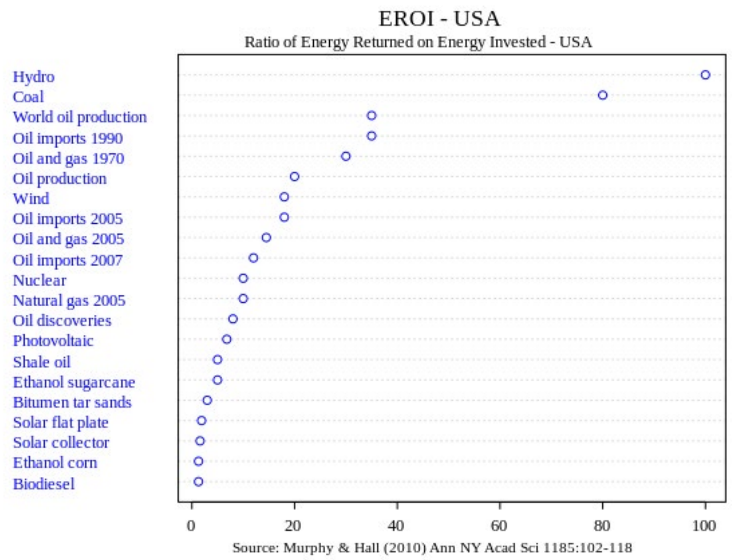

Figure 1.3: EROI — Ratio of Energy Returned on Energy Invested.

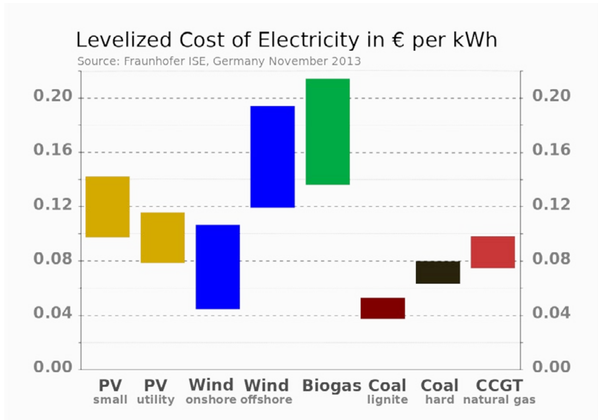

Figure 1.4: EROI — Comparison of the levelized cost of electricity for some newly built renewable and fossil-fuel based power stations in in euro per kWh (Germany, 2013)

In physics, energy economics and ecological energetics, energy returned on energy invested (EROEI or ERoEI); or energy return on investment (EROI), is the ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource.
The superiority of fossil fuels, as en energy resource, over most of the existing renewable energy resources found on the market, is mainly due to their relatively low EROEI ratio. This means that the amount of energy that’s needed to be invested in order to extract and produce oil, gas and coal is significantly lower than the amount earned, which makes these resources extremely profitable and economical.
The graph above (figure 1.3) shows the relative EROEI ratios for some of the most common non-renewable and renewable

energy resources found on the market.

The inefficiency of most renewable energy resources in comparison with fossil fuels (with the only exception of wind and hydro energy, which are suitable only to specific contexts), and therefore their high costs (figure 1.4), is one of the main reasons for their incapabilty of substituting fossil fuels in the future and for the need to scale down our energy consumptions by changing our lifestyles in a more sustainable manner (arguments which will be discussed in detail in later chapters).
Other factors included are huge land requirements (also a depleting natural resource which will be discussed later) for the production of biodiesels and huge space requirements and use of rare minerals (cadmium, tellurium and copper ,which are finite resources as well) for the creation and installation of photovolatic fields, etc. .Moreover, wind, solar and geothermal systems are heavily reliant on the natural characteristics of the specific sites in which they are located, rendering them practical only in limited parts of the planet (for example, photovoltaic systems are much more practical in countries closer to the equator with arid climates).

1.2. The Ecological Footprint

For more than 40 years, humanity's demand on nature has exceeded what our planet can replenish. Our Ecological Footprint - which measures the area (in hectares) required to supply the ecological goods and services we use outstrips our biocapacity - the land actually available to provide these goods and services.
Biocapacity acts as an ecological benchmark against which the Ecological Footprint can be compared. Both biocapacity and Ecological Footprint are expressed in a common unit called a global hectare (gha).
Humanity currently needs the regenerative capacity of 1.5 Earths to provide the ecological goods and services we use each year. This "overshoot" is possible because, for now, we can cut trees faster than they mature, harvest more fish than the oceans can replenish, or emit more carbon into the atmosphere than the forests and oceans can absorb. The sum of all human demands no longer fits within what nature can renew. The consequences are diminished resource stocks and waste accumulating faster than it can be absorbed or recycled, such as with the growing carbon concentration in the atmosphere. Technological innovation, such as increasing efficiency in the use of resources and energy, or improving ecosystem yields, could reduce overshoot - but may also bring trade-offs. For example, enhancing agricultural biocapacity through fertilizers and mechanization has required greater use of fossil fuels, leading to a larger carbon Footprint.

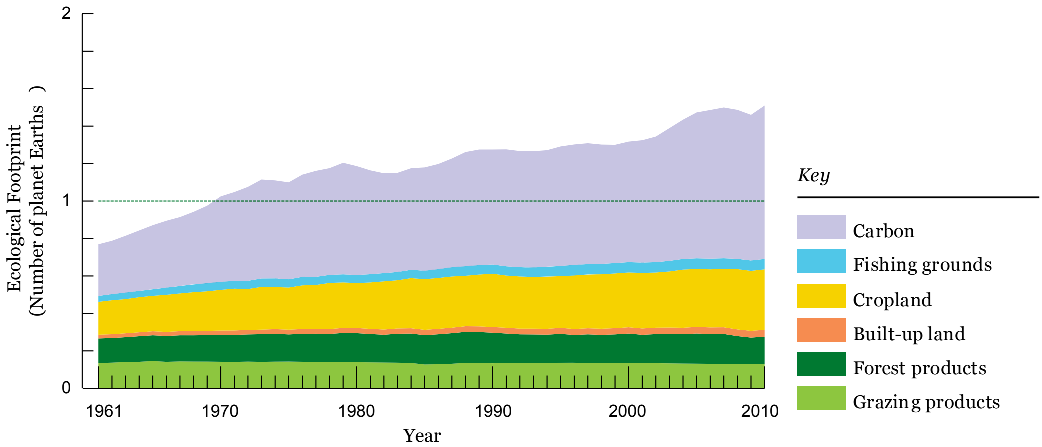

Figure 1.5: Global ecological footprint by component (1961 - 2010) (Global Footprint Network, 2014)

As shown in the graph above (figure 1.5), taken from the WWFs Living Planet Report 2014 (see bibliography),between the years 1961 and 2010 the global ecological footprint was in constant increase, with carbon constituting the largest single component (53 percent) in 2010, whereas the rest of the components of the ecological footprint are mainly a product of industrial agricultural practices around the world (a topic i will explore in the next section).

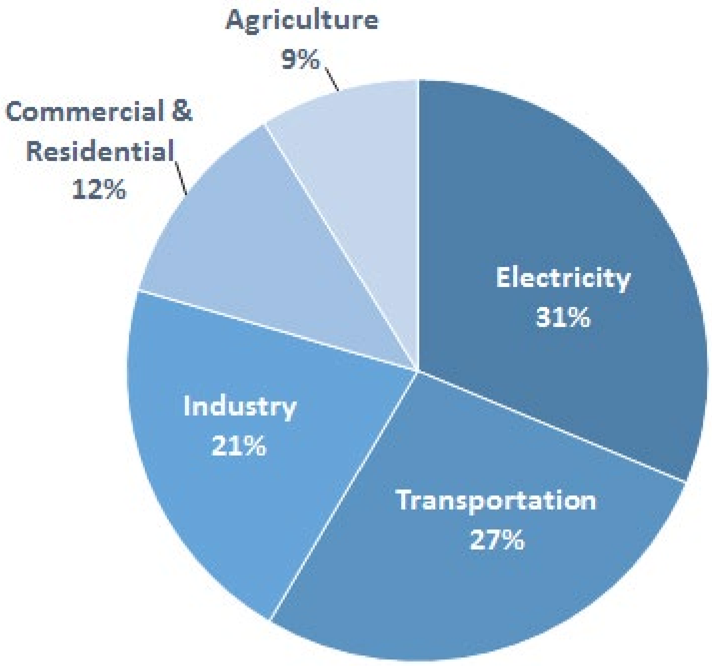

Figure 1.6: Total U.S. Greenhouse Gas Emissions by Economic Sector in 2013. Source: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013

In the United States for example, the country with seventh biggest carbon footprint on earth[17], The primary sources of greenhouse gas emissions are:

- Electricity production (31% of 2013 greenhouse gas emissions) - Electricity production generates the largest share of greenhouse gas emissions. Approximately 67% of the electricity in 2013 came from burning fossil fuels, mostly coal and natural gas.[18]
- Transportation (27% of 2013 greenhouse gas emissions) - Greenhouse gas emissions from transportation primarily come from burning fossil fuel for our cars, trucks, ships, trains, and planes. Over 90% of the fuel used for transportation is petroleum based, which includes gasoline and diesel.[19]
- Industry (21% of 2013 greenhouse gas emissions) - Greenhouse gas emissions from industry primarily come from burning fossil fuels for energy as well as greenhouse gas emissions from certain chemical reactions necessary to produce goods from raw materials.
- Commercial and Residential (12% of 2013 greenhouse gas emissions) - Greenhouse gas emissions from businesses and homes arise primarily from fossil fuels burned for heat, the use of certain products that contain greenhouse gases, and the handling of waste.
- Agriculture (9% of 2013 greenhouse gas emissions) - Greenhouse gas emissions from agriculture come from livestock such as cows, agricultural soils, and rice production.
- Land Use and Forestry (offset of 13% of 2013 greenhouse gas emissions) - Land areas can act as a sink (absorbing CO_2 from the atmosphere) or a source of greenhouse gas emissions. In the United States, since 1990, managed forests and other lands have absorbed more CO_2 from the atmosphere than they emit.

This data comes from the the U.S. Greenhouse Gas Inventory Report 1990 - 2013, published by the EPA.[20]

As we can see from the data above the vast majority of CO_2 and other greenhouse gas emmissions comes from the burning of fossil fuels. On top of the massive contribution to the global ecological footprint, greenhouse gases are the major cause of climate change. One of the most daunting challenges humanity will have to confront in the coming decades. This is the topic of the next section.

1.3. Climate Change - causes and implications

Climate change and global warming are scientific facts. There are multiple scientific proofs for the changes in the average world temperature and climate patterns over the last century. Some of the main observations are presented in the IPCC Climate Change 2014 - Synthesis Report.[21]
More than 90% of the additional energy stored in the climate system since 1970 has gone into ocean warming; the remainder has melted ice, and warmed the continents and atmosphere.[22] Many of the observed changes since the 1950s are unprecedented over decades to millennia.[23]

Scientific understanding of global warming has been increasing. In its fifth assessment (AR5) in 2014 the Intergovermental Panel on Climate Change (IPCC) reported that scientists were more than 95% certain that most of global warming is caused by increasing concentrations of greenhouse gases and other human (anthropogenic) activities.[24][25][26]

According to National Geographic, some impacts from increasing temperatures are already happening.[27]

- Ice is melting worldwide, especially at the Earth’s poles. This includes mountain glaciers, ice sheets covering West Antarctica and Greenland, and Arctic sea ice.
- Researcher Bill Fraser has tracked the decline of the Adélie penguins on Antarctica, where their numbers have fallen from 32,000 breeding pairs to 11,000 in 30 years.
- Sea level rise became faster over the last century.
- Some butterflies, foxes, and alpine plants have moved farther north or to higher, cooler areas.
- Precipitation (rain and snowfall) has increased across the globe, on average.
- Spruce bark beetles have boomed in Alaska thanks to 20 years of warm summers. The insects have chewed up 4 million acres of spruce trees.

Other effects could happen later this century, if warming continues

- Sea levels are expected to rise between 18 and 59 centimeters by the end of the century, and continued melting at the poles could add between 10 to 20 centimeters.
- Hurricanes and other storms are likely to become stronger.
- Species that depend on one another may become out of sync. For example, plants could bloom earlier than their pollinating insects become active.
- Floods and droughts will become more common. Rainfall in Ethiopia, where droughts are already common, could decline by 10 percent over the next 50 years.
- Less fresh water will be available. If the Quelccaya ice cap in Peru continues to melt at its current rate, it will be gone by 2100, leaving thousands of people who rely on it for drinking water and electricity without a source of either. Some diseases will spread, such as malaria carried by mosquitoes.
- Ecosystems will change—some species will move farther north or become more successful; others won’t be able to
- move and could become extinct. Wildlife research scientist Martyn Obbard has found that since the mid-1980s, with less ice on which to live and fish for food, polar bears have gotten considerably skinnier. Polar bear biologist Ian Stirling has found a similar pattern in Hudson Bay. He fears that if sea ice disappears, the polar bears will as well.

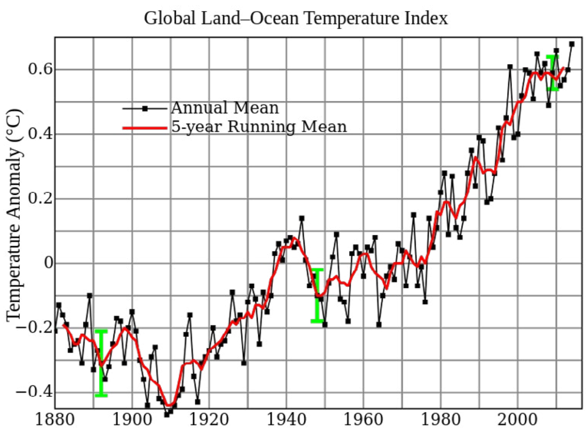

Figure 1.7: Global mean surface temperature change from 1880 to 2014, relative to the 1951-1980 mean. The black line is the annual mean and the red line is the 5-year running mean. The green bars show uncertainty estimates. Source: NASA GISS.

1.4. The Carbon Footprint of buildings and of the building industry

The Carbon Footprint and energy use of the cement and steel industries

Throughout the 20th century, following the Second Industrial Revolution, new construction methods were invented and propagated across the world. One of the most important changes was the transition to buildings built with structural frames, mostly made from reinforced concrete (mostly reinforced with steel bars) or steel. This transformation rendered concrete and steel the most popular construction materials in the developed world (and also in most developing countries in subsequent decades).

Concrete is the most widely used building material across the world today and cement, used for the production of concrete, is actually the second most consumed substance on earth after water.[32]
Cement is the primary ingredient in concrete, which in turn forms the foundations and structures of the buildings we live and work in, and the roads and bridges we drive on. On average, each year, three tons of concrete are consumed by every person on the planet.[32]
Concrete is used globally to build buildings, bridges, roads, runways, sidewalks, and dams. Cement is indispensable for construction activity, so it is tightly linked to the global economy. Cement production is growing by 2.5% annually, and is

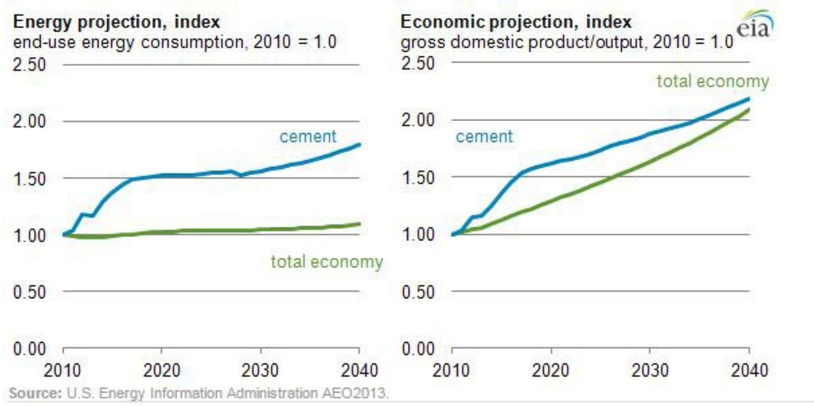

Figure 1.8: Over the long term, EIA projections show an increasing contribution from the cement industry to energy consumption as well as increasing share of total gross output of goods and services. Cement output is strongly tied to various types of construction.

expected to rise from 2.55 billion tons in 2006 to 3.7-4.4 billion tons by 2050.[32]
The cement and the steel industries constitute a significant part of the Global Ecological Footprint of the industry sector (figure 1.6). The cement industry accounts for around five percent of global carbon dioxide (CO_2) emissions.[32]
And according to the U.S. Energy Information Administration, The cement industry is the most energy intensive of all manufacturing industries, so much so that in the United States its share of national energy use is roughly 10 times its share of the nation's gross output of goods and services (figure 1.8).[33]

The steel industry as well contributes greatly to global greenhouse gas emmissions and energy consumption. On average, 1.8 tonnes of CO_2 are emitted for every tonne of steel produced. According to the International Energy Agency, in 2013 the iron and steel industry accounted for approximately 6.7% of total world CO_2 emissions. [33]
Although energy use in the steel industry has been steadily declining, with the biggest decline recorded between the years 1991 and 2002 of 22 percent (figure 1.9), it is still one of the most energy intensive manufacturing industries.
As shown in the graph below (figure 1.10), in 2006 the steel industry was responsible for 5 percent of all energy consump-

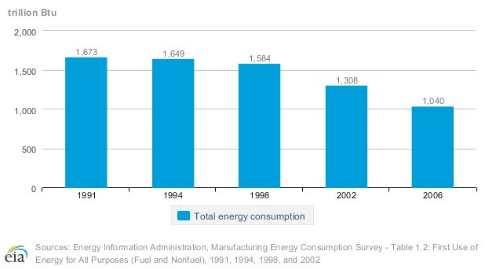

Figure 1.9: Steel industry used 22 percent less total energy over a ten year period

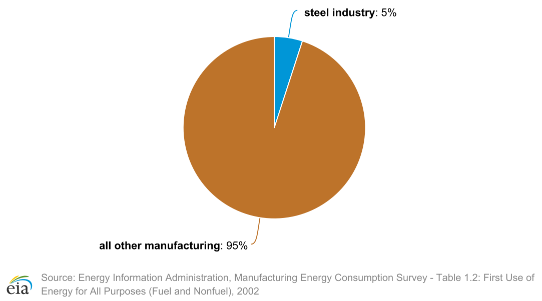

Figure 1.10: Steel industry used six percent of the total energy usid in U.S. manufacturing in 2006

tion in U.S. maufacturing.

As we can see from the data presented above, the two main construction materials of modern buildings have a huge impact on the environment in terms of contribution to greenhouse gas emmissions and use of massive quantities of energy. In the next chapter i will explore different construction materials with minimal impact on the environment. These materials and construction methods are mainly suited for small scale buildings. This delineates further the need for our society to scale down and shows how a redevelopment of the country side, an issue i will discuss in subsequent chapters, could contribute to such a transition.

The environmental impacts of buildings

As was shown previously (figure 1.6), between the years 1999 and 2013, residential and commercial buildings in the United States were responsible for around 12 percent of global greenhouse gas emmissions.

Residential and commercial activities contribute to emissions in a variety of ways[20]:

- Combustion of natural gas and petroleum products for heating and cooking needs emits carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emissions from natural gas consumption represent about 81% of the direct fossil fuel CO_2 emissions from the residential and commercial sectors. Coal consumption is a minor component of energy use in both of these sectors.
- Organic waste sent to landfills emits CH_4.
- Wastewater treatment plants emit CH_4 and N_2O.
- Fluorinated gases (mainly hydrofluorocarbons, or HFCs) used in air conditioning and refrigeration systems can be released during servicing or from leaking equipment.
- Generation of electricity consumed in houses. Most of the electricity produced nowdays come from fossil fuels.

In this respect, much is being done by governments around the world in order to drastically minimize the Carbon Footprint of buildings through legal measures like the european Directive 2010/31/EU, whose Article 9 requires that “Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings”. Member States shall furthermore “draw up national plans for increasing the number of nearly zero-energy buildings” and “following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings”. [13]

Some of the measures being taken inside building projects are the use of passive heating and cooling systems (thermal mass, thermal insulation, appropriate building orientation in relation to the sun path, etc.), biological systems for the recycling of water and the collection of rainwater, integration of renewable energy producing systems within buildings (example: photovoltaic panels), etc.

In the next chapters we will review some of these technologies, as some of them will be integrated into the Urban Farm Project presented in the last chapter.

1.5. The unsustainability of industrial agriculture

During the past century world annual agricultural production has more than tripled. This unprecedented achievement in humanity's quest for food security and abundance was largely made possible by the development of chemical fertilizers, pesticides, and herbicides; new hybrid crop varieties; the application of irrigation in arid regions; and the introduction of powered farm machinery.

Central to most of these strategies for intensifying farm productivity were fossil fuels, especially oil and natural gas. Natural gas provides the hydrogen and energy used to produce most nitrogen fertilizers, and both gas and oil are the sources for other agricultural chemicals, including pesticides and herbicides. Meanwhile, oil fuels most farm machinery, and has enabled growth in the scale and distance of transportation of crop inputs and outputs. Today, food items are shipped worldwide and enormous quantities of food are routinely transported from places of abundance to sites of scarcity, enabling cities to be built in deserts.

This application of fossil fuels to the food system has supported a human population growing from fewer than two billion at the turn of the twentieth century to nearly seven billion today. In the process, the way we feed ourselves has changed profoundly.

Particularly in industrialized nations, the food system has become more articulated (it has more basic components) and more centralized. Today in most countries, farmers make up a smaller proportion of the population, and they typically work larger parcels of land. They also typically sell their harvest to a distributor or processor, who then sells packaged food products to a wholesaler, who in turn sells these products to chains of supermarkets. The ultimate consumer of the food is thus several steps removed from the producer, and food systems in most nations or regions have become dominated by a few giant multinational seed companies, agricultural chemicals corporations, and farm machinery manufacturers, as well as food wholesalers, distributors, and supermarket chains. In the U.S. for example, the process of getting food from the farm to the plate uses over four times as much energy as farming (Figure 1.11).

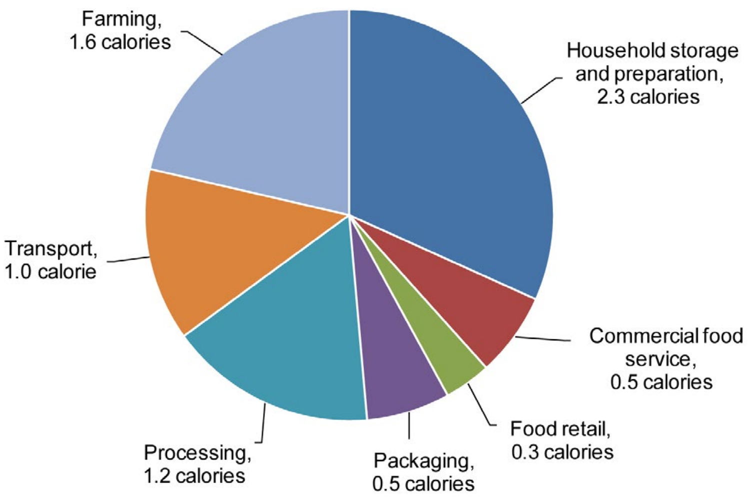

Figure 1.11: Energy expended in producing and delivering one food calorie. Approximately 7.3 calories are used by the U.S. food system to deliver each calorie of food energy. Farming accounts for less than 20% of this expenditure, but still consumes more energy than it delivers.[28]

From an energy perspective, industrialization presents a paradoxical reversal. Before the industrial revolution, farming and forestry were society's primary net producers of energy. Today the food system is a net user of energy in virtually every nation; this is especially so in industrial countries, where each calorie of food energy produced and brought to the table represents an average investment of about 7.3 calories of energy inputs (Figure 1.11).

The benefits of industrial (that is to say, fossil fuel-based) food production and distribution are easy to see: our modern food system delivers products that are themselves cheap and abundant. In 2005, for example, the average U.S. family spent less than 12 percent of income on food, whereas 50 years ago that percentage was about twice as high. Exotic foods are widely available in supermarkets, whose shelves display thousands of distinct food products. Famine, which used to be common throughout the world, is banished from most countries. Hunger, where it still exists, is nearly always due to an inability to afford food, rather than absolute scarcity. But this enormous benefit has come at a cost. Out of all human activities, agriculture has arguably been the source of greatest human impact on the environment. Fertilizer runoff has led to the proliferation of oceanic dead zones fanning out from the mouths of rivers; the search for more arable land has driven widespread deforestation; irrigation has caused the salinization of soils; pesticide and herbicide pollution of air and water has adversely affected the health of humans as well as thousands of plant and animal species; and the simplification of ecosystems for the production of monocrops has exacerbated the ongoing loss of habitat for birds, amphibians, mammals, and beneficial insects.[29]

Agriculture also contributes to climate change—principally through soil degradation, which releases carbon sequestered in soil into the atmosphere as carbon dioxide, but also through the combustion of fossil fuels. Climate change in turn adversely impacts agriculture through extreme weather events, altered seasons, and changing precipitation patterns.

Industrial agricultural production accounts for 92 per cent of the global water footprint, with 78 per cent of world crop production relying on rainfall.[17]

Meanwhile, the industrialization of the food system has lowered food quality.[30] Hundreds of millions of poor, middle-class, and even wealthy individuals in industrialized nations suffer from malnutrition, often hidden and sometimes paradoxically accompanied by obesity resulting from the consumption of highly processed foods low in essential nutrients. Four of the leading causes of death in these nations—heart disease, stroke, Type 2 diabetes, and cancer—are chronic diseases linked to diet.

Soil degragation, greenhouse gas emmissions (and contribution to climate change), lowered food quality and malnutrition, extensive animal abuse, all these are amongst the problems created by industrial (fossil fuel-based) agriculture. However, the biggest threat to industrial agricultures survival remains its utter dependence on depleting fossil fuels, as discussed above, without which the entire global food industry wouldn't be able to survive. The graph below (figure 1.12) shows the variations in the price of certain crops in relation to the price variations of crude oil in the years between 2000 and 2008. This graph demonstrates the vulnerability and dependency of agriculture on fossil fuels.

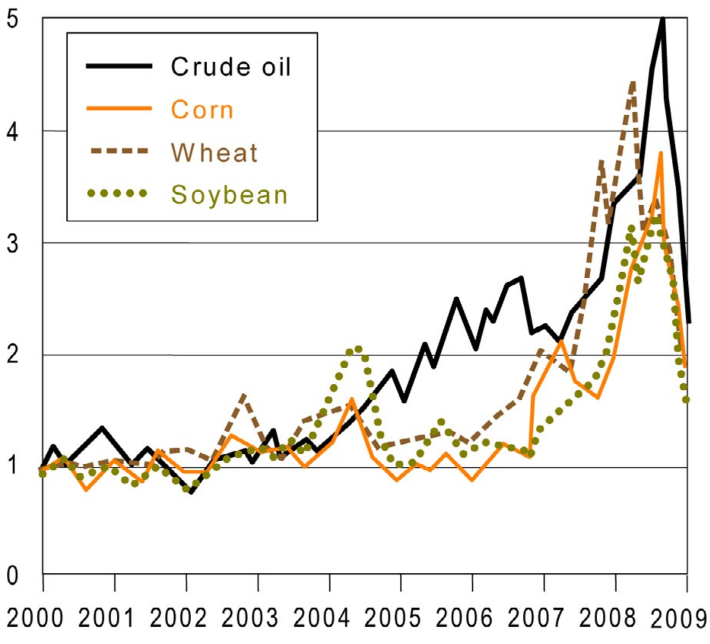

Figure 1.12: Relative price of crude oil, corn, wheat, and soybean on world markets, 2000-2008. (2000 price = 1).[31]

Factory farms - animal abuse, health and environmental problems

On today's meat and milk industries' factory farms, animals (pigs, cows, chicken, turkeys, horses, and dogs in some countries) are crammed by the thousands into filthy, windowless sheds and stuffed into wire cages, metal crates, and other torturous devices.The natural instincts and behaviors of these animals are oppressed, causing significant psychological stress for the animals. This animals are deprived of sunlight, fresh air, and the freedom to move freely. Their babies (chicks, calfs, piglets, etc.) are taken from them at birth (for milking cows) or prematurely by force, leaving the mothers in significant stress. The animals are subject to numerous physical abuses by actions such as: the stamping of a serial number on their skins with hot rods; castration and amputation of tails and other body parts for piglets without anesthetization; physical violence from workers whilst being mobilised and transported;and the obvious pain and fear in the process of the slaughtering, etc., [37] [38]

Animal farms strive to maximise outputs whilst minimizing costs. This means that animal welfare is always left as the last priority if at all. The giant corporations that run most factory farms have found that they can make more money by squeezing as many animals as possible into tiny spaces, which causes these animals to develop diseases and infections, thus creating the need for the use antibiotics. These antibiotics wind up in people's foods, and according to research are one of the major causes for the resistence developed by bacteria in recent decades to antibiotic treatment - a major health concern for global society.[37] [42] Additionaly, animals are given grow hormones and most factory-farmed animals have been genetically manipulated to grow larger or to produce more milk or eggs than they naturally would. Some chickens grow so unnaturally large that their legs cannot support their outsized bodies, and they suffer from starvation or dehydration when they can't walk to reach food and water. [37]

When they've grown large enough to slaughter or their bodies have been worn out from producing milk or eggs, animals raised for food are crowded onto trucks and transported for miles through all weather extremes, typically without food or water. At the slaughterhouse, those who survived the transport will have their throats slit, often while they're still conscious. Many remain conscious when they're plunged into the scalding-hot water of the defeathering or hair-removal tanks or while their bodies are being skinned or hacked apart.[37]

- In average, 94 percent of all animal food products come from factory farms.[39]
- 30 percent of all of the earths ice-free surfaces is used to raise grain, fruits and vegetables, not for direct human consumption, but rather for the support of chickens, cattle and pigs.[40]
- Livestock production uses one third of the worlds fresh water.[40]
- A 2006 report from the Food and Agriculture Organization estimated that livestock were responsible for about 18% of human-caused greenhouse gases.[41]

Factory farms must be stopped not only for their immense cruelty and negative impact on society's health but also for their significant role in the global environmental crisis we are facing. From the information presented above, it is becoming obvious that one of the first challenges of society, in its transition to a sustainable course, will be a significant reduction in the consumption of animals products; mainly meat and milk. Furthermore, with less demand for meat and milk products more humane ways of raising animals for food production will have to be established as the standard. This need will be answered by different organic modes of farming, which i will explore in the next chapter.

1.6. The global water footprint:

Water is used in some form in almost all food production and manufacturing processes. The “water footprint” of a product is the quantity of water used in its production. Water footprint is made up of three types of water use, known as blue, green and grey water footprints. The green water footprint is the volume of rainwater stored in soil that evaporates through crop growth. The blue water footprint is the volume of freshwater taken from surface (lakes, rivers, reservoirs) and ground water (aquifers) that is used and not returned to the system it was withdrawn from. The grey water footprint is the volume of water polluted as a result of production processes (industrial and agricultural) and from waste water from household water use. It is the volume of water required to dilute pollutants to such an extent that the water quality reaches acceptable levels. (figure 1.13) The largest share of global blue water footprintoccurs in crop fields as a result of evaporation of irrigation water. There is no green water footprint of household and domestic water uses, although they do show blue and grey water footprints.[17]

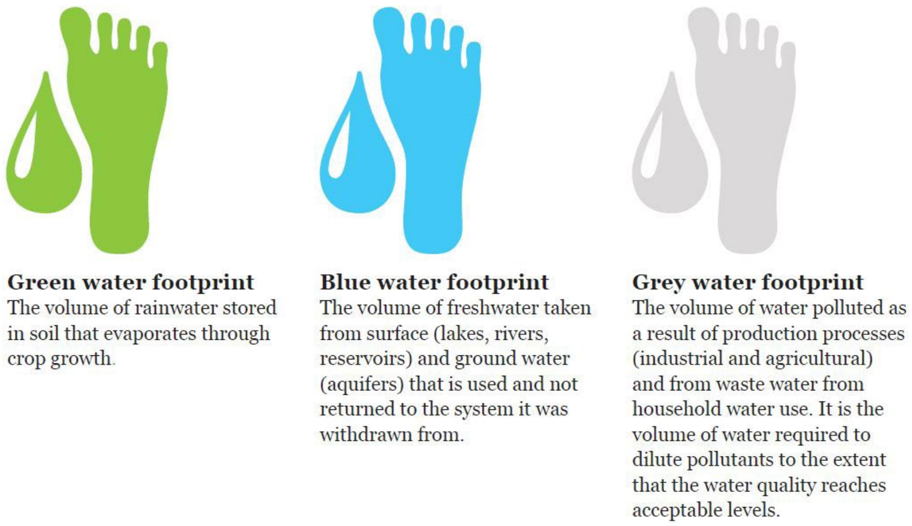

Figure 1.13 : The three different types of water footprint, divided by colour, i.e. green, blue and grey, determined by the water use. [17]

- Some 97.5 percent of our planet’s water is salt water
- Almost all of the remaining fresh water is locked up in glaciers and ice caps, or in aquifers deep under the surface
- A fraction of 1 percent of water is renewed each year by the hydrological cycle
- The available fresh water is unevenly distributed with serious water shortages in the worlds poorest countries
- Agricultural production accounts for 92 per cent of the global water footprint, with 78 per cent of world crop production relying on rainfall.
- While some countries are discovering significant groundwater reserves, in other parts of the world – such as Australia, India and USA – these life-giving aquifers are being severely depleted.
- Globally, the number of people affected by absolute or seasonal water shortages is projected to increase steeply – owing to climate change and increasing water demands (Schiermeier, 2013; Hoekstra and Mekonnen, 2012).
- More than 200 river basins, home to some 2.67 billion people, already experience sever water scarcity for at least one month every year [17]

An important feature of ecological agriculture practices, such as Permaculture and Aquaponics (topics which i will introduce in the next chapter), is the ethical use of water. In these food production systems water is not being polluted by toxins which permeate to underground water sources. Water is recycled to the maximum or put back into the ground where it can percolate back to underground water aquifers, therefore resolving the issues presented above. These topic will be discussed further in the next chapter.

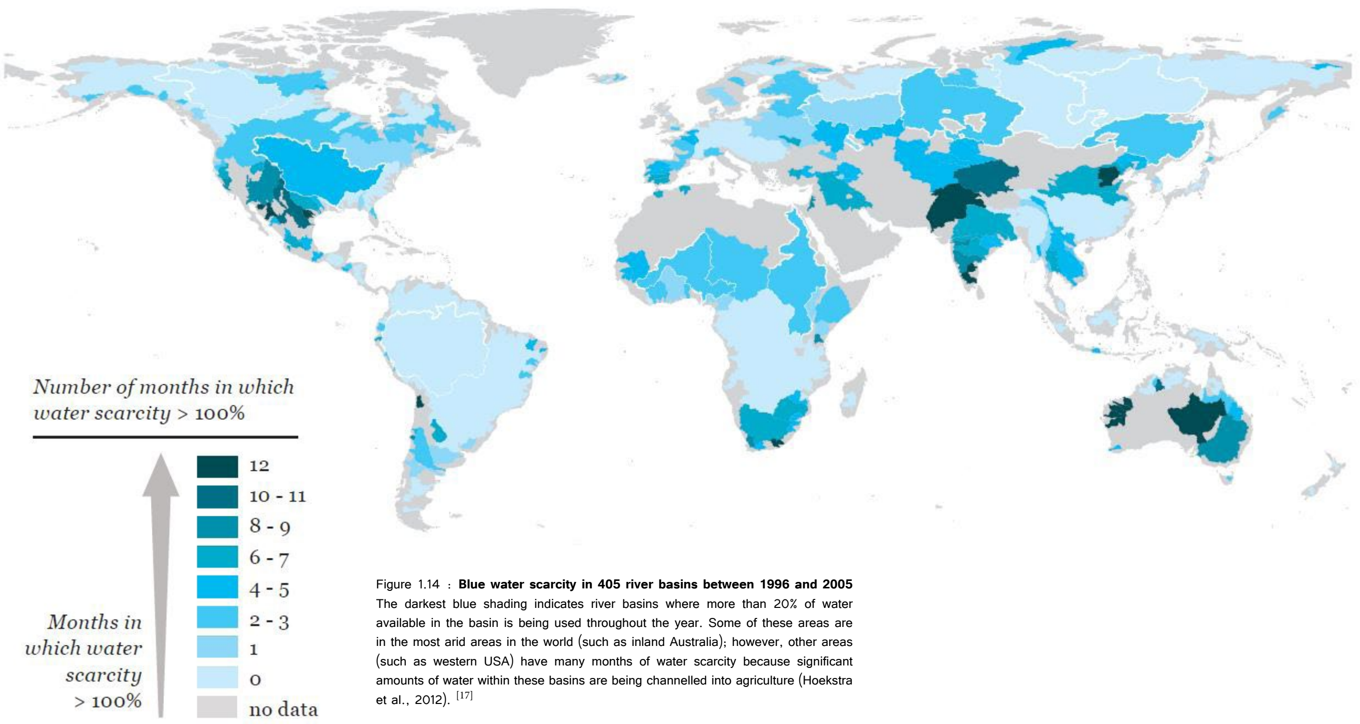

Figure 1.14 : **Blue water scarcity in 405 river basins between 1996 and 2005**
The darkest blue shading indicates river basins where more than 20% of water available in the basin is being used throughout the year. Some of these areas are in the most arid areas in the world (such as inland Australia); however, other areas (such as western USA) have many months of water scarcity because significant amounts of water within these basins are being channelled into agriculture (Hoekstra et al., 2012). [17]

Conclusions of chapter 1

In this chapter we explored the main challenges and problems contemporary society will have to confront and solve in order to prevent the destruction of the natural environment, and thereby to permit the continuation of livable conditions on our planet for the next generations to come.
In the first section we explored the issues of the depletion of the main energy providing resources to our society, which will probably occur in the next decades (different predictions for each energy resource). We examined the extent of the dependency our society has on non-renewable energy resources, especially fossil fuels, and the risks entailed by the depletion of such resources to our economies and agriculture.
I tried to show how fossil fuels were responsible for the immense technological innovations and revolutions humanity has witnessed in the last century, thanks to their unique properties and abundance. I tried to demonstrate the superiority of fossil fuels over other conventional renewable energy resources, in order to express the need our society has to scale down its operations and energy consumption due to the probable lack of energy supply in a future without fossil fuels.

In the second section the notion of the Global Ecological Footprint was introduced. This tool, which permits us to calculate humanitys demand on the Earth's ecosystem, allowed us to comprehend the extent of the overexploitation of the earth's resources and the need to change our lifestyles in order to live within the regenerative capacities of our planet.
The problems of greenhouse gas emmissions was explored through the notion of the Ecological Footprint and in relation with climate change - one of the biggest dangers for our planet's future - caused mainly by the increasing amount of greenhouse gas emmissions in the atmosphere.

In the last section we explored the problems of industrial agriculture. I tried to show how this sector is reponsible for large part of the destruction of the natural environment through deforestation for grazing pastures; pollution of fresh water resources and of the oceans; soil erosion created by unsustainable land management practices and biodiversity loss through the use of monocultures, etc.

In the next chapter i will explore different sustainable solutions in energy, food, and building construction. I will try to demonstrate how it is possible to create a sustainable human settlement by the integration of the different methodologies ,technologies and systems presented. The integration of these different elements into a holistic sustainable system for human settlements will be the focus of the urban farm community project presented in chapter 3.

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Chapter 2 - Methods and techniques for sustainable living (solutions for the environmental crisis)

As we saw in the previous chapter, humanity in the 21st century will have to deal with the threats of climate change, peak oil, resource depletion and the destruction of the natural environment. These are all phenomenons created by the modern industrial lifestyle that developed around the world throughout the 19th and 20th century and prevails nowdays in most parts of the world. Following the analyses elaborated in the previous chapter, it is now evident that modern society will have to accomplish a radical transformation in the way it produces its food and goods; in the way it procures its energy; in how it exploits the natural resources and relates to the natural environment; and in how it designs and builds its own cities and settlments.

In my opinion, a new typology of human settlements, that breaks from the modern division of city-suburbs-countryside, and fuses the urban sphere together with the agricultural and natural spheres, is necessary in order to combine the different methodologies and technologies which will be able to form a new society capable of living off the earth's resources without damaging and destroying it and without undermining its own survival.

The main characteristics of this new typology of human settlements would be:

- Maximum self sufficiency in terms of food and energy for each family and household, and for each small community.

- The new human settlements will be composed of small cooperative communities which will rely on each other for survival whilst simultaneaously maintaining the maximum level of self-sufficiency and independence for each household.

- Methods and practices based on the principles of ecology and natural systems will be used for the cultivation of food and for the harvest of energy and other natural resources by each family, household and community. The principles of ecology will also be taken a step further into the design of the layout and functioning of entire settlements.

- Wastes will be reduced to a minimum by the elimination of non biodegradable materials, by recycling, and by employing sustainable farming and building methods which generate minimum waste and pollution.

- Recycling of nutrients is paramount as well as the protection of the natural environment and of the local resources. Every settlement will possess systems for the recycling and reuse of rain water, grey water, human and animal excrements and organic and inorganic waste.

- Every settlement would ideally possess the appropriate systems (according to the geographical characteristics of the site and the local climate) for the production of its own energy and electricity, with the sole use of renewable energy resources.

- Ideally, every community will create its own economic enterprises including green industries and technologies.

- The communities of these settlements will protect the natural environment within and adjacent to the settlements property.

- Most goods consumed by the community would ideally be produced locally or transported there sustainably.

In this chapter i will try to outline the main existing methodologies, practices and technologies which will permit the creation of such communities and of the new proposed settlement typology.

2.1. The design philosophy of Permaculture

'Permaculture is a philosophy of working with, rather than against nature; of protracted and thoughtful observation rather than protracted and thoughtless labor; and of looking at plants and animals in all their functions, rather than treating any area as a single product system.'

—Bill Mollison,[1]

Permaculture (stands for "Permanent Agriculture" or "Permanent Culture") is an ecological design philosophy for sustainable human settlements which merges sustainable farming practices, developed from the study of ecological principles of natural environments and from the practices of indigenous "primitive" cultures who lived off their environments sustainably, with sustainable building construction methods, renewable energy production systems and systems for the recycling of water, wastes and nutrients. It was later developed to encompass not only agriculture, horticulture, architecture and ecology, but also economic systems, land access strategies and legal systems for businesses and communities.
The term was coined by Bill Mollison, considered to be 'the father of Permaculture'[2], and David Holmgren in 1978. The two australian scientists collaborated to develop a systems approach design philosophy that would substitute modern industrial agriculture and its negative impacts on the environment. In 1978 they released 'Permaculture One' followed by the release of 'Permaculture Two' in 1979. In these two practical guidebooks Mollison and Holmgren develop their new design philosophy in detail with detailed instructions for practitioners. Mollison further refined and developed the ideas by designing hundreds of permaculture sites and writing more detailed books, notably Permaculture: A Designers Manual.

Although, most of the practices employed by permaculturists weren't actually invented by them, Mollison and Holmgren built the framework for a new movement of ecological designers around the world, developing and enriching the existing techniques and practices into a holistic discipline.

The first mention of the idea of permanent agriculture was in the 1929 book of Joseph Russell Smith: 'Tree Crops: A Permanent Agriculture', in which Smith summed up his long experience experimenting with fruits and nuts as crops for human food and animal feed.[3] Smith saw the world as an inter-related whole and suggested mixed systems of trees and crops underneath.

Other influential figures in the development of the Permaculture discipline are:

- Masanobu Fukuoka (figure 2.1) was a Japanese farmer and philosopher celebrated for his natural farming and re-vegetation of desertified lands. He was a proponent of no-till, no-herbicide grain cultivation farming methods traditional to many indigenous cultures,[4] from which he created a particular method of farming, commonly referred to as "Natural Farming" or "Do-nothing Farming".[5][6][7]

- Josef "Sepp" Holzer (figure 2.2) is a farmer, author, and an international consultant for natural agriculture. After an upbringing in a traditional Catholic rural family, he took over his parents' mountain farm business in 1962 and pioneered the use of ecological farming, or permaculture, techniques at high altitudes (1100 to 1500 meters above sea level)[8] after being unsuccessful with regular farming methods.
  Holzer was called the "rebel farmer" because he persisted, despite being fined and even threatened with prison,[9] with practices such as not pruning his fruit trees (unpruned fruit trees survive snow loads that will break pruned trees).[10] He has created some of the world's best examples of using ponds as reflectors to increase solar gain for Passive solar heating of structures, and of using the microclimate created by rock outcrops to effectively change the hardiness zone for nearby plants. He has also done original work in the use of Hügelkultur and natural branch development instead of pruning to allow fruit trees to survive high altitudes and harsh winters.

  He is currently conducting permaculture seminars both at his Krameterhof farm (figure 2.3) and worldwide, while continuing to work on his alpine farm. His expanded farm now spans over 45 hectares of forest gardens, including 70 ponds, and is said to be the most consistent example of permaculture worldwide. His farm is famous for its extensive use of animals (for example the use of pigs for digging beds, etc.) and for not using any fertilizers, pesticides or irrigation.

Figure 2.1: Masanobu Fukuoka - inventor of the 'Do-Nothing' grain farming technique.

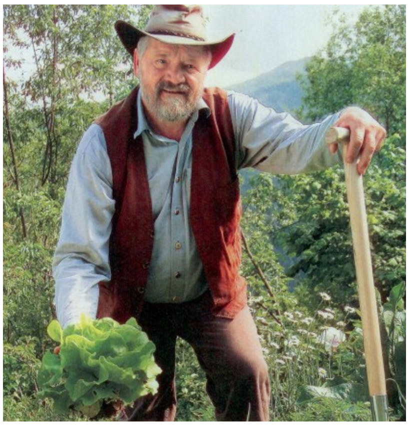

Figure 2.2: Sepp Holzer - one of the worlds most prominent ecological farmers and permaculturists.

Figure 2.3: Der Krameterhof - Sepp Holzers' alpine farm. One of the worlds prime examples of large-scale ecological farming and permaculture.

2.2. Theory of Permaculture

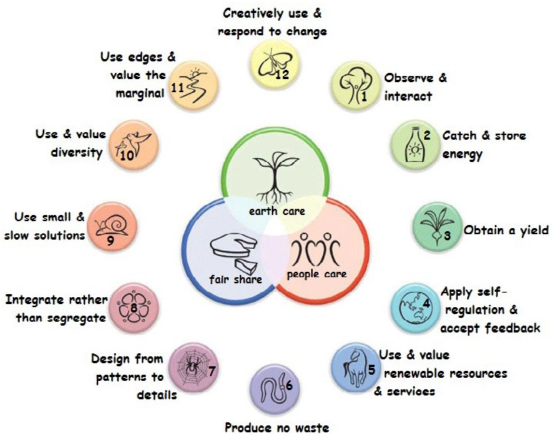

Figure 2.4: Permaculture principles. Image source: Holmgren, D., Permaculture: principles and pathways beyond sustainability.[13]

Core tenets and principles of design

The three core tenets of permaculture are:[11][12][13]

Care for the earth: Provision for all life systems to continue and multiply. This is the first principle, because without a healthy earth, humans cannot flourish.

Care for the people: Provision for people to access those resources necessary for their existence.

Return of surplus: Reinvesting surpluses back into the system to provide for the first two ethics. This includes returning waste back into the system to recycle into usefulness.[14] The third ethic is sometimes referred to as Fair Share to reflect that each of us should take no more than what we need before we reinvest the surplus.

Permaculture design emphasizes patterns of landscape, function, and species assemblies. It determines where these elements should be placed so they can provide maximum benefit to the local environment. The central concept of permaculture is maximizing useful connections between components and synergy of the final design. The focus of permaculture, therefore, is not on each separate element, but rather on the relationships created among elements by the way they are placed together; the whole becoming greater than the sum of its parts. Permaculture design therefore seeks to minimize waste, human labor, and energy input by building systems with maximal benefits between design elements to achieve a high level of synergy. Permaculture designs evolve over time by taking into account these relationships and elements and can become extremely complex systems that produce a high density of food and materials with minimal input.[13]

The design principles which are the conceptual foundation of permaculture were derived from the science of systems ecology and study of pre-industrial examples of sustainable land use. Permaculture draws from several disciplines including organic farming, agroforestry, integrated farming, sustainable development, and applied ecology.[15] Permaculture has been applied most commonly to the design of housing and landscaping, integrating techniques such as agroforestry, natural building, and rainwater harvesting within the context of permaculture design principles and theory.

Twelve design principles (figure 2.4)

David Holmgren in his ‘Permaculture: Principles and Pathways Beyond Sustainability’ book articulates these twelve Permaculture design principles:[13]

Observe and interact: By taking time to engage with nature we can design solutions that suit our particular situation.

Catch and store energy: By developing systems that collect resources at peak abundance, we can use them in times of need.

Obtain a yield: Ensure that you are getting truly useful rewards as part of the work that you are doing.

Apply self-regulation and accept feedback: We need to discourage inappropriate activity to ensure that systems can continue to function well.

Use and value renewable resources and services: Make the best use of nature’s abundance to reduce our consumptive behavior and dependence on non-renewable resources.

Produce no waste: By valuing and making use of all the resources that are available to us, nothing goes to waste.

Design from patterns to details: By stepping back, we can observe patterns in nature and society. These can form the backbone of our designs, with the details filled in as we go.

Integrate rather than segregate: By putting the right things in the right place, relationships develop between those things and they work together to support each other.

Use small and slow solutions: Small and slow systems are easier to maintain than big ones, making better use of local resources and producing more sustainable outcomes.

Use and value diversity: Diversity reduces vulnerability to a variety of threats and takes advantage of the unique nature of the environment in which it resides.

Use edges and value the marginal: The interface between things is where the most interesting events take place. These are often the most valuable, diverse and productive elements in the system.

Creatively use and respond to change: We can have a positive impact on inevitable change by carefully observing, and then intervening at the right time.

Layers

Layers (figure 2.5) are one of the tools used to design functional ecosystems that are both sustainable and of direct benefit to humans. A mature ecosystem has a huge number of relationships between its component parts: trees, understory, ground cover, soil, fungi, insects, and animals. Because plants grow to different heights, a diverse community of life is able to grow in a relatively small space, as each layer is stacked one on top of another. There are generally seven recognized layers in a food forest, although some practitioners also include fungi as an eighth layer.[12]

The canopy: the tallest trees in the system. Large trees dominate but typically do not saturate the area, i.e. there exist patches barren of trees.

Understory layer: trees that revel in the dappled light under the canopy.

Shrubs: a diverse layer of woody perennials of limited height. includes most berry bushes.

Herbaceous: Plants in this layer die back to the ground every winter (if winters are cold enough, that is). They do not produce woody stems as the Shrub layer does. Many culinary and medicinal herbs are in this layer. A large variety of beneficial plants fall into this layer. May be annuals, biennials or perennials

Soil surface/Groundcover: There is some overlap with the Herbaceous layer and the Groundcover layer; however plants in this layer grow much closer to the ground, grow densely to fill bare patches of soil, and often can tolerate some foot traffic. cover crops retain soil and lessen erosion, along with green manures that add nutrients and organic matter to the soil, especially nitrogen

Rhizosphere: Root layers within the soil. The major components of this layer are the soil and the organisms that live within it such as plant roots (including root crops such as potatoes and other edible tubers), fungi, insects, nematodes, worms, etc.

Vertical layer: climbers or vines, such as runner beans and lima beans (vine varieties)[13][14]

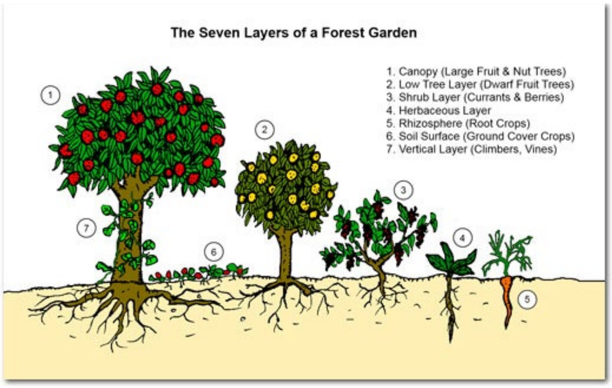

Figure 2.5: The seven layers of a forest garden. Image source: Permaculture a Beginner's Guide, by Graham Burnett[16]

Guilds

Another tool used extensively in Permaculture is guilds. Guilds are groups of species in an ecosystem (animals, plants or insects) which form symbiotic relationships between them and mutually support each other. Some plants may be grown for food production, some have tap roots that draw nutrients up from deep in the soil, some are nitrogen-fixing legumes, some attract beneficial insects, and others repel harmful insects. When grouped together in a mutually beneficial arrangement, these plants form a guild. By using guilds appropriately, one could avoid the use of artificial (and unsustainable) pest control and fertilizers.[17] Guilds are one of the main reasons for the extensive use of polyculture crops in Permaculture, that is the inter-mixed cultivation of different species instead of the traditional monoculture crops of industrial agriculture.

Edge effect

In ecology, constrating environments placed side by side form the so-called edge effect. Permaculturists believe that these edge zones, in which vastly different ecosystems meet, are extremely fertile and that they produce useful connections that cannot exist under different conditions. For example: coasts, where the land and the sea meet, are particularly rich areas that can meet a disproportionate percentage of human and animal needs. Therefore, in permacultural designs different strategies are used to maximise the edge effect for different elements. For example: ponds are created with an undulating shoreline rather than a simple circle or oval.

Zones

Permaculture systems are usually organized by different zones, each zone corresponds to a different frequency of maintenance or different plant or animal needs. Frequently manipulated or harvested elements of the design are located close to the house in zones 1 and 2. Less frequently used or manipulated elements, and elements that benefit from isolation (such as wild species) are farther away. The goal is to save as much energy by reducing futile trips to a minimum.

Ususally, the house or the community are considere zone 0. Zone 1 is the closest to the house, where plants and species

which need the most frequent care and maintenance are located. (example: salad crops)
Zone 2 is where perennial plants, which require less maintenance, are usually located as long as other elements such as beehives, composting bins, etc..
Zone 3 is where the main crops are grown, which after reaching maturity require minimal maintenance.
Zone 4 is a semi-wild area used mainly for forage and collection of wood and timber.
Zone 5 is a wilderness area destined for the preservation of nature.

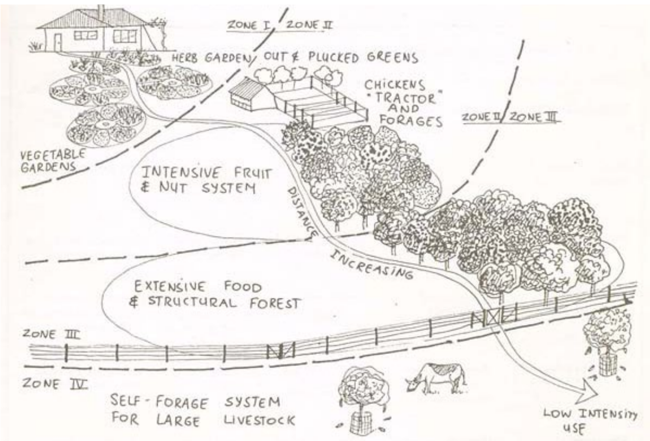

Figure 2.6: The relationship between distance and intensity of use. Frequently-visited areas are placed closest to the house.[12]

2.3. Common practices in Permaculture

Agroforestry: is a land-use approach in which trees and shrubs are combined with crops and livestock. Beneficial interactions between these different components create land-use systems which are more diverse, fertile and profitable.[18]
In Permaculture, the term used more often for these techniques is 'Forest Gardening'- a term coined in 1980 by Robert Hart, an english horticulturist, for ancient techniques of securing food in tropical areas adapted by him for temperate climate forests.[19]

Hügelkultur: is the practice of burying large volumes of wood to increase soil water retention. The porous structure of wood acts as a sponge when decomposing underground. During the rainy season, masses of buried wood can absorb enough water to sustain crops through the dry season.[20] This technique has been used by permaculturalists Sepp Holzer, Toby Hemenway, Paul Wheaton and Masanobu Fukuoka.[21]

Sheet mulching: is a protective layer placed over the soil. Any material or combination can be used as mulch, stones, leaves, cardboard, wood chips, gravel, etc., though in permaculture mulches of organic material are the most common because they perform more functions. The practice of the protection of fertile organic soils is at the foundation of Permaculture. Sheet mulching serves to protect soils from erosion, to reduce evaporation of water, to retain rainwater in soils, to provide nutrients, to increase organic matter in the soil, to suppress weed growth and seed germination, to moderate diurnal temperure variations and to protect against frost. It is a technique which tries to mimic naturally occuring phenomenons in forests.[22]

Intensive rotational grazing: managed grazing systems (figure 2.7), in which cattle is systematically moved to fresh pasture, range, or forest followed by a period of rest, have been shown to have positive results on plant growth and soil fertility.[23] Managed intensive rotational grazing can be used with cattle, sheep, goats, pigs, chickens, rabbits, geese, turkeys, ducks and other animals depending on the natural ecological community that is being mimicked.

Other common practices in Permaculture: include rainwater harvesting, natural building methods and materials, Keyline Design, which is a technique for maximizing beneficial use of water resources of a piece of land developed in Australia by farmer and engineer P. A. Yeomans[24],and fruit tree management - techniques that usually involve no-pruning, etc.

Figure 2.7: A chicken tractor. The chickens inside this mobile cage, which is rotated periodically, carry out the functions of eating pests larvae and eggs whilst fertilizing the soils with their excretions. [25]

The potentialities of Permaculture

Permaculture could be a reference point for the ecological development modern society will have to endure. Permaculture provides proven methods, systems and practices for the creation of sustainable human communities. It is a design philosophy developed especially for a future without fossil fuels and for a transition into an energy-scarce society.
Furthermore, Permaculture offers potentialities for abundance in food, quality of life, positive social connections and spirituality.

Countrysides across the world are being slowly abandoned. The average age of farmers in Europe, for example, is constantly rising whilst their portion of the total population is diminishing.[26]
Permaculture, and ecological farming communities in general, could be the key for the revitilization of the countryside of western and developing countries; a phenomenon that could also reduce the increasing stress on cities and counteract worldwide urbanization.[27] Therefore, Permaculture could guide the design and the formation of the new typology of urban-farm settlements.

In the next section i will introduce 'Polydome' - a new approach for sustainable greenhouse agriculture, based largely on the principles of Permaculture and systems design, developed by Except - a dutch cooperative of scientists, designers, and social entrepreneurs dedicated to the development of sustainable projects and enterprises. Polydome draws from the same techniques and principles of Permaculture integrating them with large-scale climate-controlled environments and other innovative technologies, and adpating them to urban context.

2.4. Polydome - high performance polyculture systems (figure 2.8 & 2.9)

'Except - integrated sustainability' (www.except.nl) is a team of dutch researchers, scientists and designers commited to the development of projects in different areas that aim to find sustainable and innovative solutions for societys needs.
Their projects span from architectural rehabilitation and development projects for various cities around the world, to business plans and sustainable infrastructure and technological systems schemes.

The Polydome concept aims to establish a commercial-scale, net-zero food production system that brings to fruition the theory of ecological design and the methods of Permaculture and other sustainable agricultural philosophies inside a controlled greenhouse environment that is easy to reproduce in different parts of the world. The closed environment should provide control of important factors such as climate, air humidity, temperature, etc,. Further ecological food production systems could be integrated into the systems, such as Aquaponics and Aeroponics (topics i will discuss further ahead), as well as different systems for the production of renewable energy or the recycling of nutrients and resources.

In 'Polydome - integrated sustainability' introduction booklet, the authors state the aim of the project as follows:

-' Polydome is a step toward truly sustainable agriculture and can double our food production by 2050 while reducing the overall impact of agriculture. It can be applied to large scale commercial situations, urban agriculture, rooftop placement and used for social purposes.' [28]

Greenhouse technologies

The Polydome system is destined to be hosted inside a controlled greenhouse system. In the development of the Polydome system Except did not focus primarily on the physical designs of greenhouses. However, given that the goal of the Polydome is to become a net-zero-impact and carbon-neutral food production system, and these properties should apply to the design of the greenhouse system as well, a quick overview of several green technologies for the greenhouse system, that could be integrated into the polydome system, was presented:

Closed Greenhouses: This type of greenhouses are not ventilated during the warm seasons. The excess heat is accumulated and stored through a system of ground water in flux serving as a heat battery that transfers heat between the ground and the air in warm and cold seasons according to necessity.

This approach can save up to 30 percent of annual energy demands. The stored heat can also be exported to heat neighboring residential areas.

Other advantages of not venting the greenhouse are: higher internal CO2 levels, which can boost yields by over 20 percent; fewer exposure to pests; and lower rates of evaporation which leads to water savings.

FiWiHex: Fine Wire Heat Exchangers, or FiWiHexes, are one of the technologies that allow closed greenhouses to work. Using a heat exchanger with a multitude of fine wires increases the surface area available for heat transfer, ensuring a fast and efficient exchange of heat.

Geothermal Heating: In the right locations and geographic contexts, deep well geothermal energy could provide large part of the heating demand.

Other technologies proposed are integrated solar technologies, such as thermal collectors and photovoltaic panels; biogas fueld Combined Heat and Power systems; and sensor technologies and LED lighting for greater control over the fraction of light spectrum used.

The Polydome case study

In the Polydome introduction booklet[28] ,Except have considered a case study of a one-hectare (100m x 100m) greenhouse containing several modules (figures 20 & 21). There are perennial and annual crops grown in soil; a Hydroponic system for fast growing greens and herbs; a fish aquaculture system; a mushroom module; chickens; and a vermiculture composting system. All nutrient flows are designed to interlink in a cyclical fashion; the output of one module constituting the input of the other. This one-hectare model could be multiplied to reach any desired size.

Figure 2.8: A 3D simulation of what a Polydome system could look like. [28]

Figure 2.9: A 3D simulation of what a Polydome system could look like. In the image the hydroponics system is suspended over the temperate zone. [28]

Performance criteria and projects goals

In the introduction book Except lays out the following performance criteria and goals for the Polydome project:

Energy & materials: goals

- The Polydome greenhouse is energetically self-sustaining. All lighting, cooling, filtration, and other operations should be powered by renewable energy sources and managed through structurally-integrated energy technologies.

- It requires low or zero material inputs from outside the system boundaries. Material inputs should be from frenewable sources.

- Rainwater collection systems should be installed and water should be conserved to the greatest extent possible.

- Material and energy cycles are closed to the greatest extent possible. The system is designed to recover all local materials of value, approaching or achieving "zero waste" status.

- By satisfying the targets named above, Polydome also supports both climate mitigation and adaptation strategies.

Ecosystems & species: goals

- The Polydome greenhouse is a polyculture. It has a diversity of plant and animal species coexisting and benefiting from one another.

- It maximizes beneficial plant-plant and plant-animal interactions; relies on natural feedback loops to manage diseases and pests; and uses natural pollination services.

- It derives maximal benefit from natural thermal, lighting, and moisture conditions through crop placement.

- It maximizes productivity per square meter through the stacking of species in both space and time.

- It provides benefits to ecosystems outside of its own; it actively builds soil communities where applicable.

- It consideres animal welfare a top priority. Within the system, animals are not treated as "prodcuts", but rather as part of an ecosystem. Their natural behaviors are encouraged rather than restricted.

Culture & economy: goals

- The Polydome greenhouse is economically viable within a short- to mid-range time horizon.

- It produces significant quantities of high-quality, marketable products year-round.

- It minimizes difficult and undesirable labour.

- Polydome production is more flexible than normal greenhouse production, making the sector more resilient to economic fluctuation and improving both food security and access.

- It beneficially supports and responds to local food culture.

- It provides opportunities for functions in addition to food production, such as education, social uses, retail, processing, and others.

- It can reduce the demand for food transportation by offering a single point of sale for a wide range of locally produced goods.

- It can be used for longer than a conventional greenhouse, it integrates better into the landscape, and provides a more inspiring environment for workers and visitors alike.

Health and happinnes: goals

- The Polydome greenhouse is a healthy, safe, and enjoyable environment to work in.
- It does not rely on the use of any toxic chemicals or materials that may pose a threat to human or ecosystem health.
- It produces healthy and nutritious food for the local community, long-term food security and improving food access.
- It is a source of enjoyment to both owners and local residents through its role in the community and relevance to the local population.
- It is aesthetically pleasing in its outside appearance, enriching rather than detracting from landscape quality.
- It provides opportunities for functions in addition to food production, such as education, social uses, retail, processing, and others.

Layout of a Polydome greenhouse system (figure 2.10)

In the introduction book Except presents the following layout of a Polydome greenhouse:

Greenhouse Modules

There are two category of functions in the Polydome greenhouse: production and support.

The primary role of production modules is the output of marketeable products, tough each one also plays a unique supporting role in the system.

The support modules provide key functions to the greenhouse, such as pollination, pest control, or logistics management.

Hydroponics Crops:

- High profit, quick turnover crops consisting of greens, herbs, and strawberries.
- Procudes year-round.
- Runs partially above the soil crops, providing additional vertical stacking.
- Uses recirculated waste water effluent from the fish aquaculture system, which is monitored and supplemented with liquid nutrients from the compost module.

Temperate Crops in Soil:

- Consistes of two sub-components: perennials and annuals.
- The annual crop zone is operated year-round and provided with supplementary heat and lighting in winter months.
- The perennial zone is chilled and allowed to go dormant in winter.

- The perennial zone, which primarily consists of crops such as tree fruit, berries, and vegetables such as asparagus and artichoke, takes several years to reach full maturity. In that time, it is intercropped with annual crops to provide additional yields.

Chickens:

- Eggs and meat are sold as products.
- Chickens provide extra CO_2 and heat through vents connected to the main plant zone.
- Chicken manure is collected to enrich compost.
- For several months of the year, the chickens are given free access to the greenhouse to till soil and control pests.

Mushrooms:

- Cultivated in heavily shaded areas of the greenhouse (under rows of hydroponics beds and underneath trellised vines), mushrooms utilize an otherwise unusable space.
- Year-round production of a high value crop.
- Provide a large part of the supplemental CO_2 needed to raise crop yields.

Fish aquaculture:

- Very high production per square meter allows for a high output of product.
- Wastewater is used as a primary nutrient input for the hydroponic crops.

Bees:

- Twenty hives are included in a special zone that can be opened either to the outside or inside of the greenhouse for pollination.
- Honey can also be harvested from the hives once a year as a supplemental product.

Vermiculture Compost:

- Processes excess plant and animal wastes into usable compost.
- Liquid extracts from this compost supplement the hydroponic production system.
- Worms cultivated in the compost aerate the soil zones in the main greenhouse.
- Provides extra CO_2 and heat into the main plant zone.

Support Crops:

- Pest repelling crops and dynamic accumulators are interplanted with commercial crops.
- The dynamic accumulators (comfrey, borage) enrich and activate compost.
- The pest repelling crops reduce the need for other pest control measures.

Plant Nursery:

- Contains a germination zone with higher degrees of environmental control as well as an early-stage growth zone.

Logistics Center:

- A central area in the core of the greenhouse is used for crop collection, washing, and preparation for retail.
- The hydroponics channels are uniquely designed to bring crops to a central work station as they mature, creating a central, social work environment.

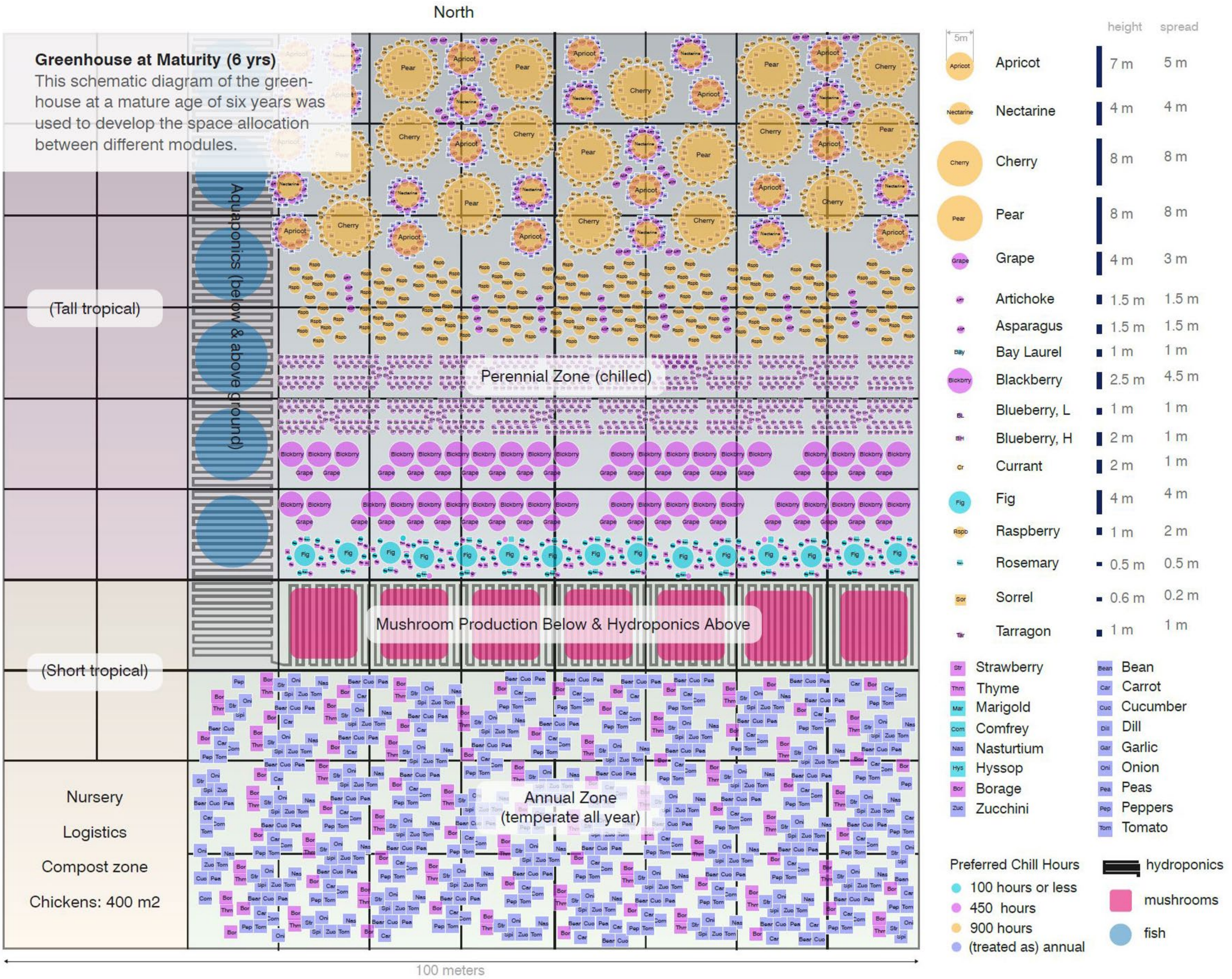

Figure 2.10: A schematic diagram of a 100m x 100m Polydome greenhouse layout. The different plant species are positioned with consideration to sunlight and shading needs as well as the symbiotic relationships between the different components of the system.[28]

Practices of the Polydome system

Stacking in space

In the Polydome system, each crop occupies a different “niche” in space and time, allowing for crop stacking and extremely high density production.

Different forms of stacking are being employed: companion stacking, that is dense planting of mutually beneficial crops that don’t compete for nutrients; vertical stacking, that is the placement of crops on top of one another as a function of each plants light requirements; Trellising, that is encouraging plants to grow vertically in order to save horizontal space for other species.

Stacking in time

Different forms of stacking in time are being employed: succession planting- the successive planting of crops according to season, shading or other factors determined by the state of existing crops; continuous cropping - the practice of planting small supplies of short-time yield crops in quick succession to extend the duration of the harvest; space sharing - early season crops are intermixed with late season crops, allowing a single space to be used to its maximum potential by several rounds of yielding plants; and crop rotation - that is, the alternation of crops planted in a single location. It is a practice that must be followed for the sake of soil health, and to avoid nutrient depletion.

Microclimates and Microzones

In traditional greenhouses the internal conditions are created for the requirements of a specific plant or crop. In the poly-dome greenhouse, the condition are created for an “average” plant. In order to cater for the specific need of each crop and species, different microclimates and microzones are created through crop placement, in a way that echoes how plants in a natural environment find more optimal conditions by selectively placing themselves in specific niches.

Material and energy flows

The ultimate goal of the Polydome system is to have a fully closed energy and material flows. That is, each input (feed, water, nutrients, etc.) for each component of the system (animal or plant species, mushroom, etc.) should be provided as a waste product of another component, creating in this manner a closed ecosystem.
The diagram below (figure 2.11) shows the calculations made by the Except team for the material flow within the model one-hectare greenhouse.

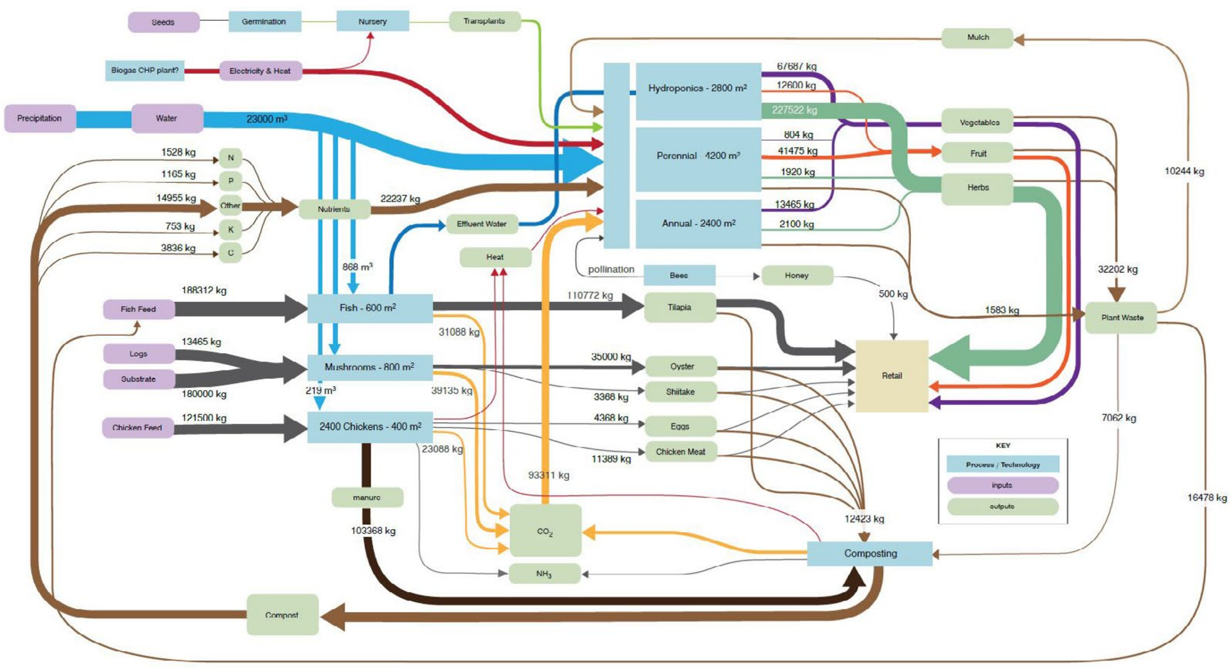

Figure 2.11: A diagram of the one-hectare Polydome case studys material and energy flows.[28]

Economic analysis and viability study

In the Polydome introduction booklet[28], the Except team constructed a simplified economic analysis of the one-hectare Polydome greenhouse model. In this analysis many factors had to be roughly estimated given the lack of a concrete technical project and the uncertainties present. The Polydome greenhouse is meant to be productive for a long period, of at least 30 years, thereby rendering the estimation of crop values very difficult. Also, some of the technological systems of the project are not fully designed, therefore a general probable figure was reduced. Due to the uncertainty in the estimation of different costs, two scenarios have been proposed - a “low earnings scenario” and a “high earnings scenario”.
The estimation of annual earnings is based on a preceding calculation of the estimated annual crop yields. Figure 2.12 is a summary of different annual crop yields. Figure 2.13 show a graph of the estimated earnings, over a long period of time (approximately 15 years), of the two aforementioned scenarios in comparison with expected costs. Based on the Except teams calculations, it is estimated that a single one-hectare Polydome greenhouse could supply most annual food demand for 2000-5000 people. The highest earnings, for a one-hectare Polydome greenhouse system, are estimated to be around 4 million euros per year, whilst the lowest earning are estimated to be around 1.5 million euros per year.

Summary of Annual Yields

Category	kg / year	people supplied
Fruits	*27455*	*458*
Vegetables	*110471*	*1841*
Mushrooms	*69800*	*6980*
Herbs	*190543*	*38109*
Fish	*105233*	*7016*
Chicken meat	*10479*	*233*
Eggs (not in kg)	*1404000*	*5200*
Honey	*500*	*1250*

Figure 2.12: Summary of annual yields of different crops in a one-hectare Polydome greenhouse system.[28]

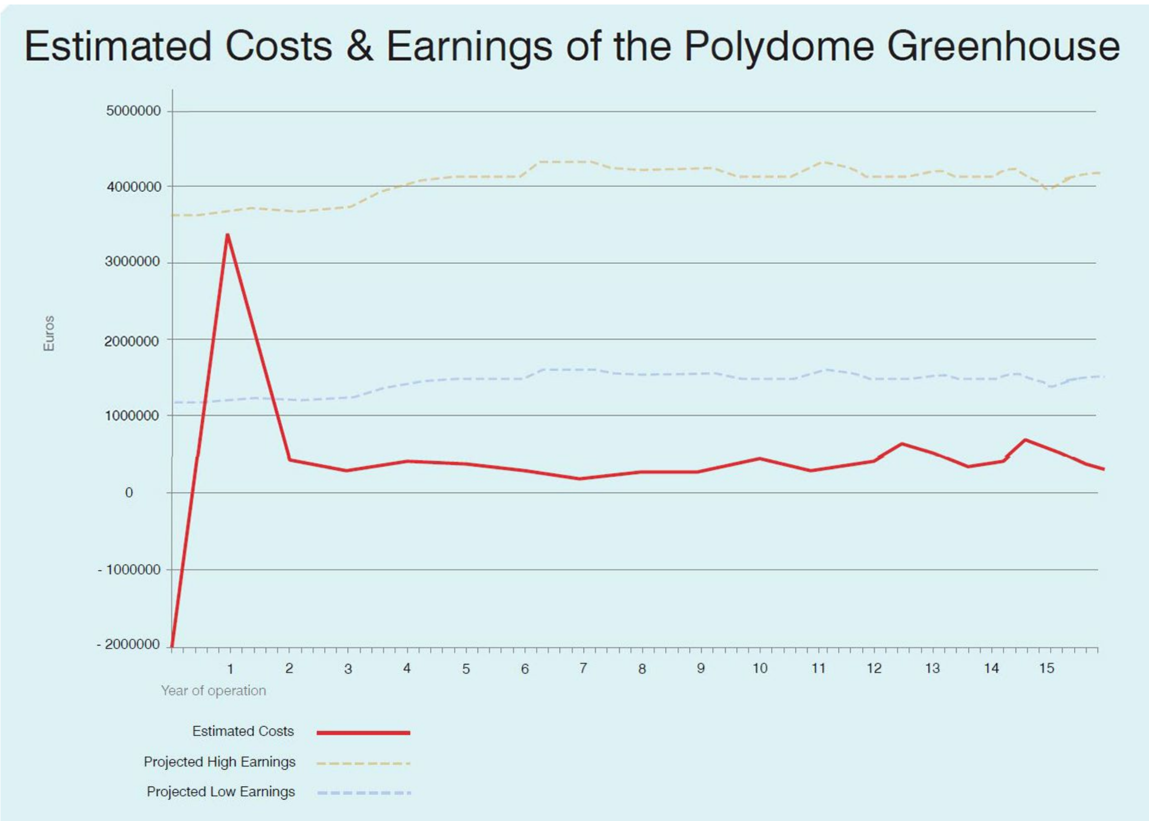

Figure 2.13: Estimated costs & earnings of the Polydome greenhouse.[28]

Aquaponic gardening

‘Aquaponics is the cultivation of fish and plants together in a constructed, recirculating ecosystem utilizing natural bacterial cycles to convert fish waste to plant nutrients. This is an environmentally friendly, natural food-growing method that harnesses the best attributes of aquaculture and hydroponics without the need to discard any water or filtrate or add chemical fertilizers.’

— Aquaponic Gardening Community, November 2010 [29]

Aquaponics is the combination of two distinct food production systems: aquaculture - the cultivation of fish in tanks for food purposes, and hydroponics - a method of growing plants using mineral nutrient solutions, in water, without soil.
Both of these techniques require lots of intervention. In Aquaculture, for example, one has to ensure that the waste from the fish is removed before it builds to toxic levels, or the fish will die. In Hydroponics, on the other hand, one has to constantly replenish the chemical nutrients and maintain a chemical balance, or the plants will die. By combining the two systems, a symbiotic relationship occurs between the aquaculture system and the hydroponic system. The waste product from the fish provides the food for the plants, and the plants in turn filter the water that goes back to the fish.

A Brief History of Aquaponics

Aquaponics has ancient roots. The Aztecs practiced a form of early aquaponics by raising fish alongside crops. They built artificial islands known as chinampas in swamps and shallow lakes and planted them with maize, squash and other plants. Canals navigated by canoe surrounded the islands and were used to raise fish. Waste from the fish fell to the bottom of the canals and was collected to fertilize plants.[30]

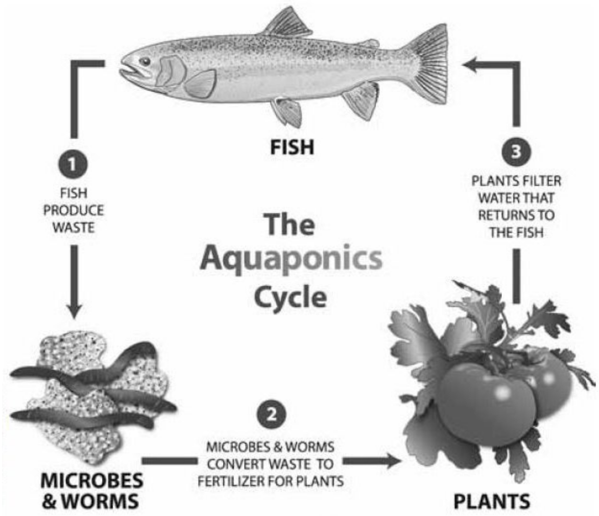

Figure 2.14: A diagram of the Aquaponics cycle. Image source: www.theaquaponicsource.com

In modern times, The New Alchemy Institute - a research center that did pioneering investigation into organic agriculture, aquaculture, and bioshelter design between 1969 and 1991 founded by Jon Todd, Nancy Jack Todd and William McLarney, made the first steps in the development of modern aquaponics. In their research, New Alchemy experimented with growing edible fish in ponds. They developed solar aquaculture ponds that consisted of translucent water tanks held above-ground. The fertile pond water was used for irrigating other crops located in the same greenhouse. This proved to be a successful way to raise edible fish, floating hydroponic crops, and irrigated greenhouse food crops. Thus, New Alchemy gave birth to the first form of a modern aquaponics system.[31]

In the 1980s Dr. Mark McMurtry and Doug Sanders at North Carolina State University developed an aquavegeculture system based on tilapia fish tanks sunken below the greenhouse floor. Effluent from the fish tanks was trickle-irrigated onto sandcultured hydroponic vegetable beds located at ground level. The nutrients in the irrigation water fed tomato and cucumber crops, and the plants and sand beds served as a biofilter. After draining from the beds using bell siphons, the water recirculated back into the fish tanks. The only fertility input to the system was fish feed. This system, later followed by other modifications and developments like the Speraneo system, the University of the Virgin Islands system, etc. became the basic standard for contemporary aquaponic gardening systems worldwide.[32]

Components of an Aquaponics system

The following are the basic components every aquaponics system should have regardless of the type of the system (the different system types will be discussed in the next section):

Fish tank
Theoretically any container that can hold water is sufficient. The size of the container depends on the type of fish used and the size of the entire system.

Tray for the plants
The type of tray used depends on the type of the system used. There are three types of aquaponics systems - media-based, NFT and deep water or raft (which will be discussed in the next section). Depending on the system, one should use rain guttering, half barrels, Styrofoam sheets, PVC pipe or channels, buckets or plastic containers. These need to be deep enough to hold between 15 and 30 cms of growing medium or water.

Growing medium
Again, this will be determined by the type of system used. Media-based systems usually use beds filled with gravel, peat moss, clay pebbles, perlite or coir as a growing medium. The other two systems (NFT and raft) don't use any growing medium apart from water.

Pumps
A water pump is needed to circulate the water from the fish tank through the growing medium and back to the tank.
An air pump is needed to aerate the water in the fish tank to achieve good levels of oxygen for both the fish and the plants. It works by taking air from outside the system and pushing it into the water.

Plastic tubing
Tubing is needed to carry the air and water through the system. Water pumps generally use 1.5 cm tubing while air pumps are set up for 0.5 cm tubing. Black plastic tubing is usually used for deterring algae from growing and clogging the tube.

A timer
Some systems require a timer to manage the turning on and off of the water pump, as with an ebb and flow system.

Biological filter
Some systems necessitate the use of a biofilter. An aquaponics system is just like an aquarium; good bacteria need to build up to convert dangerous toxins from the fish waste into less-harmful nitrites and nitrates. Gravel in the bottom of the fish tank is effective or a separate biological filter might be needed. Gravel, as part of the aquaponic system, can act as a biofilter, but bacteria needs to be built up again after every cleaning.

Plants
A wide range of plants can be used in an aquaponics system. Herbs, leafy greens like spinach, silverbeet and lettuce, strawberries or broccoli are examples of easy plants to grow which are suited for begginer practitioners. The type of system used will determine the type of plants grown. Most experts advise against trying to grow root vegetables like carrots, radishes and potatoes.[33]

Fish
Fish are the other part of the process that makes aquaponic gardening work. Decorative fish like goldfish or cichlids can be used or edible fish species like trout, carp or tilapia, the most common farmed fish worldwide, can be grown. It is important to source the fish according to the local climate of the aquaponics system in question.

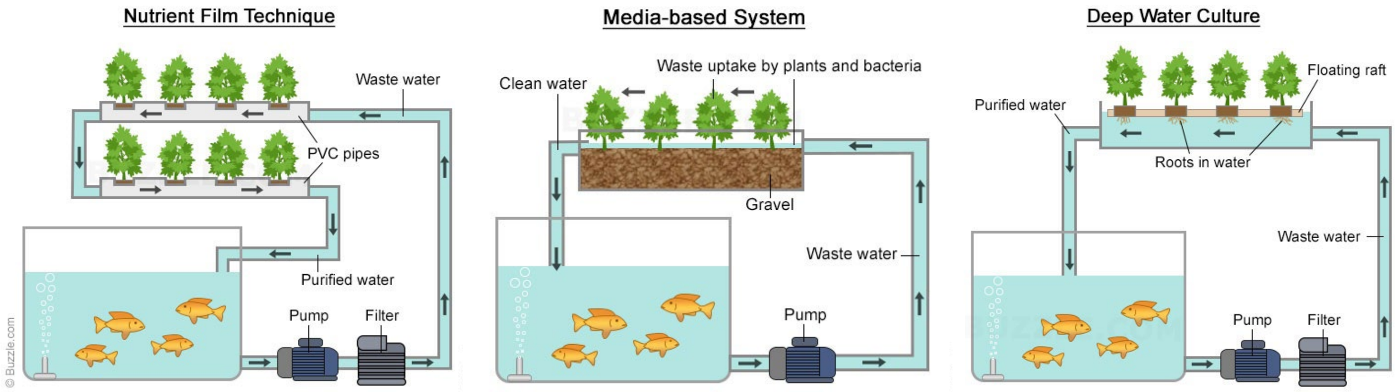

Figure 2.15: Diagrams of the three acuaponic systems: NFT, Media-based and DWC. Image source: www.buzzle.com [34]

Types of Aquaponics systems (figure 2.15)

Nutrient film technique (NFT)

This system is more appropriate for large-scale and commercial production because it requires an extensive system of pipes and filters to keep the water clean and the fish healthy.

With this system, plants are grown in suspended pots embedded in the pipe that feeds them water. A thin trickle of nutrient-rich water is run along the bottom of the PVC pipes, and the plants roots are able to reach the water and absorb as much as needed.

This system is designed for plants with small root systems, such as leafy greens veggies. Larger root would block the pipes and prevent the normal functioning of the system.

This system requires a separate filtration system given that there's no growing medium in which bacteria can develop.

Media-based systems

A media-based system uses gravel beds as the "soil" for the plants to grow. Containers are filled with rocks, gravel, or clay pebbles, and the seedlings are planted directly into this media. The water from the fish tank is pumped upward using a hydroponic system, and passes over the plants, through the rocks or pebbles, and back down into the fish tank.

This porous growing bed provides ample spaces for the growth of beneficial, nitrifying bacteria, therefore acting as a filter for the water containing the fish excrements and ammonia, and also allows for the cultivation of larger flowering and fruiting plants like tomatoes or cucumbers, as compared to the other two systems.

Deep Water Culture (DWC) or Raft system

In this system, a raft is made out of foam and floated on the water. Holes are cut into the foam, and the plant pots are inserted into the holes. The roots of the plants dangle in the water, which has been pumped from the fish tank, after it has been filtered to remove any waste materials.

This system as well require a separate filter given that there is no growing medium. This method is used mainly for large-scale commercial purposes as it requires large quantities of water to work efficiently. This system is appropriate for small root system plants. It's not possible to grow heavy plants, such as tomatoes and cucumbers.

a b c

Figure 2.16 (a,b,c): a. A commercial aquaponics system. An electric pump moves effluent rich water from the fish tank through a solids filter to remove particles the plants above cannot absorb. The water then provides nutrients for the plants and is cleansed before returning to the fish tank below where the process repeats. b. A Deep Water Culture hydroponics system where plant grow directly into the effluent rich water without a soil medium. Plants can be spaced closer together because the roots do not need to expand outwards to support the weight of the plant. c. Plant placed into a nutrient rich water channel in a Nutrient film technique (NFT) system. [35] [36] [37]

The ecological benefits of aquaponic gardening

Reduction of the overfishing of oceans:

- Over 2000 marine species are already extinct.[38] [39]
- In March 2009, the Food and Agriculture Organization of the United Nations reported that more than 70 percent of fish species were currently endangered.[38] [40]
- In a study at the National Center of Ecological Analysis and Synthesis at the University of California, scientists projected that, barring significant changes, the oceans would become barren of fish by 2048.[38] [41]
- According to some estimates, 85 to 95 percent of the fish caught by commercial fishers is bycatch (aquatic life accidentally harvested by trawlers). We only end up eating about 10 percent of all the marine life that is killed in order to feed us.[38] [40]

Aquaponic systems are closed systems that use nearly a fraction of the water used in other food production industries. It is a food production system with one of the lowest water footprint due to the symbiotic benefits created by the combination with Hydroponics (water is constantly recycled with the only loss being due to evaporation). Moreover, all of the nutrients in the system come from biological processes and therefore no toxins are emitted to the environment from runoff water. Therefore, aquaponics systems have no negative impacts on the oceans or marine life whatsoever.
By the adoption of large-scale aquaponic food production, the destructive effects of overfishing could be reduced, or perhaps even ceased altogether. The fish cultivated in aquaponic systems could constitute a healthy and nutritious food and protein source (there are no chemicals involved in the process.Furthermore, many nutrients such as omega-3 fatty-acids, which are not present to a great extent in conventional fish farming, are abundant in aquaponic fish products due to the ecosystemic conditions of the system)[42] that could substitue fish products cought in oceans. Furthermore, aquaponic systems don't necesserily have to be expensive and could therefore constitute an alternative profession for the millions of poor fisherman in developing countries.

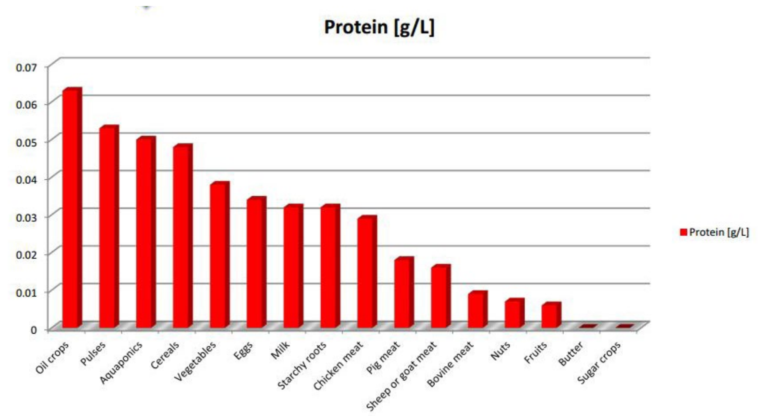

Figure 2.17 : Protein production per litre of water used of different food production systems. Aquaponics is one of the most water efficient systems in terms of protein production, outperforming most conventional food industries such as meat, milk and cereals. [43]

Reduction of the global food production water footprint:

As we saw in the previous chapter, industrial agriculture is responsible for the bulk of green water footprint around the world. Aquaponics systems do not discharge or exchange water. The system recirculates and reuses the water, with minimal losses due to surface evaporation and transpiration of the plants. As a result aquaponics systems use 90 to 99 percent less water than traditional food production systems for the growth of the same plants.[44] Therefore, if society will carry out a major shift to large-scale food production with aquaponics systems, it could significantly reduce global green water footprint, therefore saving large amounts of water for sustainable uses.
Aquaponics will also permit the reduction of the discharge of polluted and toxic waters, prevalent in industrial agriculture, which contributes to the pollution of potable water sources and of the oceans, as was discussed in the first chapter, thereby potentially contributing to a significant reduction of the global grey water footprint of industrial agriculture.

Reduction of land exploitation and deforestation:

- About half of the world's tropical forests have been cleared.[45]
- Forests currently cover only about 30 percent of the world's land mass.[46]
- Forest loss contributes between 6 percent and 12 percent of annual global CO_2 emissions.[47]
- About 36 football fields worth of trees lost every minute.[48]
- In the Amazon, around 17% of the forest has been lost in the last 50 years, mostly due to forest conversion for cattle ranching. [48]

As one can see from the list of facts above, forests and soils are precious resources under threat which have to be preserved. Aquaponic systems can be set up almost anywhere thanks to greenhouses and other technologies. Cities could contain large part of the food production systems with the use of Aquaponics. Aquaponic systems could be set up indoors, or outdoors, as well as in places such as public spaces or building rooftops. By reducing world meat consumption and shifting into large-scale aquaponics food production (including protein from fish) large tracts of land could be saved for forestation purposes and therefore the positive impacts of forests, such as carbon sequestration, fertile soil creation, development of beneficial ecosystems, increase in precipitation,etc., could be augmented.

a

b

Figure 2.18 (a,b) : An artificially lit Aquaponics system in the Belgium pavilion of the Milan 2015 Expo. Photographer: Tom Becker.

Figure 2.19 : An artificially lit Aquaponics system in the Oman pavilion of the Milan 2015 Expo. Photographer: Tom Becker.

Ecological and natural building materials and methods - benefits and a brief overview

As we saw in the first chapter, the building sector is one the major human activities with the biggest negative environmental impact (see p. 9). The production industries of conventional modern building materials (cement, steel, etc.) require enormous amounts of energy and emit signifcant amounts of greenhouse gases into the atmosphere. Moreover, the functioning of buildings contributes further to their environmental impacts; activites such as heating, cooling, electricity consumption, and waste generation constitute the major contributors to greenhouse gas emissions and energy consumption.

Ecological building methods usually employ natural materials, such as wood, earth and straw, due to their environmentally-friendly properties such as renewability, biodegradabilty and low energy demands. Recycled materials are also used extensively in order to minimize waste and exploit free or cheap locally available building materials.

Lo-tech building methods, with the use of natural or recycled materials, have several significant benefits over more conventional 'hi-tech' building methods, that usually make use of industrial building materials such as composite timber products, glass, reinforced concrete, steel and non-biodegradable polymers for coatings and insulation:

- Natural and/or recycled materials have very low energy requirements for their harvest, extraction or production in comparison to the more conventional industrial 'hi-tech' building materials, which require complex industrial processes for the extraction of the raw materials needed to produce them, and high quantites of energy for their production in factories.

- Natural or recycled building materials can be usually found locally, therefore reducing the costs and energy demand required by conventional building materials for transportation.

- Natural and recycled building materials can be frequently found for free in proximity of the building construction site, or for significantly low prices in comparison to those of conventional building materials. Furthermore, these materials are less (if at all) dependent on market conditions and therefore their prices are not as prone to sharp fluctuations.

- Natural building materials are non-toxic and are therefore healthy for the environment and for the people who occupy the buildings.

- Natural building materials are biodegradable and can be easily disposed of, or recycled, with low quantities of energy, low costs and minimal environmental damage if any.

- Lo-tech ecological building methods with natural or recycled materials are significantly simpler than conventional building construction methods and can be done with simple manual tools, rather than industrial machinery and cranes. Therefore, it is much easier for home owners or small communities to build their own houses and settlements, saving on labour costs and thus contributing to a renewed social and spiritual connection with buildings.

Some of the downsides of the use of natural building materials are: the susceptibilty to biological infestations, depending on the building materials used; higher maintenance needs; the impossibility of building above a certain number of storeys or height (usually with wooden-frame buildings four storyes are the limit, although engineering studies have confirmed the feasibiliy of up to thirty-storey engineered wooden-frame buildings)[49]; and in earth construction, major susceptibility to damages created by rainwater or exposure to certain types of weather.

However, some of these conditions don't necessarily have to be negative in a social context. For example, the need for constant maintenance of lo-tech houses can strengthen the emotional connection between home owners and their houses through the maintenance operations executed by them; a phenomenon we rarely see in modern society. Moreover, the height limit imposed by lo-tech building technologies is not significantly relevant for the purposes of building small self-sufficient urban farmer communities, which is the subject of this thesis work, since it is better for buildings to maintain a humane scale and high population densities may even impede the appropriate functioning of urban farms.

A brief overview of prevalent natural building methods and materials

The following section is based largely on information retrieved from 'Networks Production's website; a non profit organization that promotes different ecological buildings and agricultural projects around the world (www.networkearth.org).

Adobe

Adobes are sun-dried mud bricks stacked with a mud mortar to create thick-walled structures. These thick earthen walls provide what is known as "thermal mass" which helps to modulate interior temperatures by absorbing excess heat during the day and slowly releasing it at night. (In chilly climates, thermal mass needs to be insulated to prevent creating a net heat loss in winter.) The use of adobes dates back centuries in traditional earth-building areas such as North Africa, the Middle East, South America and the United States Southwest.

Figure 2.20 : Adobe brick house under construction in Romania. [50]

Adobe bricks are made with a completely saturated mixture of clay and sand, poured or pressed into forms, which are removed either immediately or after the brick has partially dried. Adobes can take an infinite number of shapes and sizes which are utilized for specific techniques (for example, small leaning bricks used for building arches). After the bricks have dried for several days, they are turned on edge for further drying, then stacked for transport or for use on site. The adobes are laid on an appropriate foundation (usually stone or concrete) using typical masonry techniques with thick joints to take up the difference in size of the adobes. Typically, mud mortar is used, but a concrete- or lime-based mortar can also be used.

Different measures should be taken to protect adobe walls from water: wide eaves are necessary to protect the walls from rain (except in arid climates), the foundations must protect the walls from ground moisture and gutters are used to prevent splashing. Adobe walls are ususally finished with mud plaster which requires replenishment every few years.

Cob

Cob is an ancient technique of building monolithic walls using loaves of "cobs" of moist earth and straw that has similar thermal properties to adobe and rammed earth.
In recent years this technique is being revived by green builders in North America and Northern Europe.[52] Virtually unknown in North America, cob was reintroduced by Welsh architect and permaculturist Ianto Evans, who started the "Cob Cottage Company" with his wife Linda Smiley after intense interest in his $500 self-built cob home.[52]
This technique lends itself to sculptural curved objects.
Owner-builders can "sculpt" their own houses into endless forms, including decorations and details. The process of building with cob entails mixing local subsoil with sand and/or clay (depending on the composition of the base earth) and straw or other fibrous materials to create a stiff mud which is formed into small loaves (cobs). Cob walls are then costructed in proceeding layers of up to 45 cm (using higher layers poses the risk of slumping). Each layer needs to be given time solidify before proceeding with the next; that is why cob construction is a labor-intensive and has a significantly long construction period (cob walls take up to a year to cure fully). The benefits of cob are its cheapness, thermal properties, availability, and the great expressive architectural freedom it permits for owner-builders and architects, as well as the ecological benefits of earth stated previously.

Figure 2.21 : A modern cob house near Ottery St Mary in the United Kingdom. [51]

Compressed Earth Blocks/Bricks (CEB)

Compressed Earth Blocks are similar to adobes, with the main differences being they are not fully saturated with water, are more dense than adobes, and are usually significantly more uniform. These blocks are created using a variety of machines. Some, like the Cinva-Ram invented in South America, use human labor and are relatively inexpensive.[54] Expensive fuel-powered machines, on the other hand, can produce thousands of bricks in a day (figure 2.23).

Because of their uniformity, compressed earth blocks need little mortar, and can even be dry-stacked. This uniformity also speeds up the laying process and results in straighter walls. A house was built several years ago by CRATerre, a French earthbuilding education and research group, in a total of 24 hours using compressed earth blocks.[55]
More recently, an inexpensive, innovative machine has been invented in Auroville, India, which can make a wide variety of sophisticated block shapes using human power. This machine was demonstrated at the UN Habitat II conference in Istanbul, where a domed prototype house was built in a week by volunteers and local labor.[55]

Figure 2.22 : Building a CEB project in Midland, Texas in August 2006 [53]

Figure 2.23 : Compressed earth block press. Image source: http://opensourceecology.org/wiki/CEB_Press

Earthbag construction

Earthbag is a technique that entails the use of sacks or tubes filled with stablised (usually with lime) earth for the construction of walls, arches and domes (figure 2.24). This technique has been used in Europe by the german architect Gernot Minke and is currently being pioneered in the U.S. by Persian architect Nader Khalili of the California Institute of Earth Art and Architecture (Cal Earth), who has dubbed the technique "superadobe."

To build with this technique, moistened soil is placed into a bag set in place on the wall, the bag is lowered into place, then compressed using a hand tamper.

Heavy earth mixtures can be used with weaker burlap bags as the compressed soil makes the bags redundant once it sets, while stronger, structural polypropylene bags are preferable for sandy soils. The polypropylene deteriorates with prolonged exposure to sunlight, so it is important that the structures are plastered quickly. Long tubes of the bag material are filled and stacked like a coiled ceramic pot. Recycled sacks are often available free or at minimal cost.

Figure 2.24 : Construction of the Eco Dome. For each room a string is staked to ground in the at the center of curvature, the string is then used as a guide as the structure is built up so that each layer is evenly distributed. Image source: www.calearth.org

Figure 2.25 : A house built with earthbag construction. Image source: www.calearth.org

Rammed Earth

Rammed earth is an ancient earthbuilding technique currently undergoing a renaissance in developed countries across the world. It has been revived in France by CRA-Terre, in Australia by Giles Hohnen and others, while its main proponent is the U.S. is David Easton, author of The Rammed Earth House. Usually more expensive than conventional construction, this technique has been updated with improved engineering, sophisticated forms, and innovative design to make rammed earth competitive with conventional construction.

Rammed earth has the advantage of excellent thermal mass (which in some climates would be a detriment unless insulated) as well as strength, comfort and beauty. Rammed earth can be built with simple forms and tools, with less handling than other earthbuilding techniques, as the material cures in the wall, and can be built in a variety of climates. Walls do not need to be plastered and will last for hundreds, even thousands of years (the great wall of China is partially built of rammed earth). It has been used to build structures of up to seven stories in Yemen.

First setting up forms on top of an appropriate foundation (usually stone or concrete), a soil mixture with a clay content of 20% and a moisture content of 10% is then rammed in layers or "lifts" of 15-20 cm using mechanical or hand tampers. Different soil types can be layered to create decorative effects and the whole is topped by a concrete bond beam which then holds the roof.

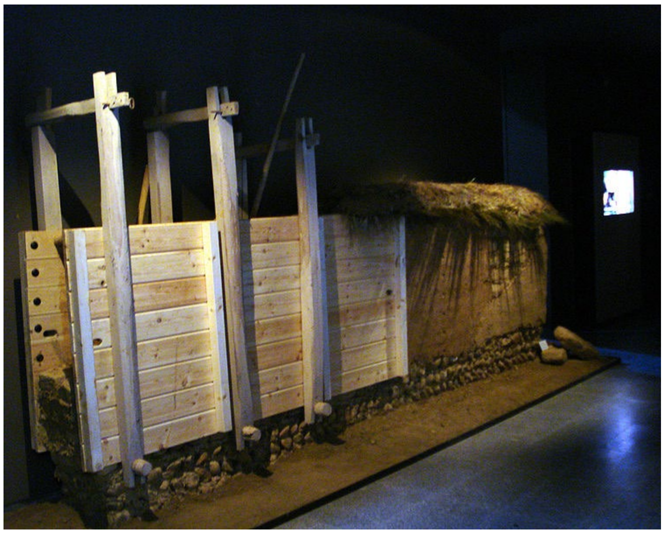

Figure 2.26 : Model showing construction of rammed-earth wall on foundation. [56]

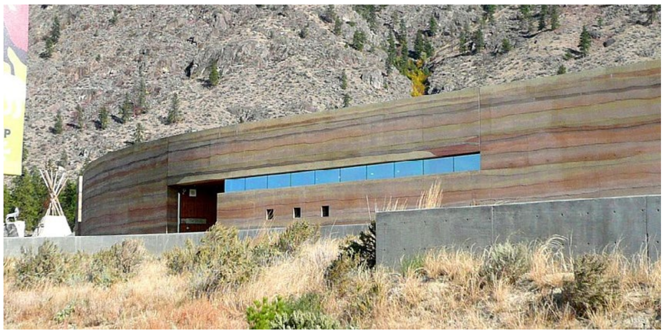

Figure 2.27 : Nk'Mip Desert Cultural Centre in Osoyoos, British Columbia, Canada, completed in 2006. [57]

Straw-bale construction

Initially invented by american farmers, the construction of walls with bales of straw is becoming ever more popular in North America, Europe, Australia and other countries across the world. Straw-bales are cheap to buy and easy to build with. Straw is an annualy renewable crop which is actually a waste product of agriculture. Most of the straw is currently burned in fields. Therefore, straw can be used without any energy requirements for its production. The thick walls offer superior insulation value, averaging R-48 for an 45 cm wall. Bales are easy to work with, lightweight and require a minimum of tools. With a natural plaster, straw bale walls "breathe," and together with the sound-absorbing qualities, provide a quiet, healthful interior environment. Straw bales can also be combined to great effect with other natural building systems. Bales of straw can be used either as infill in post and beam construction, usually with a wooden-frame, or even as load-bearing

Figure 2.28 : Straw bale construction [58]

Figure 2.29 : Exterior view of straw bale library in Mattawa, Washington taken in 2008 (constructed 2002 by IronStraw Group) [59]

walls in small buildings and ceratin types of climate. Bales are secured to a foundation (usually concrete or stone) with pins or strapping. They are laid in a running bond and pinned together using rebar, wood stakes or bamboo. The roof is then attached to a top plate. The bales are commonly wrapped with stucco netting and plastered with mud, lime-sand or cement plaster. In some cases plaster is applied directly to the bales.

Straw bales aren't currently made to the same levels of tolerance and specification as bricks or cement. The fact they're generally slightly different sizes combined with the need to keep bales dry during construction has meant most conventional builders would not, until recently, consider straw bales a viable solution. This is why, for the last ten years, the University of Bath, UK, has been working with a local company, ModCell (www.modcell.com), to develop prefabricated straw bales. The development of prefabricated wall panels using straw bale for insulation permit the standadization of this building material and easier use for conventional contractors and builders. Prefabrication, or off-site manufacture, means that wall panels can be made to a very high specification in a factory, protected from variable weather conditions that would otherwise inhibit on-site building with straw.

Earthships

"Earthships" are the name for the independent living structures utilizing passive-solar design and recycled materials developed by Michael Reynolds of Solar Survival Architecture. Earthship construction integrates natural buildings materials, such as adobe and lime plaster, with recycled waste, such as car tires and retrieved window panes.

Figure 2.29 : Brighton Earthship, UK [60]

Earthship is a system rather than a technique: initially, the structure is dug into a south-facing hillside; soil-filled tires are then stacked like giant bricks to form side and interior walls providing a source of thermal mass; old bottles and cans are used to create interior walls and a variety of detail features, and to fill in gaps between tires; the building is framed in wood on the south side and roofed to collect rain water. Other systems include integrated wastewater treatment, photovoltaic electrical systems, solar hot water and passive-solar heating.

Advantages of the system include near-total self-sufficiency, the use of recycled materials and local soil, and technical and aesthetic sophistication. Disadvantages include the complexity of construction and high labor requirements.

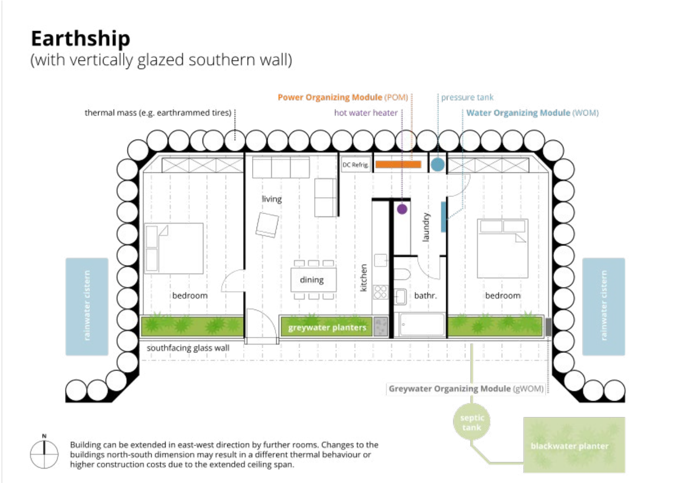

Figure 2.30 : Earthship typical floorplan [61]

Wood

The benefits of wood as a building material are well known across the world in conventional and vernacular building practices: It's flexibility, availability, cheap costs, sturdiness and aesthetic characteristics. As we have seen in the previous chapter, deforestation is a major problem that has significant negative consequences on the environment. In countries such as The United States, Canada, Australia and New Zealand, most private houses are still built entirely out of wood. The massive demand for timber and other construction wood products could be reduced significantly by the use of some of the building methods presented above (adobe, cob, rammed earth, straw-bale, etc.) for the construction of infill walls, whilst leaving the use of timber and other wood prodcuts only to parts of the buildings where the properties of wood are essential, such as roofs, and structural frames.
Moreover, wood used for construction should come only from forests managed sustainably. In the United States and Canada for example (countries in which most houses are built completely out of wood) tree growth each year greatly exceeds the volume of trees harversted[62], so with sustainable forestry practices, and a reduced demand for wood as an infill material

for walls, wood can become an entirely renewable and ecological resource for building materials.

The canadian architect Michael Green, of Michael Green Architecture, has developed together with structural enginners, a feasibility study - 'The Case for Tall Wooden Buildings' (see bibliography), in which he tries to demonstrate the viability of wood as a structural building material for skyscrapers of up to 30 storyes. The study introduces a new construction model for tall buildings known as 'Finding the Forest Through the Trees' (FFTT). This structural solution utilizes mass timber panels - solid panels of wood engineered for strength through laminations of different layers - to achieve a much lighter carbon footprint than the functionally equivalent concrete and steel systems. Preconceptions of mass timber construction are acknowledged throughout the study, showing that this mass timber structures are capable of meeting fire and life safety needs while staying within cost competitive marketplace conditions.

In the future, high-rise buildings and skyscrapers in addition to being constructed with FFTT structural model (having structural frames built with wood), may also utilize some of the natural building material presented above as infill materials for the walls. This could constitute a new green revolution in the history of architecture.

Figure 2.31 : The completed frame of a modern timber frame home. [63]

Figure 2.32 : Micheal Greens hypothesis for a 30 storey skyscraper with a mass timber panels structural frame and a glulam curtain wall. [64]

A brief overview of green technologies

In this section i will present a brief overview of some of the most important green technologies that, in my mind, will and are already an important part of the transition our society will have to undergoe, and that will constitute an integral part of the urban-farm settlement typology proposed in this thesis. Most of the information in this section was taken from the NREL's (national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy) website (see bibliography).

Renewable energy production systems:

Photovoltaic panel systems:

Photovoltaic panels convert sunlight into electricity. Although many types of solar electric systems are available today, they all consist of basically three main items: **modules** that convert sunlight into electricity; **inverters** that convert that electricity into alternating current so it can be used by most household appliances; and possibly or sometimes **batteries** that store excess electricity produced by the system. The remainder of the system comprises equipment such as wiring, circuit breakers, and support structures.

Photovoltaic panel modules can be integrated into glass walls, building façades and skylights, therefore constituting an integral part of the architecture of ecological buildings, influencing their form and aesthetic and contributing to their self-sufficiency and economy.


Figure 2.33 : The Solar Settlement, a sustainable housing community project in Freiburg, Germany. [65]

Passive solar heating and lighting systems:

Designs that exploit sun exposure for heating and lighting purposes in buildings, without any mechanical devices, pumps or fans are called 'Passive Solar'. Its most basic features include large, south-facing windows that fill the home with natural sunlight, and dark tile or brick floors that store the sun's heat and release it back into the home at night. In the summer, when the sun is higher in the sky, window overhangs block direct sunlight, which keeps the house cool. Tile and brick floors also remain cool during the summer.

Passive solar designs are usually integrated with energy-efficient construction features, such as energy-saving windows, highly-insulated walls, and natural ventilation systems, in order to maximise the performance of the building.

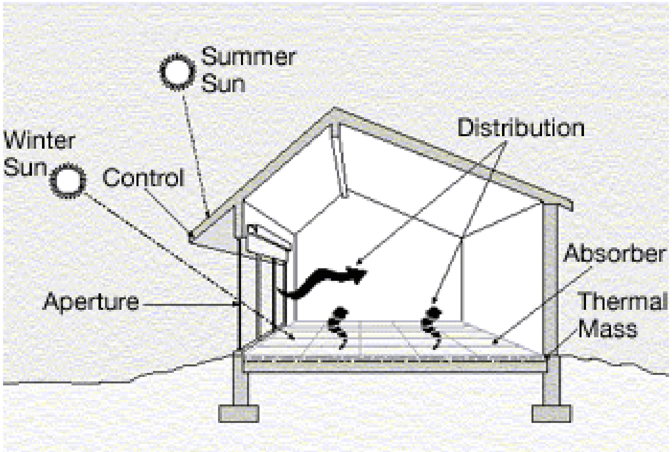

Figure 2.34 : Elements of passive solar design, shown in a direct gain application. [66]

Solar water heating systems:

Most solar water-heating systems consist of a solar collector and a water storage tank. Solar water-heating systems use collectors, generally mounted on a south-facing roof, to heat either water or a heat-transfer fluid, such as a nontoxic antifreeze. The heated water is then stored in a water tank similar to one used in a conventional gas or electric water-heating system.

There are basically three types of solar collectors for heating water: flatplate, evacuatedtube, and concentrating. All three types of collectors heat water by circulating household water or a heat-transfer fluid such as a nontoxic antifreeze from the collector to the water storage tanks. Collectors do this either passively or actively (that is, with or without the use of electricity). Passive solar systems don't have any electrical compononents and are usually considered more reliant, easier to maintain and longer-lasting. Active systems are more expensive but also more efficient. The amount of water heated depends on local climate, solar orientation and the type and size of the system.

Figure 2.35 : Passive (thermosiphon) solar water heaters on a rooftop in Jerusalem, Israel. [67]

Geothermal heat pumps:

While air temperatures can vary widely through the seasons, the temperatures of the shallow ground only range from 10° to 20°C depending on latitude. Geothermal heat pumps draw on this relatively stable temperature as a source for heating buildings in the winter and keeping them cool in the summer.

Through underground piping, a Geothermal heat pump discharges heat from inside a building into the ground in the summer, much like a refrigerator uses electricity to keep its interior cool while releasing heat into your kitchen. In the winter, this process is reversed; the Geothermal heat pump extracts heat from the ground and releases it into a building.

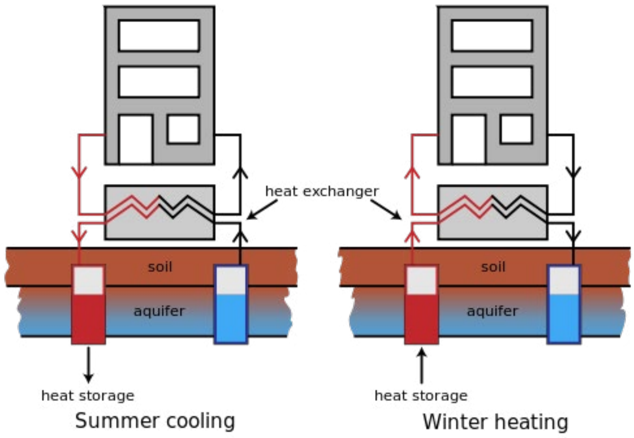

Figure 2.36 : A heat pump in combination with heat and cold storage. [68]

Because Geothermal heat pumps actually move heat between homes and the earth, instead of burning fuels, they operate very cleanly and efficiently. In fact, Geothermal heat pumps are at least three times more efficient than even the most energy-efficient furnaces on the market today.

Biomass electricity generators:

Electricity can be generated with biomass in a process called gasification - the conversion of biomass into gas, which is burned in a gas turbine. The decay of biomass in landfills also produces gas, mostly methane, which can be burned in a boiler to produce steam for electricity generation or industrial processes. Biomass can also be heated in the absence of oxygen to chemically convert it into a type of fuel oil, called pyrolysis oil. Pyrolysis oil can be used for power generation and as a feedstock for fuels and chemical production.

Biofuels:

Biomass can be converted directly into liquid fuels, called biofuels. They can be used for fueling vehicles and for power generation. The most common biofuel is ethanol, an alcohol made from the fermentation of biomass high in carbohydrates, made usually from corn or soy beans.

Hydropower plants:

Hydropower plants convert the kinetic enregy of flowing water, usually from waterfalls, into electric energy through the use of tubines. They are therefore extremely context-dependent and usually constitute a viable solution on a national or regional level rather than in local community settings. However, especially in mountainous settings, hydropower plants can generate a significant part of the electricity needs also for small-scale communities and households if these are situated in the proximity of a natural water source or waterfall.
Therefore, hydropower will continue to be one of the most important renewable energy resources in the world on the national level while it probably won't constitute a significant part of the urban-farm community model presented in this thesis.

Wind turbine technology:

Wind turbines are highly sophisticated power systems that produce electricity from the kinetic energy of winds with the use of blades called **airfoils**. Wind turbines range in size and capacity from small 50 KW systems, used to charge batteries, electrify homes, pump water for farms and other similar uses, to large scale 1 or 2 MW systems that provide electricty directly to national grids.

The assessment of the output potential of a wind power plant in a specific location is a difficult and complex operation, depending on the characteristics of the winds that blow in the area where the plant is to be created. The conformation of a land affects the speed of the wind. Obstacles can strongly influence the speed, power, direction and distribution of winds.

Nevertheless, wind energy is one of the most efficient renewable energy resources and it has been the fastest growing source of energy in the world sinche 1990, increasing at an average rate of over 25 percent per year; a trend driven largely by dramatic improvements in wind technology.[72]

Figure 2.37 : A bus fueled by biodiesel. [69]

Figure 2.38 : A small Quietrevolution QR5 Gorlov type vertical axis wind turbine in Bristol, England. Measuring 3 m in diameter and 5 m high, it has a nameplate rating of 6.5 kW to the grid. [70]

Figure 2.39 : The Nordex N50 wind turbine and visitor centre of Lamma Winds in Hong Kong, China. [71]

Reuse of used cooking oil as biofuel:

In London, two companies, Uptown Oil and Pure Fuels, manufacture diesel out of discarded oil used for frying collected from nearby bars, restaurants and cafes, manufacturing an average of 25,000 to 30,000 litres of low-emission biodiesel every week, serving a large portion of London's taxies.[73]
After intensive filtration and treatment, a clear fuel arrives; ready for the waiting vehicles. Even the by-products are sold: glycerol for instance is used to make soap. The product is much more environmentally friendly than regular fuel. The carbon-dioxide emissions from the oil are about 80% below those from normal diesel, while particulates - tiny pollution particles associated with heart and lung disease and responsible for around 4,000 premature deaths in London each year - are 60% lower.[73]

This is an example of a private enterprise that could become a model for a new policy of local governments for the promotion of laws which encourage similar businesses to form, and for the creation of appropriate legislation which obiges restaurant and cafes to cooperate. It is also a strategy that could be used on a local scale, in urban farm settings and sustainable households.

Water and nutrients reuse and recycling methods

As was discussed in the previous chapter, water is one of the most important natural resources and is currently under threat by pollution, climate change, and desertification caused by deforestation and harmful agricultural practices. Also, large part of the nutrients found in the food we eat ends up in the sewers or as waste that is burned down. Therefore, systems for the reuse and the recycling of water and nutrients are and will be an integral part of any sustainable design for human settlements or agricultural lands. The following are some of the most efficient sustainable water and nutrient reuse and recycling systems in use nowdays in various ecovillages, sustainable households and ecological farms across the world. These systems will become an integral part of sustainable design in the future and of the urban-farm project presented in the next chapter.

Use of biodegradable and non-toxic detergents and soaps:

Wastewater that is discharged to the greywater system ends up in the garden soil and can either be beneficial or harmful to soil, water systems, and plant life. Salt and Boron found in soaps and other chemical toxins found in different cleaning products may kill soil, water and plant life and therefore should not be used in grey water recycling systems. Therefore with grey and also black water recycling systems only products labeled as biocompatible or biodegradble should be used. [74]

The effect of certain cleaning product ingredients depends in part on what type of greywater system is in place. If the greywater is going into the soil through a terrestrial basin, Nitrogen and Phosphorus ingredients are not a problem and in fact end up as soil nutrients. If the greywater is passing through a freshwater wetland, however, Nitrogen and Phosphorus can lead to harmful algae growth and should be avoided. Conversely, Sodium is much more harmful to soil health than it is to a wetland system. A detailed chart of these variables can be found in Art Ludwig's book Create an Oasis with Greywater (see bibliography).

Use of greywater for irrigation:

Greywater is used water from sinks, baths, washing machines, etc., which doesn't contain any fecal matter. This water, if only biocompatible cleaning products are used, can be used for irrigation of plants (as well as food growing plants) and gardens. Houses which reuse grey water need to have two separate water drainage systems for grey and black water respectively. The water from greywater drainage system, instead of being disposed to the sewer, will be collected in appropriate containers and reused.
Rain water collection systems:

Rainwater from roofs and streets can be collected with approriate systems and reused for different purposes such as irrigation, water for livestock, domestic uses and, if properly treated, even as drinking water.
Furthermore, the use of permeable surfaces for streets and roads, as well as keeping as much vegetation and open green areas for the percolation of rain water into the soil, is extremely important in order to prevent the run-off of fresh water to sewers, where they will become unusable.


Figure 2.40 : Rainwater capture and storage system at the Monterrey Institute of Technology and Higher Education, Mexico City. [75]

Compost toilets:

Composting toilets are a type of dry toilet that uses a predominantly aerobic process to treat human excrements. There are usually two types of composting toilets, those that complete the composting process 'in situ' and those that are emptied to a separate compost pile remote from the toilet itself. Soak materials are usually added to the excrements in order to absorb excess liquid, cover human waster materials, exclude flies, reduce odours and balance carbon to nitrogen ratio.
The feces are left to decompose aerobically in a cointainer for long periods of time. The process of converting human excrement into safe and usable compost material can take between 3 months to a few years depending on factors such as climate, temperature and the particular system being employed; and in 4-6 years will become highly mineralized soil. Some composting toilet models are concomitantly turning urine into an odor-free, pathogen-free organic liquid fertilizer. Some countries, for example Sweden, allow this liquid to be used in agriculture after a storage period of 6 months. In the full size composting toilets, urine is going through a process called nitrification, resulting in an odor free and practically bacteria free liquid fertilizer.[77]

Figure 2.41 : Composting toilet at Activism Festival 2010 in the mountains outside Jerusalem, Israel. [76]

Organic waste compost:

Organic waste left to decompose can be used as a fertilizer or for soil amendment. The simplest form of composting is just accumulated green waster left to decompose in become hummus fater a period of a few weeks or months. The decomposition process is aided by shredding the plant matter, adding water and ensuring proper aeration by regularly turning the mixture. Worms and fungi further break up the material. Bacteria requiring oxygen to function (aerobic bacteria) and fungi manage the chemical process by converting the inputs into heat, carbon dioxide and ammonium. The ammonium ($NH4$) is the form of nitrogen used by plants. When available ammonium is not used by plants it is further converted by bacteria into nitrates ($NO3$) through the process of nitrification.

The result is a nutrient rich organic matter which is highly affective as a fertilizer, soil conditioner, a natural pesticide, and as an addition of vital hummus (fertile layer) to the soil.


Figure 2.42 : Compost. [78]

Constructed wetlands:

Constructed wetlands are engineered bodies of water designed for the treatment of polluted wastewater from plants, sewage or stormwater runoff. They can be used to treat greywater, or for waste water treatment (black waters). They can be used after a septic tank for primary treatment, in order to separate the solids from the liquid effluent. Vegetation in a wetland provides a substrate (roots, stems, and leaves) upon which microorganisms can grow as they break down organic materials. This community of microorganisms is known as the periphyton. Constructed wetlands can also be used to remove sediments and contaminants such as heavy metals from water.

There are two main types of constructed wetlands: subsurface flow constructed wetland and flow constructed wetland.

Subsurface flow constructed wetlands can be either with vertical flow or horizontal flow. In the vertical flow constructed wetland, the effluent moves vertically from the planted layer down through the substrate and out. In the horizontal flow constructed wetlands the effluent moves horizontally, parallel to the surface. Vertical flow constructed wetlands are considered to be more efficient with less area required compared to horizontal flow constructed wetlands. However, they need to be loaded at intervals and their desing is considered more complex than that of horizontal flow constructed wetlands.[80]

Surface flow wetlands can be used for treatment of wastewater plant and runoff stormwater. Pathogens are destroyed by microorganims, natural decay, exposure to sunlight (UV radioation) and sedimentation.
However, surface flow constructed wetlands may encourage mosquito breeding. They may also have high algae production that lowers the effluent quality and due to open water surface mosquitos and odours, it is more difficult to integrate them in an urban neighbourhood.

Figure 2.43 : Constructed wetland in an ecoological settlement in Flintenbreite near Luebeck, Germany. [79]

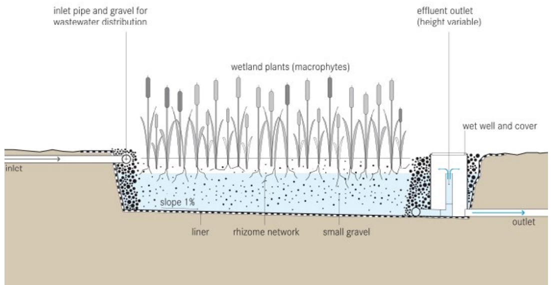

Figure 2.44 : Schematic of a horizontal subsurface flow constructed wetland: Effluent flows horizontally through the bed, from one side to the other. [81][82]

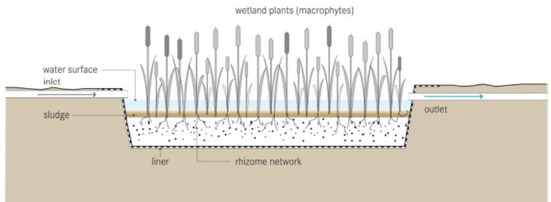

Figure 2.45 : Schematic of a free-water surface constructed wetland: It aims to replicate the naturally occurring processes, where particles settle, pathogens are destroyed, and organisms and plants utilize the nutrients. [83]

Conclusions of chapter 2

In this chapter we explored the main solutions for the enrgy and environmental crises in different areas such as: construction materials and methods, renewable energy production systems, organic agriculture, and reuse of water and nutrients.

These different methods and technologies will not be able to solve our current energy and environmental crises: if global energy demand will not be drastically reduced; if global meat consumption will not be drastically reduced; if we will continue with our consumerist lifestyles and obsession with materialistic values; without appropriate legislation and governmental support in the national and regional levels; and without an appropriate environmental planning schemes which will allow the growth of holistic ecological settlements which incorporate all or most of the different strategies described in this chapter.

Contemporary society will undergoe a systemic revolution in the century to come. With the wise application of the different available solutions examined above this revolution could be a positive and pleasurable experience for human beings.

In the next chapter i will describe the urban farm community project for the Innocenti area in Milan. I will firstly begin with the description of the site's characteristics, geographical features, history ,and urban and spatial potentialities.
In the second section i will proceed with the verbal description of the project, starting with the goals and strategies employed, and proceeding to the description of the project's functioning, contents and structure.

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Chapter 3 - A project for a new urban-farm community in the ex-Innocenti area of Lambrate, Milan

3.1. Lambrate and the ex-Innocenti's Lambretta factory area

context, geography, and potentialities

The site (37 hectares) i chose for the project is the area where the Lambretta scooter factory of the Innocenti metal works company used to be located until 2012. The project's site is located in the eastern periphery of the metropolitan area of Milan, between the Lambrate and Rubattino districts of Milan to the west and the Redecesio district of the satellite town of Segrate to the east. The project's site is confined to the west by the A51 highway, which seprates it from the Lambrate and Rubattino districts, and by the Lambro river that flows under the highway. To the east, the project's site is confined by the industrial zone of Redecesio, which separates it from the residential neighborhoods of Redecesio further east. The northern and southern confines of the project's site are bordered by mixed industrial and agricultural terrains with the presence of the 'Fondazione Sacro Cuore' to the north, a traditional historic farmsted (cascina) to the northeast, and various industrial activites to the south.

Figure 3.1 : Satellite image of the project's with it's urban context. Image scale: 1 : 17,000. Coordinates: 45°28'50.28"N 9°15'24.37"E. Image source: Google Earth

3.2. A project for a new urban farm eco-community - description

The project's main goal is to create a new model for ecological human settlements as a solution for the environmental crisis. This ecological settlement will be comprised of a community of eco-farmes and workers, an intensive ecological food production system inside the renovated warehouses of the abandoned Lambretta factory, a local biomass fueled CHP plant and green public spaces.The urban farm eco-community will present the following properties:

- exclusive use of renewable energy resources

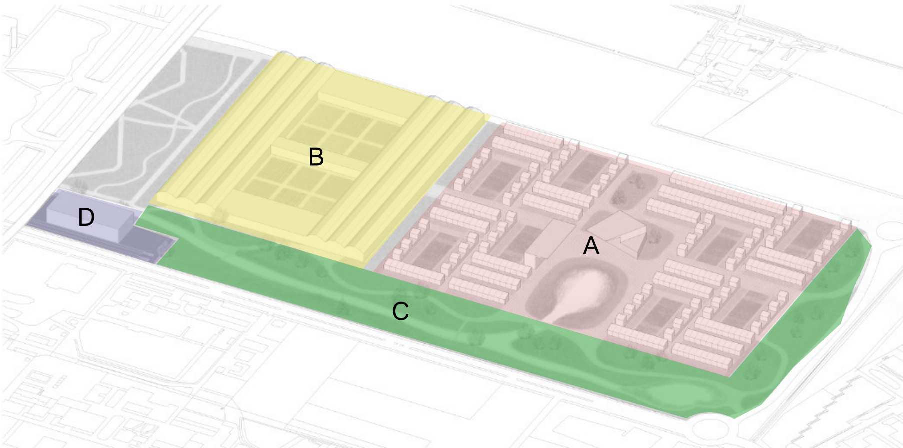
- low energy requirements

- economy based on local production

- self-sufficiency

- holistic management based on the principles of ecology (no waste)

The project will aim to reach these goals by the merging of the three different spheres of human activities: living, agriculture and production, in order to become a holistic self sufficient entity which functions in the same cyclical fashion as nature.



Different zones of the project

A. Residential quarter:

The residential quarter for a population of 1156 will be composed of Zero energy single family houses divided into two different block typologies: blocks of east-west orientation (with a deviation of approximately 15°) of row-houses, and blocks of north-west orientation (15°), in which the ground floor is a continuous volume, and the first and second floors are a series of monoblock single family houses. This arrangement is chosen in order to maximise the numer of south facing facades for the houses. In the central part of the residential district the two large buildings containing the community center and other community services are positioned. A big organic lake, for fish cultivation and for the collection of rainwater, constitutes the focal point of the residential district. The space formed between the two communal buildings and the lake creates a semi - roofed plaza which functions as a the neighborhood's main public space.

B. Warehouses:

The renovated warehouses of the abandoned Lambretta factory will host the main agricultural activites. The warehouses will include a polyculture zone, an aquaponics zone, food forest gardening zone, logistic centers, offices and a commercial center. (for full description see presentation board n. 6)

C. Green public spaces:

The area around the Lambro river deviation will combine green public spaces with private patches of land destinted for bio-intensive food production. A system of bike lanes and pedestrian trails will run through this area connecting Lambrate to the west with the residential district and Redecesio to the east. The idea is to integrate ecological food production with the urban and public landscape.

Different compononets of the urban eco-farm community project (for a full description see presentation board n. 5):

a. A polydome system for bio-intensive food production with integrated commercial center and food market

b. Outdoor polyculture food cultivation

c. Constructed wetlands for grey water treatment and reuse

d. A natural lake for rainwater collection and fish cultivation.

e. A system of bicycle lanes which connect Milano and Segrate

f. Community center and communal services

i. Electric car sharing point

j. CHP plant

The urban farm eco- community as an holistic closed system

The project aims to establish a closed system in which the different zones of activity (residential, agricultural, energy production) all provide each other with different inputs in order to minimise dependency on external systems and to maximise self-sufficiency. The residential district, which integrates living with small-scale food production, provides workers and employees for the CHP plant and the polydome system, as well as compost from organic waste and excrements and biomass from gardens.

The polydome system provides food for the residential quarter as well as biomass for the CHP plant. The CHP plant provides both the polydome system and the residential quarter with heated water and electricty.

In ideal conditions the urban farm community could survive without any external input, that is without connection to the national electricty grid, without dependency on food from external sources as well as without the need for the inhabitants to work outside of the community. The principle of self-sufficiency and energy recycling (also in the form of water and nutrients) is applied also to the domestic scale: each house is provided with a food production polyculture garden, a solar roof for the production of electricty, compost toilet and organic waste system, and a water collection and reuse system.

FOOD	WORK	ENERGY	RECYCLING	TRANSPORTATION
permaculture	CHP plant	CHP plant	grey water reuse	electric car sharing
food forests	polydome	PV	rainwater collection	public transportation
polydome	home workshops	solar	compost	bicycle lanes
aquaponics	commercial center	energy effieciency	waste recycling	car-free neighborhood
horticulture	community	biofuels		
veg gardens				

figure 3.2: an overview of the different project's systems

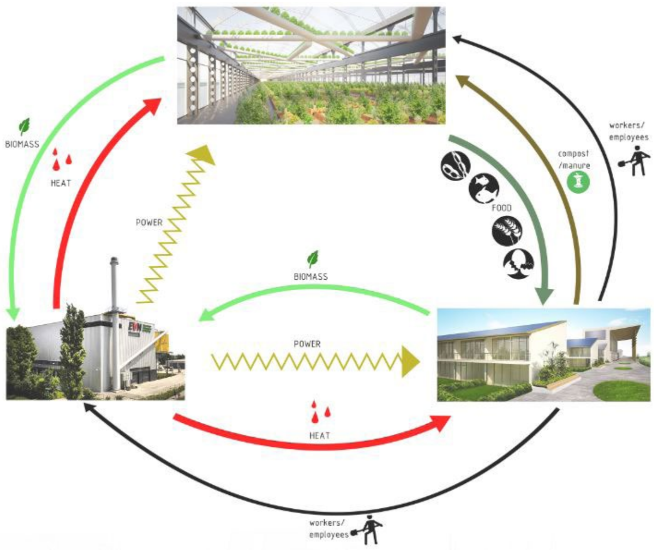


figure 3.3: a schmeatic diagram of the symbiotic relationships between the project's different activity areas

Each of the jouses is provided with a series of systems in order to maximise it's sustainabilty and resilience and to help achieve the community project's goals:

- Passive solar design with thermal mass and heavy thermal insulation

- A photovoltaic solar roof

- Rainwater collection and reuse system

- Private garden for ecological food production

- Ground-source heat pump for heating in winter and cooling in summer

- Hot water supply from CHP district heating plant

- Design for natural ventilation and cooling

- A "Clivus Multrum" combined toilet and organic

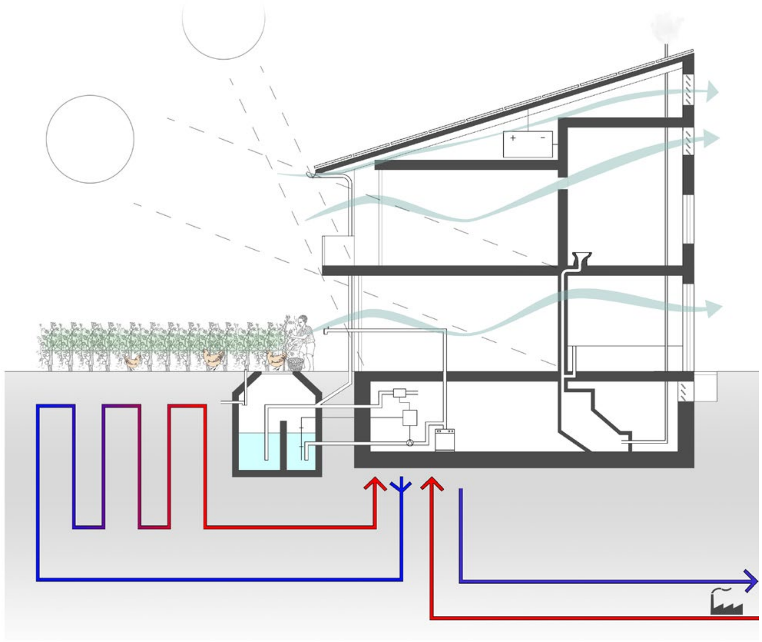


Figure 3.4: A diagram of the house's different systems (for further detail see presentation board n. 8b)

Materials & methods of house's construction

The chosen construction system for the house's envelope is a product developed in Britain called ModCell®, which is basically a pre-fabricated engineered wall panel system made out of straw-bales and a wooden-frame that constitute the panel. The ModCell® prefabraicated wall panels could be assembled on-site in a temporary structure with locally provided straw-bales and wood.

These walls are designed to be load-bearing, therefore eliminating the need for a structural-frame and saving wood for the more important parts such as the floor slabs and the roof.

The chosen construction method for the basements walls are insulating concrete formworks (ICF) which save construction time and have high thermal performances.

For a further description of the construction materials chosen for the houses see presentation board n. 9.

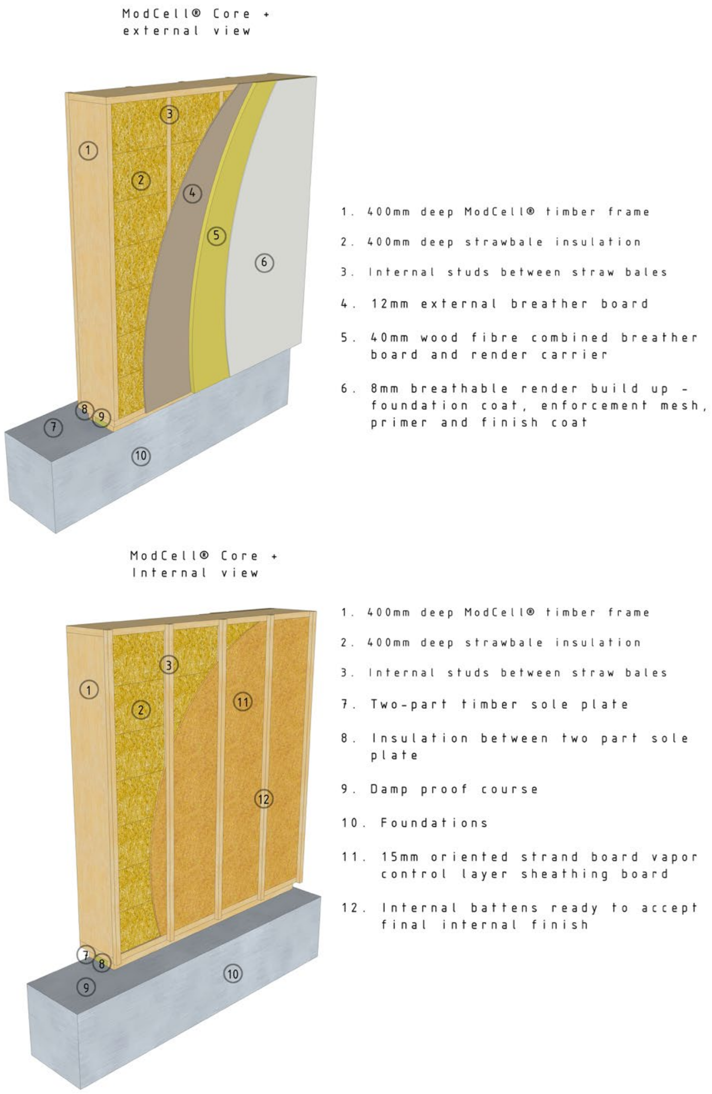


Figure 3.5: A description of the ModCell wall panel system

Conclusion

In the first two chapters we have explored the main challenges humanity will have to face in the 21st century and the different existing strategies in different areas which could become the basic mechanisms of a sustainable society capable of overcoming these challenges.

Global warming, peak oil, the depletion of natural resources ,and the destruction of the natural environment and of the earth's ecosystem are the four different categories of challenges in the undergoing environmental crisis we are facing.
Probably the main "culprit" for the situation humanity is facing are fossil fuels which, as i already mentioned in previous chapters, are a 'once-in-a-lifetime gift' of massive quantities of solar energy densed into an extremely useful and abundant substance that is relatively easy to extract and manipulate. The industrial revolution, the subsequent digital revolution and the so-called 'green revolution' in agriculture would all not have been made possible if it weren't for the massive quantities of cheap energy provided by fossil fuels. This 'once-in-a-lifetime gift' will most probably not repeat itself with other energy resources, at least not in the near future. Therefore, hoping for a discovery of a new miraculous source of energy, such as coal and petroleum, that on top of supplying the immense increasing quantities of energy our technologically-oriented society consumes doesn't include the other negative impacts of fossil fuels such as pollution and greenhouse gas emissions, is not a viable solution for combatting the environmental crisis the earth is facing.

There are four main human activites that cause the negative environmental impacts i described in the first chapter (global warming, desertification, destruction of wildlife habitats, etc.) i.e.: industrial agriculture; the construction of buildings and their use; transportation; and industry. Each of these activities is highly dependent on fossil fuels; Industrial agriculture uses fossil fuels for transportation, for fueling machinery and for the creation of artificial fertilizers and pesticides; the building industry uses massive amounts of energy for the extraction of the main building materials (reinforced concrete, steel, etc.) for construction as well as for transportation; in transportation, the most popular means of private transportation in most industrialised countries are automobiles and airplanes which are almost entirely fueld by gasoline and diesel which are fossil fuel products; and industry consumes worlwide more than half of all energy consumed, the vast majority of it comes from fossil fuels.

It is obvious that one of the strategies society should implement, and that is already being implemented by many governments, organizations and companies across the world, is minimizing the negative impacts of our activities through increasing environmentally-friendly practices such as energy efficient technologies, recycling of wastes, the use of biodegradable materials for packaging, etc,. However, in order to become truly sustainable, contemporary society will have to change at it's core.

From the study of the different strategies and methodologies presented in the second chapter, and especially of the ecological design philosophy of Permaculture, a bigger picture emerges of what will be the characteristics our society should aspire to have in order to become truly sustainable:

Exclusive use of renewable energy resources: as we have seen, non-renewable energy resources , apart from contributing to pollution and climate change, are dwindling, and it is highly probable that in the coming decades, due to declining rates of production, will become uneconomical. Renewable energy resources are mostly 'clean', can be produced locally, and can be owned by small communities or individuals thereby conducing to greater self-sufficiency and resilience. A truly sustainable society will be based exclusively on renewable energy resources such as hydroelectric, wind, solar, biofuels and geothermal.

Low energy requirements: As was shown in the first chapter (see p. 5), the recent decades have witnessed an increasing energy demand that doesn't show any signs of slowing down (mainly due to the developments in recent years of emerging economies such as China and India), the vast majority of this energy is provided by fossil fuels. From the study of the EROEI coefficients of the different energy resources, it is evident that renewable energy resources (with the only exception of specific localities rich with energy sources such as waterfalls ,underground geothermal heat reserves and extremely windy climates) will not be capable of catering for the massive energy demand created by fossil fuels and high technologies.

Therefore, in order to become a truly sustainable society, it is imperative that we drastically reduce our energy requirements, and that we increase the energy efficiency of our buildings, industries and activities.

Economies based on local production: We are now living in a global society subject to the mechanisms of the global market. Almost all of the world's markets are connected, and goods and services are constantly flowing between different parts of the world. Supermarkets in developed countries sell food products imported from different continents; financial investments are being taken by companies and individuals on assets all over the world; shares and stocks of companies can be purchased an sold by individuals and entities all over the world in a matter of seconds; multinational corporations control the global market for most products such as electrical appliances and food; and the majority of the items, clothing items, accessories, etc,. sold in developed countries are produced in and imported from southeastern asian countries. These are all relatively new conditions which began to form in the second half of the 20th century, and which are possible thanks to new technologies in transportation and communication which are mostly reliant on energy from non-renewable sources such as fossil fuels. Therefore, globalization is possible only thanks to the massive amounts of energy harnessed from the burning of fossil fuels and will not be able to sustain itself in an energy-descent future. This is why sustainable societies will have to rely more on locally produced goods and services. By doing so they will be able to cut on energy costs for transportation and maintenance, and to strengthen the resilience of local communities through greater self-sufficiency.

Self-sufficiency: Apart from the excess waste of energy and resources caused by globalization, global markets are also inherently unstable as we have witnessed in the last global economic crisis of 2008. In a world which is witnessing repeatedly unpredictable extreme weather events such as droughts and hurricanes, and dwindling natural and energy resources, the global market is expected to become ever more volatile, and therefore, future events such as water scarsity, famine and wars are becoming always more probable, especially in the poor parts of the world, but not only. Therefore, resilience is a highly important goal for sustainable societies, which could be achieved through greater self-sufficiency for individual households and communities in terms of food security, autonomous energy production and stronger self supporting local communities.
The theories and practices of the design philosophy of Permaculture, which puts major emphasis on self-sufficiency of small communities and individual households, could guide the actions needed to be taken in order to create resilient communities and societies. Practices such as home or local community ecological food production, horticulture, generation of energy in homes through different technologies and systems, the minimization of waste, and the recycling of water and nutrients from human waste will become the defining structure of self-sufficient communities and will lead society into a sustainable future. Food production in dense urban contexts could also be promoted through technologies such as aquaponic gardening, biointensive gardening, vertical farming, etc,. Production of everyday items such as clothing items, accessories, home appliances, etc. should become locally-produced on a smaller scale with the use of intermediate technologies. This will reduce the depedency on the volatile global market and will thus enhance the resilience of communities and societies whilst cutting on energy needs.

Holistic management based on the principles of ecology: Natural systems work in a cyclical fashion. Light energy from the sun is converted by plants into chemical energy. This chemical energy is stored in carbohydrate molecules, such as sugars, which are synthesized from carbon dioxide and water. This chemical energy is than consumed by animals who feed on the carbohydrates in these plants and who breathe the oxygen which is the waste product of photosynthesis. The same animals are than preyed by predators who use the chemical energy present in the meat for their own living. Once the animals perish they are decomposed by insects, bacterias and other microorganisms. The nutrients in carcasses and animal feces wind up in the soil creating a fertile setting for the growth of new plants. Fungi and soil ecosystems of microorganisms also disassemble dead trees and plants and recycle their nutrients for future growth. Therefore, nature works in a close cycle, which has only one input - light energy from the sun, and that tries to maintain and recycle this energy as much as possible.
However, modern society doesn't function in the same way. Industrial capitalist society works in a more linear fashion where energy and natural resources are harvested from nature and converted into consumable goods. Once the goods are consumed they turn into waste which is than disposed of without being returned into the natural cycle. In this process most of the nutrients and energy found in the natural resources harvested are lost. This process causes the constant diminishing of natural resources and the destruction of the natural environment by breaking the natural cycle of reuse of nutrients and energy.
Therefore, a human settlement, in order to become truly sustainable, has to adopt the same mechanisms of nature in its

function, and by doing so to become a closed system in which natural resources and nutrients consumed are constantly recycled and replenished, ecosystems are preserved, growing conditions are maintained and the symbiotic relationships that form in ecosystems between the different animal and plant species are exploited to the maximum.

These charcateristics are at the core of the Permaculture design philosophy, which strives to mimick the cyclical fashion of natural systems and adapt it into human needs. Aquaponic gardening as well functions as a result of the symbiotic relationships developed between the different components of the system (i.e. plants, water, worms, bacteria and fish).
Therefore, we can see that any solution, in order to be fully sustainable, has to embrace the cyclical mechanisms of nature and therefore to function as a whole, rather than an assembly of different parts.

For these reasons, a new typology of human settlements, that breaks from the traditional division of cities-suburbs-countryside, and that integrates all of the characteristics described above, is proposed in this thesis as an architectonic answer to the environmental crisis.
This new typology will combine different mechanisms such as: dense living; bio-intensive home-made food production; community ecological food production systems; community ecological factories for green technologies; water harvesting and recycling systems; nutrients recycling systems and practices; ecological and natural building techniques and materials; and local renewable energy production systems, all this with preference for lo-tech or intermediate technologies whenever possible.

Nowdays, around the world, various ecovillages and intentional communities are already attempting to create a sustainable human environment with the different techniques discussed above. Communities such as the Lammas ecovillage in wales, Findhorn ecovillage in Scotland, The Sieben Linden ecovillage in Germany, the Greater World Community in Taos, New maxico and many others, constitute the role model for the new typology of human settlements proposed in this thesis as a new architectural norm.
These communities were all set up by pioneers and individuals independently, often encountering clashes with local authorities. One of the goals of this thesis work is to promote this kind of human settlement as a legitimate and standard way of development in developed countries, which could be promoted by governments and regulated by adequate norms and building codes in order to become a new status-quo in the built environment.

The urban farm eco-community project developed in this thesis and described in the last chapter is an example of how a settlement that integrates all of the solutions and strategies explored in this thesis, and that posseses the properties layed out above (see pages 57-58) might look like. In this project, i try to show how such a new typology could be planned and adapted to a specific context; in this case Milan, Italy.

Figure 3.6 : A 200 m² plus Eco-house in Findhorn Ecovillage, Scotland. [1]

Figure 3.7 : Sieben Linden Ecovillage in Germany. [2]

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Presentation boards list and description

Presentation board n. 1 - Unsustainable human activities

This presentation board succinctly outlines the major human activites that generate the environmental crisis contemporary society is facing. These human activites are divided in four macro-categories: Industrial agriculture, the building sector, transportation and industry. Each category is represented graphically and accompanied by different facts that describe and explain the negative environmental impacts it creates.

Presentation board n. 2 - Environmental challenges

This presentation board succinctly outlines the major environmental challenges our society is facing in four different categories (albeit their interdependency): global warming, peak oil, depletion of natural resources, and the destruction of the natural environment (the earth's ecosystem). Each category is grapichally represented and is accompanied by facts and data which explains, on the one hand, the scientific proofs for these phenomena, and on the other, the implications and threats imposed by them.

Presentation board n. 3 - Green solutions and technologies

This presentation board succinctly outlines the major green solutions and technologies for the challenges presented in the previous presentation boards. The solutions are divided into different categories: agriculture, construction, energy, and water and nutrient saving and recycling. Each category is grapichally represented and is accompanied by a succinct verbal description.

Presentation board n. 4 - context, potentialities and urban strategy

This presentation board analyses the urban and geographic context of the site chosen for the project, that is the ex-Innse factory site in the eastern periphery of Milan, and its inherent potentialities. The presentation board depicts the site's location in relation to Milan and the neighboring city of Segrate with description of the natural and urban elements that define it's character, such as the wide countryside, the Lambro river that crosses and delimits the site's western border, the system of vast green public spaces which could be integrated with the project, etc. Further potentialities are explored, such as the possibility of linking the site with specific public transportation lines, the potential extension of the existing system of bicycle and pedestrain routes, the creation of a green public corridor that will connect the Lambrate district of Milan to the west with Redecesio district of Segrate to the east and the use of the Lambro river water within for ecological and aesthetic purposes.

Presentation board n. 5 - project's masterplan 1 - 2000

In this presentation board a plan view and an axonometric view of the project's masterplan in 1 - 2000 scale are presented. A series of images and verbal descriptions of the different elements and functions of the project is associated by numbers to their location on the plan. The western part of the project hosts the warehouses which are converted into an intensive ecological food production system greenhouse, which makes use of different methodologies such as polyculture and aquaponics.
In the eastern part the residential district is located. The zero energy solar houses are layed out in two different block typologies: blocks of two-storey row houses aligned along the east-west axis (with a deviation of 20 degrees) and blocks of a three story building aligned along the north-south axis, in which the ground floor is a row of workshops and laboratories, and the upper two floors are a series of physically disconnected single family houses in order to maximise the number of south facing surfaces. At the center of the residential district an organic lake, used for rain water collection and breeding of different fish and shellfish species for food, is located. The organic lake constitutes the epicentre of the neighborhood. Other elements present in the project are constructed wetlands for the purification of grey water, a system of vegetable garden and food forest for intensive bio- agriculture, etc.

Presentation board n. 6 - description of the Polydome project for the warehouses 1 - 1000

In this presentation board a plan view in 1 - 1000 scale of the Polydome project for the warehouse is presented. The plan view is accompanied by a series of photos and photorealistic rendering which describe the different functions and elements of the project with the use associated numbers which point to the specific location of each element within the Polydome.
Most parts of the warehouse will be dedicated to intensive ecological food production. The western wing of the building is largely destined for polycultural food cultivation mixed with aeroponic systems. The lower eastern wing is dedicated to intensive aquaponic gardening systems for the cultivation of vegetable and fish. The two big courtyard which are formed between the former warehouses host forest gardening food production systems. The east-northern part of the project hosts a commercial center and a community market in which locally produced products can be sold and socio- cultural events can take place.
The northern and southern wings of the building contain the logistics center of the Polydome system and other complementary functions.

Presentation board n. 7 - photorealistic renderings of the residential district

Three hypothetical visualizations of the residential district.

Presentation board n. 8 - description of the ZED residents - plans, sections 1 - 100

These three presentation boards describe with plan ,section and axonometric views the two types of modular zero energy solar houses buildings concieved for the residential district. A scheme of the different HVAC and water treatment systems used in the houses is presented as well.

Presentation board n. 9 - technological details of the houses 1 - 10

In this presentation board the construction system chosen for the zero energy solar houses is presented. The construction method chosen for the exterior walls is of a ModCell® straw bale prefabricated panel load bearing wall system. Wood originated from sustainably managed forests is the chosen material for the slabs and for the double roof. The ventilated double roof is comprised of a horizontal insulated wooden slab topped by a pitched wooden structure roof covered by a sheet metal covering on top of which a framework for the support of photovolatic panels is installed.

Presentation boards list and description

Used royalty images and images referenced previously are not referenced

Presentation board n. 1 - unsustainable human activities (from top-left to bottom-right):

All graphs are referenced

1. M.C. Heller and G.A. Keoleian, "Life Cycle-Based Sustainability Indicators for Assessment of the U.S. Food System," University of Michigan (2000).

2. http://www.worldenergyoutlook.org/2008.asp.

3. IPCC 2007

4. http://www.except.nl/consult/polydome/

5. IEA 2009

6. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013

7. IEA 2009

Presentation board n. 2 - environmental challenges (from top-left to bottom-right):

All graphs are referenced

1. "Global Temperature Anomaly" by NASA Goddard Institute for Space Studies - http://data.giss.nasa.gov/gistemp/graphs/. Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Global_Temperature_Anomaly.svg#/media/File:Global_Temperature_Anomaly.svg

2. http://climate.nasa.gov/

3. "World energy consumption" by Con-struct - www.bp.com. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:World_energy_consumption.svg#/media/File:World_energy_consumption.svg

4. "Hubbert peak oil plot" by Hankwang at en.wikipedia. Licensed under CC BY 2.5 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Hubbert_peak_oil_plot.svg#/media/File:Hubbert_peak_oil_plot.svg

5. Living Planet Report. WWF. December 2014.

6. "Desertification map" by USDA employee - http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/nedc/training/soil/?cid=nrcs142p2_054003. Licensed under Public Domain via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Desertification_map.png#/media/File:Desertification_map.png

7. Living Planet Report. WWF. December 2014.

8. Living Planet Report. WWF. December 2014.

Presentation board n. 3 - Green solutions and technologies (from top-left to bottom-right):

1. Manuale di bioedilizia / Uwe Wienke. - 4. ed. aggiornata e ampliata Roma : Dei, 2008. p. 368

2. By Avda (Own work) [CC BY-SA 3.0], via Wikimedia Commons

3. "World energy consumption" by Con-struct - www.bp.com. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:World_energy_consumption.svg#/media/File:World_energy_consumption.svg

4. The Transition Handbook: from oil dependency to local resilience. Rob Hopkins .Totnes. UK.. Publisher.Green Books (2008). cover photo.

Presentation board n. 5 - Project's masterplan 1-2000 (from top to bottom):

1. "Claire Gregorys Permaculture garden" by Claire Gregory - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Claire_Gregorys_Permaculture_garden.jpg#/media/File:Claire_Gregorys_Permaculture_garden.jpg

2. "Tilley et al 2014 Schematic of the Horizontal Subsurface Flow Constructed Wetland" by Tilley, E., Ulrich, L., Lüthi, C., Reymond, Ph., Zurbrügg, C. - Compendium of Sanitation Systems and Technologies - (2nd Revised Edition). Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland.. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Tilley_et_al_2014_Schematic_of_the_Horizontal_Subsurface_Flow_Constructed_Wetland.jpg#/media/File:Tilley_et_al_2014_Schematic_of_the_Horizontal_Subsurface_Flow_Constructed_Wetland.jpg

3. "Fernheizwerk Mödling von NordWest" by Ulrichulrich - Own work (Original text: eigene Aufnahme). Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Fernheizwerk_M%C3%B6dling_von_NordWest.jpg#/media/File:Fernheizwerk_M%C3%B6dling_von_NordWest.jpg

Presentation board n. 6 - A polydome project for the warehouses (from top to bottom):

1. http://www.except.nl/consult/polydome/

2. “Modern warehouse with pallet rack storage system” by Axisadman - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Modern_warehouse_with_pallet_rack_storage_system.jpg#/media/File:Modern_warehouse_with_pallet_rack_storage_system.jpg

3. La Boqueria.JPG https://commons.wikimedia.org/wiki/File%3ALa_Boqueria.JPG By Dungodung (Own work) [Public domain], via Wikimedia Commons

4. “CDC South Aquaponics Raft Tank 1 2010-07-17” by Bryghtknyght - Own work. Licensed under CC BY 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:CDC_South_Aquaponics_Raft_Tank_1_2010-07-17.jpg#/media/File:CDC_South_Aquaponics_Raft_Tank_1_2010-07-17.jpg

5. IEA 2009

6. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013

7. IEA 2009

Presentation board n. 8b - Description of the ZED residents (from left to right):

1. “Unterirdische Zisterne” by Stefan-Xp - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Unterirdische_Zisterne.jpg#/media/File:Unterirdische_Zisterne.jpg

2. “Geothermal shilsholepointe” by Erin Stancik, Shilsholepointe.com - Shilshole Pointe, Seattle Washington. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Geothermal_shilsholepointe.jpg#/media/File:Geothermal_shilsholepointe.jpg

3. “Metz biomass power station” by Bava Alcide57 at English Wikipedia. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Metz_biomass_power_station.jpg#/media/File:Metz_biomass_power_station.jpg

4.”Inside greenhouse of Global model Earthship” by Amzi Smith - Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Inside_greenhouse_of_Global_model_Earthship.JPG#/media/File:Inside_greenhouse_of_Global_model_Earthship.JPG

Presentation board n. 9 - Green solutions and technologies (from top-left to bottom-right):

1. www.modcell.com

Graphs and images list

Chapter 1 - The Environmental Crisis and Peak Oil - causes and implications:

Chapter 2 - Methods and techniques for sustainable living (solutions for the environmental crisis):

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*- Solar city : *Linz Pichling : Nachhaltige Stadtentwicklung / Herausgeber Martin Treberspurg, Stadt Linz Wien : New York : Springer, 2008 214 p.*

- Manuale di bioedilizia / Uwe Wienke. - 4. ed. aggiornata e ampliata. Roma : Dei, 2008. 491 p.