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Utilization of the potential of biomimetics in sustainable architecture

An investigation focusing on current developments in Austria

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I declare in the lieu of oath that I did this dissertation in hand by myself using only literature cited at the end of this volume.

Vienna, March 2011

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Abstract

This thesis was supposed to find and evaluate biomimetic approaches to sustainable architecture in Austria. By that it tried to address the question, if and to what extent the potential of biomimicry is utilized to make an essential contribution to sustainable building in Austria. This should on one hand help to define the scope of *'green architecture', 'biomimetic architecture'*, and *'sustainable architecture',* and on the other hand point out how biomimicry can positively impact the sustainability of a building.

Based on a comprehensive investigation on Austrian architecture, 32 buildings, which could be attributed to apply a biomimetic concept or approach, and by this increase or support the building's sustainability, have been identified. Following, eight well suited and documented showcase buildings have been investigated in detail to – at least qualitatively, but if possible quantitatively – evaluate their sustainability.

This work reveals that there are a number of challenges that have to be faced while successfully applying biomimetics to buildings. Moreover, in many cases, the correct interpretation and categorization of an - intentional or unintentional - biomimetic approach is difficult: A fully and comprehensively executed *'ecological timber construction'* may be referred to the *'mimicry of an ecosystem based on full biological cycles of resources'*, or simply to *'sustainable sylviculture'*.

Finally, this thesis shows by the use of realized examples how *serious sustainable building* in Austria could be and can be performed, and of what kind the *most biomimetic-like* methods and approaches are to achieve this. These buildings implement nature in terms of their materials, envelope, and/or environmental aspect to a certain and individual extent, aiming to – intentionally or not – create architecture that "*meet the needs of the present without compromising the ability of future generations to meet their own needs.*"

Kurzfassung

Das Ziel dieser Arbeit war es, bionische Herangehensweisen hinsichtlich nachhaltiger Architektur in Österreich zu identifizieren und zu evaluieren. Auf diese Weise sollte die Fragestellung beantwortet werden, ob und in welchem Ausmaß das Potential der Bionik in Österreich ausgeschöpft wird, um hinsichtlich des nachhaltigen Bauens einen entscheidenden Beitrag zu leisten. Dies sollte einerseits dazu dienen, die Begriffe '*Grüne Architektur*', '*Bionische Architektur*' *und* '*Nachhaltige Architektur*' abzugrenzen, und andererseits zeigen, wie die Bionik die Nachhaltigkeit eines Gebäudes positiv beeinflussen kann.

Basierend auf einer umfangreichen Recherche österreichsicher Architektur wurden 32 Gebäude identifiziert, welchen die Anwendung eines bionischen Konzeptes oder einer Methode zur Verbesserung oder Unterstützung ihrer Nachhaltigkeit zugeschrieben werden konnte. Anschließend wurden acht geeignete und gut dokumentierte Vorzeigeprojekte ausführlich untersucht, um – zumindest qualitativ, aber wenn möglich auch quantitativ – deren Nachhaltigkeit zu bewerten.

Diese Arbeit legt offen, dass eine Vielzahl von Herausforderungen zu lösen sind, um Bionik erfolgreich auf Gebäude anzuwenden. Darüber hinaus ist die korrekte Interpretation und Kategorisierung eines – bewussten oder unbewussten – bionischen Ansatzes in vielen Fällen schwierig: Eine ganzheitlich und umfangreich ausgeführte '*ökologische Holzkonstruktion*' kann als '*Mimikry eines Ökosystems, basierend auf dem vollständigen biologischen Zyklus von Ressourcen*', oder einfach als '*nachhaltige Forstwirtschaft*' bezeichnet werden.

Schließlich zeigt diese Diplomarbeit anhand von realisierten Beispielen, wie *ernsthaftes nachhaltiges Bauen* in Österreich praktiziert werden konnte und kann, und von welcher Art die meisten *bionisch-artigen* Methoden und Ansätze sind, um dies zu erreichen. Diese Gebäude implementieren die Natur hinsichtlich ihrer Materialien, ihrer Gebäudehülle, und/oder ihrer

ökologischen Aspekte, mit dem – bewussten oder unbewussten – Ziel, Architektur zu erschaffen, die „*den Bedürfnissen der heutigen Generation entspricht, ohne die Möglichkeiten künftiger Generationen zu gefährden, deren eigene Bedürfnissen zu erfüllen*.

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PART I:

INTRODUCTION

"The best way to describe the future is to design it."

Buckminster Fuller

I.1 Topic & motivation

Concerning the evolution of human buildings, architects have multifaceted been - intentionally or not - influenced in their work by nature [1]. The great Renaissance' master-builder Brunelleschi for example shaped the stone-made cupola of the Florentine dome '*Santa Maria de Fiore'* in an egg-like form. Around the turn from the 19th to the 20th century, the progress in building technology enabled to use biology as a library of shapes that were transformed into a new variety of architectural forms, especially represented by the work of the famous architect Antonio Gaudi. In the second half of the 20th century, Frei Otto produced efficient lightweight tensile structures by taking direct inspiration from spider webs [2]. Lately, in the early 21st century and triggered by the progress in computer-aided design (CAD) systems, the design and construction of expressively shaped buildings exhibiting natural (i.e.: biological) forms began to mature.

Addressing biomimetic architecture, in the 1960s Juri S. Lebedew wrote a comprehensive work entitled '*Architecture and bionic'* [1]. A vast collection of examples on issues around design and building has been compiled by Werner Nachtigall [3,4]. Frei Otto and his collaborators developed an experimental approach to natural design [5], and Otto Patzelt tried to draw a comparison between growing and building [6]. Recently, Petra Gruber conducted a comprehensive comparative study of the overlaps of architecture and biology [7].

Compared to mankind, the natural world uses energy far more efficiently and effectively, and it is capable of producing materials and structures that are far more benign and eco-friendly than anything we have achieved in industry [8]. Especially due to the increased reporting and discussion about the worldwide climate change and shortage of natural resources during the last years, sustainable architecture became fashionable; and often biomimetic architecture is – intentionally or not – mixed up or even equated with sustainable architecture by common awareness, but also by architects themselves. However, what is the potential for man-made structures truly to

learn from biology [9]? By which building aspect do biomimetic buildings respond to sustainable architecture, and are they really sustainable?

In the field of sustainable architecture, various forms of biomimetic or bio-inspired design are discussed by researchers and professionals [10,11]. Here it is consistently concluded that a practical application of biomimetics as a sustainable design method remains largely unrealised, as demonstrated by the small number of built examples [12,13]. There are different kinds and levels of biomimetic-, as well as of '*conventional bio-imitating or eco-architectural*' technologies and designs that on one hand may broaden the potential of biomimetics to be applied in sustainable architecture, but on the other hand may not exhibit a biomimetic approach at all.

This thesis was supposed to find and evaluate biomimetic approaches, - or such ones that at least bear a biomimetic potential - to sustainable architecture in Austria. By that it tried to address the question, if biomimicry is utilized to make a contribution to sustainable building in Austria. This should on one hand help to define the scope of '*green architecture*', '*biomimetic architecture*', and '*sustainable architecture*', and on the other hand point out how biomimicry can positively impact the sustainability of a building.

Finally, this work shows by the use of realized examples how *serious sustainable building* in Austria could be and can be performed, and of what kind the *most biomimetic-like* methods and approaches are to achieve this. These buildings implement nature in terms of their materials, envelope, and/or environmental aspect to a certain and individual extent, aiming to – intentionally or not – create architecture that "*meet the needs of the present without compromising the ability of future generations to meet their own needs.*"

I.2 Objectives & methodology

According to the OECD project '*Sustainable buildings*', such buildings can be defined as those that have minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their immediate surroundings and the broader regional and global settings [14]. The OECD project identified five objectives for sustainable buildings:

1. Resource efficiency
2. Energy efficiency (including reduction of greenhouse gas emissions)
3. Pollution prevention (including abatement of indoor air quality and noise)
4. Harmonisation with environment
5. Integrated and systemic approaches.

Following the '*Biomimetics Network for Industrial Sustainability*' there are four main targets for applying biomimetics to industrial sustainability [15], which may to a certain extent also be sufficient for building technology:

1. Energy and resource efficiency
2. Elimination and control of hazardous substances
3. Use of renewable and biological materials
4. Added functionality in materials and structures.

To address the above mentioned topics, an investigation on Austrian architecture will be performed to categorize showcase buildings situated in Austria, which fulfil at least one of the four criteria mentioned above. Specific buildings - whereat the catalogue is planned to comprehend domestic housing as well as commercial architecture – are investigated concerning their fulfilment of these criteria and the ones related to the OECD project '*Sustainable buildings*'.

In a next step, we then evaluate if these buildings use a biomimetic approach to achieve sustainability; and in the case of a truly biomimetic approach, the – at least qualitative – impact on the sustainability of the

building will be determined. Thereby, the focus will be set on three items of buildings' aspects, and the building should at least address one of the aspects that are related to:

- Building material properties
- Building envelope
- Environmental considerations.

Concerning ***'building material properties'***, natural materials are generally lower in embodied energy and toxicity than man-made materials, they require less processing and are less damaging to the environment, and when incorporated into building products, the products become sustainable [16]. The ***'building envelope'*** includes all the building components that separate indoors from outdoors, and consists of the exterior walls (taking into account windows and doors), the roof, and the fundament. With the aid of building science it is possible to identify and analyze the respective factors affecting the performance of walls, and to analyse wall structures [16]. There is an increasing recognition that buildings cannot be designed without taking ***'environmental considerations'*** into account, since buildings are responsible for almost half of the nation's energy (and hence carbon dioxide) emissions [17]. Design, construction and operation of buildings are vitally important for our daily life, and influence the health of both human and natural environment.

This work is structured into five parts. Part I introduces the topic and outlines the main objectives. Part II provides a fundamental background of *'biomimetic architecture'* as well as *'sustainable architecture'*, whereas we already set a focus on Austrian characteristics. Part III comprehends the indexed case studies of current biomimetic and sustainable buildings situated in Austria, whereas showcase buildings will be discussed in detail. Finally, the work closes with conclusion.

PART II:

BACKGROUND

"Why can't a building be designed like a tree?"

William McDonough

II.1 Sustainability and sustainable architecture

'*Sustainability*' and '*sustainable architecture*' are diffuse concepts that allow a lot of wiggle room. As Cook and Golton noted, "*the designation 'green' is extremely wide ranging, encompassing many viewpoints and open to broad interpretation,*" with sustainable architecture embodying an "*essentially contestable concept.*" [18]. Hence, in the following chapter it is intended to illuminate this diffuse concept from different viewpoints with the attempt of summarizing related literature as coherent and structured as possible. This will be divided by three parts: In the first part of this chapter, the term '*sustainability*' will be introduced, in the second part, the related concepts and definitions are elaborated, and in the third part the objectives of the various concepts of '*green architecture*' and its possible impact on the ecology, society, and economy are shown. Of course, these objectives and impacts have to be confined doubtless to the respective associated concept on aspects of sustainable architecture.

II.1.1 Sustainability as an issue

The term '*sustainability*' dates back from sylviculture (or forestry) in the 18th century. In his work '*Sylvicultura Oeconomica*' from 1713, Hans Carl von Carlowitz introduces the concept of a sustainable forestry use [19]. Hence, the concept of sustainability primarily contained solely economic-ecological components regarding the protection of resources, and was used within this context in forestry and fishery for the next 200 years [19]. Until 1987, when the United Nations (UN)-commission published the '*Brundtland-report*', the terms '*sustainable*' and '*sustainability*' have not been engrained in the English language. In this report '*Sustainable development*' is defined as [20]:

"*…development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*"

As a result of this report and the worldwide distribution of the term '*Sustainable development*', the concept of sustainable development established as one central concept of international politics of the 21st century. The '*Rio declaration*' and the vision '*Agenda 21*' established at the '*UN Climate Summit*' in Rio de Janeiro in 1992 point at climate change as a global problem for the first time, and define climate protection as an urgent and principal task of the community of states. Additionally, it has to involve social and equal opportunity [21]. In 2002, the final report of the committee of enquiry '*Globalisation of the world economy – Challenges and answers*' directed by the German Federal Parliament, again finds a more economic-ecological definition for 'sustainability' [22]:

> *"Nutzung eines regenerierbaren Systems in einer Weise, dass dieses System in seinen wesentlichen Eigenschaften erhalten bleibt und sein Bestand auf natürliche Weise nachwachsen kann."*
>
> *["Utilisation of a regenerative system in a way that this system is conserved in his essential characteristics and that his existence can grow again in a natural way".]*

The process of the concretisation and definition of sustainability is still in progress. Altogether, it appears obvious that the international politics has to set the rules for a sustainable society, addressing sustainable economic growth and a sustainable human way of live in equal measure [23]. Due to the still present ecological and social challenges, sustainability can only be implemented as an integrated model that addresses the three partly contradicting categories '*economy*', '*ecology*', and '*social justice*'. This concept can be illustrated by the model of '*overlapping circles*' (see figure II-1), which treats the categories as equal and integrated dimensions with their aims, functions and maintenances equally conserved. Hence, sustainability may be defined as a goal that enables prosperity, growth and social coexistence consistent with nature and based on equal opportunity [23].

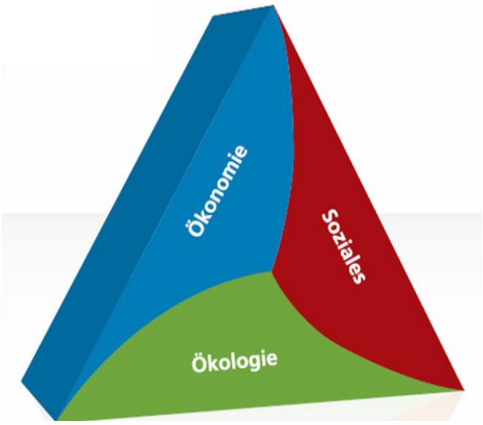

Figure II-1: *'Overlapping circles'*-model, incorporating ecology (*'Ökologie'*), society (*'Soziales'*), and economy (*'Ökologie'*) (From [23]).

II.2.2 Sustainable architecture: Concepts and definitions

'Sustainable architecture' is commonly referred as *'Sustainable buildings'* or *'Green buildings'*, or *'Green Architecture'*. Since the introduction of the term *'sustainable development'* in the *Brundtland Report* [20], there have been a number of efforts to define sustainable architecture, whereas in principle it echoes the concept of sustainable development, while targeting on the architectural issues [24]. It almost always covers the tri-state domain of *'ecology'*, *'society'*, and *'economy'*, whereas differences concerning the assignment of priority between these three aspects exist. From an environmental inclined view point, Ray-Jones sums up sustainable architecture as "*a thoughtful and well considered use of energy systems to make buildings that are more conducive to human use and comfort, without generating pollutants or borrowing the earth's resources for the future generations*" [25].

From a social viewpoint, experts suggest that sustainable architecture is regarded to encompass the design and management of sustainable human settlements. These are dealing with the creation of appropriate human settlements configurations that optimise (not maximise) the consumption of resources and manage resource extraction and waste disposal in a manner that does not deplete or degrade the environment [24].

The *'U. S. Environmental Protection Agency (EPA)'* applies on its *'Green building'*-platform a more technological approach, and defines green building as "*the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building.*" [26].

The most comprehensive (but maybe also most vague) definition derives from the OECD Project *'Sustainable buildings'* [14], which defines sustainable buildings as buildings with minimum adverse impact on the built and natural environment, regarding the buildings themselves, their immediate surroundings and the broader regional and global settings. Sustainable buildings may be defined as building practices, which strive for integral quality (including economic, social and environmental performance) in a broad way [14].

Guy and Farmer published an article in 2001, on the review of a "*myriad of articles, reports, and books on the subject of green or sustainable buildings*", and they reported to "*find a bewildering array of contrasting building types, employing a great variety of different technologies and design approaches, each justified by a highly diverse set of interpretations of what a sustainable place might represent*" [27]. In their work, Guy and Farmer follow John Hannigan by suggesting that society's willingness to recognize and solve environmental problems depends rather on the way these claims are presented by a limited number of people than upon the severity of the threats they pose [28]. This is connected with the premise that individuals, groups, and institutions embody widely differing perceptions of what *'environmental innovation'* is about [29]; and hence they may share a commitment to sustainable design but are likely to differ greatly in their "*interpretation of the causes of, and hence the solution to, un-sustainability*" [30]. Guy and Farmer's careful analysis of the search resulted in a typology of

six environmental logics, whereas they define *'logic'* as "*a specific ensemble of ideas, concepts and categorisations that are produced, reproduced and transformed in a particular set of practices through which meaning is given to social and physical realities*" [31] (see table II.1 [27]). According to Guy and Farmer, these logics are separate but not autonomous, and in practice logics may merge or simply be absent as exemplified by the analysis of individual building [27]. This approach gives a good impression about the various ideas and concepts framing the green building debate and our thinking about sustainable architecture.

Table II-1: The six competing logics of sustainable architecture (From [27])

Logic	Image of Space	Source of Envir. Knowledge	Building Image	Techno-logies	Idealized Concept of Place
Eco-technic	global context; macro-physical;	Techno-rational; scientific;	Commer-cial; modern; future oriented;	integrated energy efficient high-tech; intelligent;	Integration of global environmental concerns into conventional building design strategies. Urban vision of the compact and dense city.
Eco-centric	fragile; microbiotic	systemic ecology; metaphysical holism;	polluter; parasitic; consumer	autonomous; renewable; recycled; intermediate;	Harmony with nature by autonom. buildings with lim. ecologic. footprints. Ensuring stability, integrity, and "flourishing" of biodiversity.
Eco-aesthetic	alienating; anthro-pocentric;	sensual; postmodern science;	Iconic; archi-tectural; New Age;	pragmatic; new; nonlinear; organic;	Universally reconstructed in the light of new ecological knowledge and transforming our consciousness of nature.
Eco-cultural	cultural context; regional;	Phenomeno-logy; cultural ecology;	authentic; harmo-nious; typo-logical;	local; low-tech; com. place; vernacular;	Learning to "dwell" through buildings adapted to local and bioregional physical and cultural characteristics.
Eco-medical	polluted; hazardous;	medical; clinical; ecology;	healthy living; caring;	passive; non-toxic; natural; tactile;	A natural and tactile environment which ensures the health, well-being, and quality of life for individuals.
Eco-social	social context; hierar-chical;	sociology; social ecology;	Demo-cratic home; individual;	flexible; participatory; appro-priate ; locally managed;	Reconciliation of individual and community in socially cohesive manner by decentral., non-hierarchical, participatory communities.

In the following, we shortly review the individual types of logic as given in [27], and analyze them regarding their similarities or discrepancies with a biomimetic approach to sustainable architecture.

The ***Eco-technic Logic*** is based on a techno-rational, policy-oriented discourse, which represents that science and technology can provide the solutions to environmental problems. It is assumed that science, technology, and management take account of the environmental impacts of development by an integrative approach. A key feature of this paradigm is its globalizing viewpoint, and concerns are mainly for the universal, global environmental problems of climate change, global warming, ozone layer depletion, and transnational pollution issues, such as acid rain. There is an emphasis on the concept of futurity, as suggested by the *Brundtland definition* of sustainability as "*meeting the needs of the present without compromising the ability of future generations to meet their own needs*" [20].

In practice, these ideas are characterized by a consensual, top-down view of environmental and technological change, in which a "*progressive process of innovation mitigates the adverse effects of development*" [32]. In the case of building design, the every kind of efficiency, and – in line with global concerns – especially energy efficiency is prioritized. The resulting design strategy is adaptive, but usually based on recognizably modern high-technology buildings that attempt to maximize the efficiency of building in spatial, construction, and energy terms [27]. Famous representatives are Norman Foster, Richard Rogers, Nicholas Grimshaw, Michael Hopkins, Renzo Piano, Thomas Herzog, and Ken Yeang. Technological innovations such as translucent insulation, new types of glass and solar shading, intelligent facades, double-skin walls and roofs, and photovoltaics, as well as energy-efficient lighting, passive solar design and daylighting, the use of natural and mixed-mode ventilation, more efficient air conditioning and cooling, and sophisticated energy management systems are all part of the high-tech approach [27].

The ***Eco-Centric Logic*** stands in sharp contrast to the eco-technic logic, and is founded on a need for a radical reconfiguration of values. It assumes

that "*the challenge of sustainable design is too big, too complex, and too uncertain to deal with as a technical problem or even as an exercise in institutional design*" [33]. Eco-centric discourse combines the science of ecology with an eco-centric or bio-centric ethical framework, treating the earth not as a commodity to be bought and sold but rather as a community of which humans are an integral part [34]. Sustainability therefore requires immediate and full protection and a radical approach to rethinking building design and production [35].

In the case of buildings, the perception is that they are an unnatural form of "*pure consumption*" interrupting the natural cycles of nature [36]. In this sense: "*Each building is an act against nature; in ecological terms, a building is a parasite*" [37]. The essential mission of sustainable architecture becomes that of non-interference with nature, and where building is essential, the aim is to radically reduce the "ecological footprint" of buildings [36].

Approaches to building tend to draw directly on analogies with ecological systems as efficient, living, closed, cyclical processes. The design strategies aim towards small-scale and decentralized techniques with an emphasis on reducing, or severing dependency on centralized infrastructure services of water, energy, and waste, as for example in the autonomous house designs of Brenda and Robert Vale [38]. Building materials are preferentially renewable and natural such as earth, timber, and straw, combined with increased reuse and recycling, as for example realized by Mike Reynold's in New Mexico, where self-sufficient homes are made from used tires, bottles, and other waste materials, filled and plastered with earth [39]. In North America, the *Earthship* movement has established itself, developing self-sufficient housing made from recycled materials [40].

The ***Eco-Aesthetic Logic*** shifts the debate about sustainable architecture beyond the efficient use of resources and the reduction of ecological footprints [27]. As a theory of social change, it represents an idealist vision of a global universal consciousness, which begins with individual reflexivity and ecological awareness, and which will eventually lead to the establishment of "*whole new civilisations and cultures*" [41]. The

eco-aesthetic logic is based on eastern philosophies and the modern sciences of complexity including complexity theory itself, chaos science, self-organising systems, and non-linear dynamics [42]. It places an emphasis on individual creativity and a liberated imagination combined with a romantic view of nature that rejects western rationalism, modernism, and materialism [27].

The issue in building design is to create a new universal architectural iconography, whereas the role of green buildings is to break free from strictly formalist interpretations of architecture, and to develop a paradigm based on ecological models [43]. The rhetoric of this logic prioritizes appropriate architectural form above physical performance [42], and is mainly made possible by advances in structural engineering, computer modelling, automated production, and novel materials. Jencks suggests that the beginning of this movement can be witnessed in the '*organi-tech*' architecture of Frank Gehry, Santiago Calatrava, NOX Architects, Karl Chu, Greg Lynn, and Future Systems; in the '*cosmic*' forms of Japanese architects such as Arato Isosaki; and in the artistic fusion of landscape and architecture in the work of SITE [42].

The ***Eco-Cultural Logic*** emphasizes a fundamental reorientation of values to engage with both environmental and cultural concerns, whereas it is not the development of a novel universal culture which is promoted, but rather the preservation of a diversity of existing cultures [27]. Truly sustainable buildings need to more fully relate to the concept of locality and place, which is a reaction against the globalism of the '*International Style*'. According to Frampton, "*sustaining any kind of authentic culture in the future will depend ultimately on our capacity to generate vital forms of regional culture*" [44]. Following Arne Naess, "Any model of ecologically sustainable development must contain answers, however tentative, as to how to avoid contributing to thoughtless destruction of cultures…" [45]. The eco-cultural logic implies both the development of a sense of being indigenous to a place, and a responsibility for protecting landscape and ecosystems from disturbance [27].

As a design strategy, it draws inspiration from indigenous and vernacular building approaches. Within this logic it is suggested that sustainable architectural approaches should move away from universal and technologically based design methodologies as these often fail to coincide with the cultural values of a particular place or people, since "*adding insulation made from synthetic materials or 'Arabic-wind' towers as objects to an office block does not integrate a 'green' solution in terms of cultural considerations and sustainable design*" [46]. The eco-cultural logic's emphasis on the peculiarities of place, the use of local materials, and an appropriate formal response to climatic and microclimatic conditions is well expressed in the regionalist approaches of architects like Glenn Murcutt in Australia, Charles Correa in India, Geoffrey Bawa in Sri Lanka, and Hassan Fathy in Egypt.

The ***Eco-Medical Logic*** shifts the discussion about sustainability towards a humanist and social concern for the sustaining of individual health. A new relationship of human beings to the environment has been legitimated through an understanding that the health of individuals is conditioned by the external environment [27]. This logic utilizes a medical rhetoric to focus attention on the adverse impacts of the built environment and the causes of stress that engender health problems, both physical and psychological [47]. Here the application of technology is not considered to be a risk-free operation, and importantly, this discourse has served to highlight that reducing the technological intensity of buildings (or society) does not necessarily "*lead to a shrinking well-being: on the contrary even a growth in well-being can be imagined*" [48].

In the case of buildings, the eco-medical logic tends to focus a critical attention on the interior of buildings, where the concept of '*sick buildings*' is a familiar emblematic issue applied to both working and domestic environments [27], whereas the role of buildings as a technological barrier to a hostile natural world has been transformed to as potentially dangerous environments, in which individuals are put at daily risk from a variety of hazards [49]. These ideals are embodied in the concept of '*Baubiologie*' (building biology), where the concepts of health and ecology are

interwoven, and the aim is to "*design buildings that meet our physical, biological, and spiritual needs. Their fabric, services, colour and scent must interact harmoniously with us and the environment… to maintain a healthy, 'living' indoor climate.*" This approach has inspired the buildings of Peter Schmid, Floyd Stein, the Norwegian 'Gaia group', and 'Elbe and Sambeth'.

The ***Eco-Social Logic*** suggests that the root cause of the ecological crisis stems from wider social factors, while addressing democracy as the key to an ecological society [27]. Social ecologists believe that "*human domination and degradation of nature arises out of social patterns of domination and hierarchy, patterns of social life in which some humans exercise control or domination over others*" [50]. The eco-logical society approach proposes the decentralization of industrial society into smaller, highly self-sufficient, and communal units, with the aim to create healthy, self-reliant societies that exercise local control, take responsibility for their environment, and operate a local economy based on minimal levels of material goods and the maximum use of human resources [29].

This logic suggests the creation of buildings that embody and express the notion of a social and ecological community, in which democratic values such as full participation and freedom are the norm [27]. The design approach aims to express the organic formation of society with links to the natural locality within which communities are developed, a strategy that is as much social as technical and aesthetic. The vision of building is one of an enabling, transparent, participatory process that is adapted to, and grounded within, particular local ecological conditions. Contemporary architectural approaches range from the participatory design processes by Lucien Kroll and Ralph Erskine to the self-build projects of Peter Hübner and a number of architects working with the '*Segal method*'. [51]. The aim throughout is to construct appropriate, flexible, and participatory buildings by using renewable natural, recycled, and wherever possible, local materials. The vision of independent eco-communities is realized in a number of alternative communities like the '*Findhorn Community*' in Scotland, '*Christiana Free City*' in Denmark, and '*Arcosanti*' in Arizona.

II.1.3 Sustainable architecture: Objectives and impacts

In the EU, the energy consumption share of different consumer groups is dominated by the residential and tertiary sector, which is responsible for about 40 % of the total final energy demand. Detailing this share in the residential sector, about 57 % of the total final energy consumption is used for space heating, 25 % for domestic hot water and 11 % for electricity [52]. Energy efficient measures need to be developed especially for the existing building stock. For new buildings energy efficient measure have to be implemented already in the design phase. Energy efficiency has been more and more introduced by energy related building standards. The average annual energy demand for space heating is expressed in needed energy per square metre of heated area per year [kWh/m²a] (or cubic metre of heated volume [kWh/m³a]). The *'Directive of the European Parliament and of the Council on the energy performance of buildings'* indicates the necessity and possibility of energy savings through the implementation of traditional and modern methods based on [53]:

- Improvement of the building envelope, with the focus on thermal insulation and glazing
- Improvement of residential hot-water boilers
- Improvement of other installed equipment, e.g. lighting and air conditioning
- Implementation of environmentally friendly energy generation systems
- Introduction of bioclimatic building design.

All methods that can be applied to achieve significant reductions in energy consumption are based on 'standard' energy conservation measures, coupled with the introduction of innovative technologies including utilisation of renewable energy. All these measures will make the building consume less energy and are therefore beneficial to the environment. However, for environmentally-friendly buildings the energy conservation problem has to be considered more globally. One important issue for the environment is what kind of source is used for the energy production, what method of energy conversion is applied, and as a result

how big the impact on the environment is. Hence, apart from the 'standard' energy conservation solutions, the idea of environmentally-friendly buildings is usually realized by applying innovative technologies and measures based on renewable energies and wastes (of energy and materials), as demonstrated by bioclimatic building design, integrated solar thermal and photovoltaic systems, short and long term energy storage, heat recovery, waste sorting and collecting, and water management. Environmentally-friendly buildings are often recognised as buildings designed and constructed in accordance with the *'Green Building Challenge'* process [54]. Thus, the most important issues of environmentally-friendly buildings are as follows:

- Consumption of resources with regard to energy, land, water and material resources
- Environmental load, which includes emission of GHGs (Global Heating Gases), ODSs (Ozone-Depleting Substances), solid wastes, effluent (e.g. treated sewage) and impact on the surroundings of the building
- Indoor environmental quality, which includes thermal comfort, illumination, acoustics, air quality and ventilation
- Quality of service, which includes adaptability of the building (change of room use, preparation for new installations) controllability (autonomous and automatic control of energy systems with easy handling by tenants); maintenance of performance (e.g. access to systems); amenity.

The idea of environmentally-friendly buildings couples the main aims of energy efficiency and environmental protection, resulting in solutions, which can be defined as human-friendly building strategies. In the case of sustainable buildings, the details of energy consumption and the environmental impact of the building are integrated by using a Life Cycle Analysis (LCA) [55]. LCA considers the energy and environmental impact of buildings, its systems, elements and materials starting from the extraction through production to the end-use or recycling. In a *'sustainable buildings'*

strategy all elements of energy efficiency and environmental friendliness can be found. In addition, stress is put on the promotion of quality including [55]:

- Quality of the indoor environment
- Quality of the residential/surrounding area
- Quality of building materials.

The idea of sustainable buildings can also be transformed to (thermal) modernisation processes, and in a next step sustainable refurbishment. It is characteristic that among energy-efficient buildings, there is a significant number of new trends which consider the energy aspects from different points of view. Utilisation of renewable energies and wastes in extreme cases leads to energy self sufficient buildings. These buildings do not require energy to be supplied by external sources, with the energy produced and used at its' site.

According to the *'U. S. Environmental Protection Agency (EPA)'* in the United States, buildings account for 39 % of total energy use, 12 % of the total water consumption, 68 % of total electricity consumption, and 38 % of the carbon dioxide emissions [26]. Green buildings shall reduce the overall impact of the built environment on human health and the natural environment by [26]:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution, and environmental degradation.

According to the EPA, green buildings may incorporate sustainable materials in their construction (e.g.: reused, recycled, or made from renewable resources); create healthy indoor environments with minimal pollutants (e.g.: reduced product emissions); and/or feature landscaping that reduces water usage (e.g.: by using native plants that survive without extra watering) [26]. By adopting such green building strategies, one can maximize both economic and environmental performance. Potential benefits of 'green building' can include:

- Environmental benefits:
  - Enhance and protect biodiversity and ecosystems
  - Improve air and water quality
  - Reduce waste streams
  - Conserve and restore natural resources

- Economic benefits:
  - Reduce operating costs
  - Create, expand, and shape markets for green products and services
  - Improve occupant productivity
  - Optimize life-cycle economic performance

- Social benefits:
  - Enhance occupant comfort and health
  - Increase aesthetic qualities
  - Minimize strain on local infrastructure
  - Improve overall quality of life.

According to the OECD project '*Sustainable buildings*', such objectives may be defined as building practices, which aim for integral quality (including economic, social and environmental performance) in a broad way [14]. Thus, the rational use of natural resources and appropriate management of the building stock will contribute to save scarce resources, reduce energy consumption, and improve environmental quality. The OECD project identified five objectives for sustainable buildings [14]:

1. Resource efficiency
2. Energy efficiency (including reduction of greenhouse gas emissions)
3. Pollution prevention (including abatement of indoor air quality and noise)
4. Harmonisation with environment
5. Integrated and systemic approaches.

II.2 Sustainable architecture in Austria

In the previous chapters, we introduced the concepts of sustainability and sustainable architecture from a rather fundamental scientific and international point of view. Since this work is intended to investigate the current situation addressing *biomimetic sustainable architecture in Austria*, in the following chapters, a closer look on the Austrian building-culture and policy is taken. This shall help to understand, which political and architectural institutions are mainly driving the innovation regarding sustainable building and real estate management, and to which extent social and environmental singularities in Austria may influence architectural evolution.

The present chapter consists of two parts: In the first part, the past and present architecture policy in Austria is summarized, and a focus on the theoretical background of sustainable architecture in Austria is given; in the second part, the most important Austrian institutions dealing with sustainable building certification and/or with sustainable real estate management are introduced.

II.2.1 Architecture-policy in Austria

Since the 1960s the Austrian building stock has about doubled. 25 % of the material flow of minerals, 50 % of waste arising, and almost 40% of the final use of energy are attributable to the building sector [56]. Besides of the actual building activity, which comprises construction and renovation, also space heating and -cooling, hot water, lighting, and home appliances are counted to the energy consumption of the building sector. Additionally, the building sector and the structure of urban development have a strong impact on the energy demand of traffic and industry, especially regarding the fabrication of building material. Hence, the building sector in Austria exhibits a tremendous need for increased energy efficiency and a reduction of greenhouse gas emissions.

On the 30th of March 2004 the Austrian government held a committee of enquiry about *'Architecture-policy and building culture in Austria'*, with the objective to improve general conditions for the contemporary building and planning culture. End of 2005 the *'ARGE Baukulturreport'* has been assigned to issue the first *'Report on Austrian building-culture'* (*'Österreichischer Baukulturreport'* [57]). On this report the following paragraphs of this chapter are based.

Austrian architecture policy does not follow a nationwide offensive or sustainable strategy based on political agendas, financial aid or general conditions by law. It is rather characterized by a tradition of regionally different or even knitted networks that foster architectural quality and building culture. Architectural innovation has primarily been achieved, when the creative potential of the respective period has been facilitated and supported by a culture and quality conscious society, and when contemporary buildings are developed by architecturally interested people/experts with political or economical background. As an example, an insight into the evolution of the building culture and architectural quality in Vorarlberg is given.

Today Austria comprises a close network of institutions and initiatives, which are concerned with the mediation of architecture and building culture, and more or less act through their institutional self-conception or their regional demands, while cultivating informal contacts and cooperation. The related main institution is the *'Architekturstiftung Österreich'*, a common platform of ten architectural agencies of the federal states (*'Architektur Raum Burgenland'*, *'Kärntens Haus der Architektur-Napoleonstadel'*, *'ORTE Architekturnetzwerk Niederösterreich'*, *'afo architekturforum oberösterreich'*, *'Initiative Architektur Salzburg'*, *'Haus der Architektur Graz'*, *'aut. architektur und tirol'*, *'vai Vorarlberger Architektur Institut'*, *'Österreichische Gesellschaft für Architektur'*, and the *'Zentralvereinigung' der Architekten Österreichs'*).

The economic boom after 1955 triggered a strong growth of the population in Austria, which was accompanied by an increased building

activity. Contrary to other the federal states, in Vorarlberg architecture has been addressed open-minded while being more tolerant to innovative developments. In the 80s of the last century, a small group of people known as the '*Vorarlberger Baukünstler*' ('*Vorarlberger building artists*') realized innovative housing models and -developments. Today, Vorarlberg is known as an important regional hub for contemporary architecture, and to some extent it is a trigger for architectural development in Europe. Contrary to similar models in Salzburg ('*Salzburg-Projekt*') or Styria ('*Modell Steiermark*'), in Vorarlberg a broad '*bottom-up*' movement of contemporary, economic, and ecological buildings has been formed; an initiative that has not only been arranged and carried out by architects but also by the clients. This group of people, which was born in the 1960s and especially grew after the energy crisis at the beginning of the 1970s, showed strong interest on intelligent ecology, a new '*minimalism*', and on social architecture and living, which additionally was supported by a federal state law. As of 1985, independent counsels for architecture have been set up in several cities and communities by the local mayors, and in 1989/90 an agency for sustainable buildings, the '*Energieinstitut*' in Dornbirn, was founded. All these developments in Vorarlberg led to an open-minded climate and a broad social consciousness for innovative and sustainable architecture that is exemplary in Austria.

II.2.2 Ecological, economical, and social sustainability

Ecological sustainability

With an average technical life-expectancy, which may easily reach considerably more than 100 years and can even be prolonged by refurbishments, there is hardly any other product that exhibits a longer lifespan than a buildings [58]. Due to this fact, buildings have a long-term impact on the trivalent system of sustainability. A foresighted life-cyclic examination and related planning of the building is essential for a long-term economic investment. However, even though the economic, social, and

ecological success of a project is mainly decided by well-prepared general objectives and planning, narrow amounts of time and budget are usually scheduled for these project phases. In contrast, a long-term economic and practical use is of crucial concern. Addressing sustainability, the life-expectancy of a building can only be neglected if the construction does not affect the system in any way. This would be the case, if its material- and energy demand is met by renewable and/or inexhaustible sources, and if total recyclability is given. If these requirements are not met, the building has to be planned as low-emitting and long-living as possible.

The climatic conditions in Austria might significantly change within the next one hundred years. This may lead to increased medium temperatures especially in the alpine areas, due to decreased snow coverage and glaciers as well as increased heat storage of the rock mass [59]. Hence, an increased number of days with maximum temperatures of ≥ 30 °C during the summer period is likely, whereas extreme periods during the winter period are expected to be less frequent and shorter. Still, minimal temperatures as comparable with today will be likely [59]. As a consequence of the climate change and the shortage of fossil fuels, the possibilities of energy supply will change, whereas also the energy need may (hopefully) be positively influenced. Regarding sustainability, a decentralized and regionally optimized energy mix based on agricultural or silvicultural by-products, hydro-, wind-, solar-, and geothermal energy, industrial waste heat, and new technologies appears desirable. Nowadays, the expectable changes in climatic and energetic boundary conditions have to be addressed already in the planning of a new building as well as in the planning of the building services.

By signing the '*Kyoto protocol*', Austria committed to reduce its greenhouse gas emissions by 13 % until 2012 as compared to 1990 [61]. Nevertheless, in 2007 Austria emitted 88 million tons CO_2-equivalent, which accounts to an increase of 11.3 % as compared to the Kyoto basis year 1990; and Austria was 19.2 million tons above the averaged target value of the Kyoto protocol for 2008 to 2012 (see also figure II-2) [60]. The main reason for

this increase of the Austrian emissions is the increasing use of fossil fuels [58]. About two thirds of the greenhouse gas emissions are caused by the production of energy, hence this development as well as the mixture of energy sources has to be controlled. From 1990 to 2005 the share of emissions for space heating in Austria was constant at about 14 % [61]. Overall, the highest emission growth rates in Austria are documented for traffic, which is directly linked with territorial buildings structures: Free standing family houses, which in Austria account for almost one half (49 %) of all new built residential flats, demand 87 % of the needed area for new roads [62].

Despite the growth of buildings in Austria, building waste stagnates due to improved measures addressing recycled building materials, waste dumping, and demolition waste regulations. Today's demolition waste consists mainly of masonry, but in the future we will have to deal with a growing problematic share of composite and synthetic materials [63].

In 2006, the daily new soil sealing was about 11 hectare with raising tendency [58]. At unmetalled and with vegetation covered areas 20 % of the precipitation is drained off, at roofs, asphalted or concreted areas it is up to 90 % or even 100 %. In urban areas this may lead to aggravated flooding, which has to be controlled. The percolation of precipitation on-site helps to improve drain-off and mitigates possible drain-peaks [64].

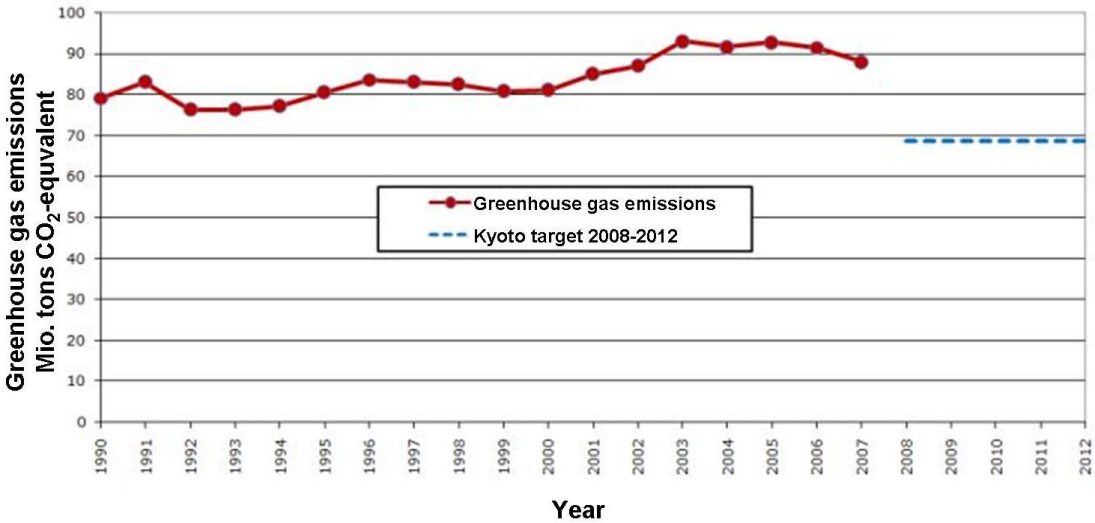

Figure II-2: Greenhouse gas emissions: Trend from 1990 to 2007 and Kyoto protocol targets 2008-2012 (Adapted from [60]).

Social sustainability

Even though there is a certain degree of consensus between experts that the '*social column*' in the concept of sustainability should have its equal share (see also chapter II.1), minor attention is very often given to social aspects. Reasons here may be the difficulty to find useful quantitative threshold values and the fact that social relationships are non-deterministic, the problems concerning political discussions about sensitive topics like poverty and the gap between social science and the actual social differentiation [58].

In general, social aspects address issues of justice and equality of opportunities, which are agendas of social, education, health, labour, and housing policy. In a sustainable society, people have the right of free access to education and health services, as well as an adequate choice on the housing and labour market. Due to a growing public debate on the 'outsourcing' of social costs, these accesses and services are less and less wanted and aided. Hence, the structure and re-structuring of urban settlements is a central object for sustainable development which, however, is mainly recognized by ecological aspects like areal demand or fragmentation of living spaces [58]. Another social aspect of sustainable settlements is the behaviour of different groups, which are commonly explained by cultural paradigms and values, and not by classical social-scientific benchmarks like age, education, sex, or nationality; and hence are 'invisible' for statistics and therefore out of reach for administrative control.

By its '*Good governance*' initiative, the EU tries to implement social aspects, the conservation of cultural differences, and improved protection of the environment into its modernisation roadmap, whereas still competitiveness appears to be the main task.

Economic sustainability

The desire for the realization of architectural claims is mostly superimposed by cost accounting, income return optimization, maximisation

of floor spaces, or 'buy best' principle. The economic conditions of cost minimisation force 'good architecture' to pass on the maximisation of building possibilities, investing into spatial qualities, and searching for new solutions and contents, which have not been approved a thousand times.

In this context, an important benchmark beside 'costs' is 'value' [58], which is a measure resulting from a valuation that goes beyond the simple summation of cost components. At equal costs of a certain product, the user or customer will choose that one which promises to have the higher value for the duration of its aspired utilization. Since real estate has a long expected useful life time and is therefore seen as a long-term investment, the value of a real estate is not only relevant at its completion or commercialization but over its whole life cycle. A building that lacks any aesthetic or cultural claim will dissipate its value faster or even much faster than its expected useful life. This can be seen at buildings from the 1970s and 1980s in Austria, which – regardless of residential or commercial – mainly experienced dramatic losses in their value, which could not be explained by their location or constructional quality only.

In the previous chapters, sustainable architecture in Austria has been discussed by a scientific approach, summarizing the theoretical background and the directives of near-past and current architecture-policy in Austria.

In the following chapters, the focus will be turned a little more on application. The reader will be introduced into the most important Austrian institutions dealing with sustainable building, and the various kinds of certificates these institutions use to evaluate the sustainability of a building.

Finally, the '*Haus der Zukunft*' initiative will be presented, a research and technology program of the '*Federal Ministry of Transport, Innovation and Technology*', which aims to provide a firm basis for innovative, sustainable concepts, both for new buildings and for refurbished ones [65].

II.2.3 'OI3-Index', 'IBO-Ökopass', 'TQB'/'ÖGNB', 'klima:aktiv haus', and 'ÖGNI'

In 2002 the EU approved the 'Energy Performance of Buildings Directive (EPBD)', incorporating four key points [66]:

- A common methodology for calculating the integrated energy performance of buildings;
- Minimum standards on the energy performance of new buildings and existing buildings that are subject to major renovation;
- Systems for the energy certification of new and existing buildings and, for public buildings, prominent display of this certification and other relevant information. Certificates must be less than five years old;
- Regular inspection of boilers and central air-conditioning systems in buildings and in addition an assessment of heating installations in which the boilers are more than 15 years old.

The directive among other things targets to introduce an 'Energy Performance Certificate' to evaluate and benchmark buildings. The 'Assessment and Improvement of the EPBD Impact (ASIEPI)' project (01/10/2007 - 31/03/2010) analyses the main aspects of the EPBD directive in the participating countries, and will make suggestions for improvements [67]. Very recently, on the 1st and 2nd of September 2009, ASIEPI has organised a workshop called *'Impact, compliance and control of energy legislations'*, to monitor the EPBD implementations of the various member states [68]. Austria did not participate in this meeting, since it is not represented in the ASIEPI.

The conversion of the *'EU Energy Performance Certificate'* into national law is in Austria to a large extend within the obligation of the federal states, which makes it difficult to find one national harmonisation, whereas a formal proposal for the harmonisation of building regulations in Austria is given by the *'Österreichisches Institut für Bautechnik, OIB'*[1] (*'Austrian Institute of*

[1] Not to mix up with the *'Österreichisches Institut für Baubiologie und Bauökologie', IBO as given in the following sentence.*

Construction Engineering') in its *Directive 6: Energy saving and thermal insulation* [69]. Nevertheless, there is a will to develop countrywide building regulations, which are developed by the *'Austrian Institute for Healthy and Ecological Building'* (*'Österreichisches Institut für Baubiologie und Bauökologie', IBO*). The IBO is an independent, scientific non-profit society, which investigates the interactions between people, buildings and the environment [70]. In the following, we will discuss the IBO *'OI3-Index'*, some kind of ecological coefficient for building materials, as well as the most important Austrian building certificates *'IBO-Ökopass'*, *'Total Quality Building (TQB)'*, and *'klima:aktiv haus'* in more detail. Additionally, we will introduce the *'Austrian Society for Sustainable Real Estate Management'* (*'Österreichische Gesellschaft für nachhaltige Immobilienwirtschaft'*, *ÖGNI*).

It is very important to mention that the beneath given coefficients and evaluation certificates are by no means comparable, since for example the *'klima:aktiv haus'* is a relatively 'simple' building certificate that targets the non-expert privately owned home builder, and the *'TQB'* is a very complex and cost-consuming LCA providing much more detailed and accurate information.

'OI3-Index'

The ecological expenditure in manufacturing for a building by the actual building standards is about the same as the ecological expenditure for the heating of a passive house for the duration of 100 years [71]. Hence, the ecological optimization of the expenditure in manufacturing is an important part of ecological and sustainable building. Ecological optimization includes the minimization of the flow of materials and the emissions of the production process of the building as well as of the building materials. This optimization process can be simplified visualized by the *'OI3-Index'* of the thermal building envelope ($OI3_{TGH,Ic}$). The basis for this evaluation are the eco-balances from the ISO-norm 14 040, by that the choice of the building material can be based on scientific research, since the respective data for

the most important building materials and constructions are available. The '*OI3-Index*' is based on an impact-oriented classification [71]:

1. In a first step the production of a building material or a construction is represented by a balance-model, whereas also by-products like waste, and emissions in air, water, ground, and energy are comprised.
2. In a second step the impacts of every product concerning its '*Global Warming Potential*' (*GWP*), '*Acidification Potential*' (*AP*), and '*Primary Energy Input*' (*PEI*) are calculated. Every impact category is normalized by a lead substance, for example CO_2 for the GWP, and the data is summarized for 1 kg material or 1 MJ energy in a database, which is provided for free.
3. In the third step the summarized evaluation for a construction or building is established. For a building the values of all building parts of one impact category are summed up and calculated to a linear function per 1 m² Construction Area (CA), with a scale from 0 to 100 points, as it is shown for GWP in figure II-3.

The '*OI3-Index*' is then calculated as follows:

$$OI3 = 1/3\ OI_{,PEIne} + 1/3\ OI_{GWP} + 1/3\ OI_{AP}$$

where OI_{GWP} is the eco-indicator for the Globing Warming Potential, OI_{AP} is the eco-indicator for the '*Acidification Potential*', and OI_{PEIne} is the eco-indicator for the '*Primary Energy Input*' non-renewable (energies).

In other words, the Global Warming Potential (GWP) describes the share of a substance in the global warming related to the share of the same amount of CO_2.

The '*Acidification Potential*' (*AP*) is the quantity of the tendency of a substance to react by nitric oxide (NO_x)- or sulphur dioxide (SO_2) gases with other air components, and is related to the acidic potential of SO_2 for every acidic substance.

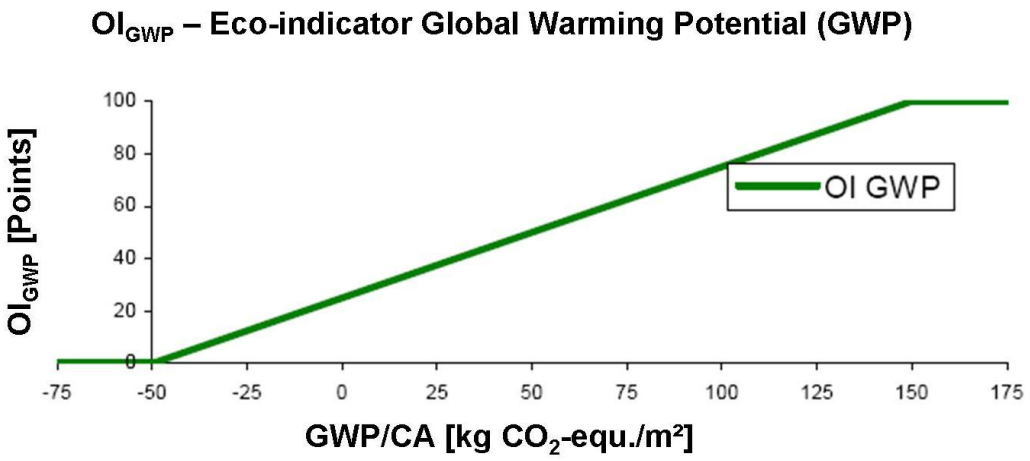

Figure II-3: Eco-indicator for *'Globing Warming Potential'* (*GWP*) as used for the *'OI3-Index'*.

The *'Primary Energy Input non-renewable'* (*PEI n. e.*) is calculated from the uppermost heating value of all non-renewable resources that have been used within the manufacturing process of the product. Even though this is a material number and not a impact category, it is used equally as compared to the other ecological impact categories.

The value of the *'OI3-Index'* is dependent on which building parts are used for its calculation. For the calculation of housing subsidies for example, at the moment only the thermal building envelope and the intermediate ceilings are comprised, which makes it possible to calculate the *'OI3-Index'* besides the energy certificate without any additional effort. This *'OI3-Index'* is denoted as $OI3_{TGH}$, whereas *'TGH'* stands for *'technical building envelope'* (*'Technische GebäudeHülle'*). If this index is weighted by the factor *'3/(2+lc)'* for the building geometry, one obtains '$OI3_{TGH,lc}$', which is used for housing subsidies in Salzburg, Lower Austria, Styria, and Carinthia. Is the value related to the *'gross building area'* (*'BruttoGeschossFläche'*) $OI3_{TGH,BGF}$ is obtained, which is used for the calculation for housing subsidies in Vorarlberg and the *'klima:aktiv haus'*. The $OI3_{TGH}$ is usually calculated from 0 to 100, whereas 0 equals the ecologically friendliest constructions.

The increased application of renewable resources and ecologically optimized production processes usually leads to superior (smaller) $OI3_{TGH,lc}$-

values for buildings. In general, one can say that, to reach the best '*OI3-Index*' category ($OI3_{TGH,lc}$ < 20), a complete and comprehensive ecological optimization of the manufacturing process of a building has to be conducted.

For the sake of completeness, we want to mention that in Austria various approval marks (or certifications) exist, which qualify building materials to be ecological certified. Such building materials are evaluated over their complete life cycle from their fabrication until their disposal and belong to the best of their product category, which assures the technical, sanitary and ecological quality. Since the fabrication, implementation, and disposal of building materials accounts for a large part of the environmental impact already arising of the moved masses, this is an important measure for the ecological optimization of the building life cycle. Common certificates are:

- '*natureplus*' (www.natureplus.org)
- '*IBO Prüfzeichen*' (www.ibo.at)
- '*Österreichisches Umweltzeichen*' (www.umweltzeichen.at).

At the moment the ongoing work aims to not only imply the thermal building envelope into the calculation of the '*OI3-Index*', but the whole building. Additionally, the '*OI3-Index*' is planned to be extended to an '*OI4-*', '*OI5-index*' or so on, by implementing further impact categories like for example ozone generation.

'IBO-Ökopass'

The '*IBO-Ökopass*' is a building certificate focusing on residential neighbourhood housing with the goal to benchmark the biological and ecological building quality of such housing projects [72]. Eight criteria are investigated by measurements and calculations, and are then assessed by a two-stage evaluation (Pre- and end-evaluation). These eight criteria are separated into two groups, namely '*quality of use*' and '*ecological quality*' [72]:

- Quality of use
  - Comfort in summer and winter
  - Indoor air quality
  - Noise protection
  - Day- and sunlight
  - Electromagnetic quality

- Ecological quality
  - Ecological quality of building materials and constructions
  - Overall energy concept
  - Usage of water

The criteria are evaluated on the basis of regulatory requirements. In case of missing regulatory requirements or regulations, the evaluation is done by referring to international state-of-the-art research, building standards, or precautionary principles.

The evaluation is done by assessing the whole residential neighbourhood housing project, whereas single flats dependent on their location may exhibit specific characteristics. The *'IBO-Ökopass'* classifies the quality of residential neighbourhood housing into four levels: *'Excellent'* (*'Ausgezeichnet'*), *'Very good'* (*'Sehr gut'*), *'Good'* (*'Gut'*), and *'Satisfying'* (*'Befriedigend'*). The housing project is classified by two steps, a pre-evaluation at the start of construction, and an end-evaluation after the completion of the building. Additional information on the *'IBO-Ökopass'* can be found at the IBO web-platform [72].

'ÖGNB'* and *'Total Quality Building (TQB)'

The *'Austrian Society for Sustainable Building'* (*'Österreichische Gesellschaft für nachhaltiges Bauen', ÖGNB*) has been founded in January of 2009 by the *'Austrian Institute for Healthy and Ecological Building'* (*'Österreichisches Institut für Baubiologie und Bauökologie', IBO*) and the *'The Austrian Institute of Ecology' ('Österreichisches Ökologie-Institut', ÖÖI*). These

two institutions also brought in the evaluation system *'TQB'* into the *'ÖGNB'*. Like many other building evaluation systems (e.g. *'LEED'*, *'BREEAM'*, *'HQE'*), *'TQB'* has been developed during the Austrian project *'GBC'98'* in 1998 [73] and during phase 1 and 2 of the worldwide project *'Green Building Challenge'* (*GBC*) [74], whereas guidelines and tool are regularly adapted according to state-of-the-art findings [75].

The evaluation system of *'TQB'* contains criteria and target systems, indicators and the valuation method (evaluation procedure and weighting). Here, social value systems determining the importance of building characteristics are relevant for which criterion is used for evaluation, whereat *'TQB'* uses criteria that have been assigned by the international *'Green Building Challenge'* group. The nine criteria/categories are [76]:

1. Conservation of natural resources
2. Reduction of impact on humans and the environment
3. Convenience for users
4. Longevity
5. Security
6. Design Quality
7. Construction quality
8. Infrastructure and Facilities
9. Cost

Depending on the building type and use, different criteria and - in some cases - also different scales are used. For each evaluation criteria, the *'TQB'* certificate utilizes concrete target systems that have been developed regarding Austrian conditions, whereas these target systems have to be fulfilled in order to reach the best rating. Individual indicators (e.g. heating energy demand per m² and year) are used to define a criterion, and to document the actual fulfilment status as compared to the target value, whereas in *'TQB'* qualitative as well as quantitative indicators are used. The indicators as well as the respective verification procedure are based on European and national engineer rules and standards (or concepts of such), if

present. A long-term object of the *'TQB'*-project is to establish a recognized system of rules for a *'Total Quality in building construction'*. Every criterion, whether it is qualitatively or quantitatively indicated, is evaluated by an eight-stage linear point scale with the maximum value representing the respective target value. The achieved values are then multiplied by their related weighting coefficient to implicate their importance, whereas several values may be aggregated to the point of one final value for the building.

The basis for the evaluation is information on the building in form of calculation results, descriptions of measures, building plans, data of measurement tools, measurement data, and testing reports. Hence, the way of data acquisition has to be precisely specified to make results comparable. A guideline (*'TQ criteria catalogue'*) comprehends information about how the respective target system values can be achieved, and gives support on the acquisition of data that is needed for the evaluation tool (*'TQ-tool'*). The complete guideline, and additional information on the *'TQB'* can be found on the related web-platforms [74], [76], and [77].

'klima:aktiv haus'

The *'klima:aktiv haus'* is a building certificate that involves the criteria for energy efficiency, ecology and comfort. The criteria catalogue is provided for two different levels of quality: *'klima:aktiv house'*, and *'klima:aktiv passive house'*, whereas a *klima:aktiv house* equates to a low energy building, and a *klima:aktiv passive house* fulfils the highest demands concerning state-of-the-art energy saving. The method is based on the review of criteria that are divides into four assessment categories [78]:

1. Planning and execution
2. Energy and supply
3. Materials and construction
4. Air quality and comfort

By a grading system the quality of a building regarding to these four criteria is assessed. In addition to arbitrary criteria, there are mandatory criteria that have to be followed in every case.

The '*Planning and execution*' category addresses planning and design aspects such as accessibility, thermal reduction and air leakage. For housing renovation and commercial buildings, the cost of the planned measures is in the focus of attention, by using a simplified calculation of life cycle costs. '*Energy and supply*' comprehends the heating demand, which has to be significantly below that of 'ordinary buildings'; for *klima:aktiv passive houses* it has to be at least 80% below the requirements for 'ordinary buildings'. Additionally, extra points for environmentally friendly and efficient heating systems and solar systems can be earned. In the case of '*klima:aktiv passive houses*' the total primary energy - the energy quality of the entire building (e.g. building envelope, heating system, and energy source) is assessed by a single value. The assessment approach for '*building materials and construction*' is based on four pillars:

- Particularly climate-harmful materials are excluded.
- Building materials that exhibit weaknesses within the life cycle are to be avoided.
- Ecological/Organic materials are to be used.
- The energy needed to manufacture the building is to be minimized.

Detailed information on building materials for *klima:aktiv buildings* can be found in the production database [79]. *Klima:aktiv buildings* have to exhibit a very good indoor air quality and a high user-comfort. Additionally, installations for fresh air or comfort ventilation systems with heat recovery are mandatory; the air quality-relevant materials have to be low in their emissivity, and pleasant temperatures during summer have to be guaranteed.

The evaluation is based on a 1000 points grading system, and the buildings get points for every criterion they fulfil. A *klima:aktiv house* has to

reach at least 700 points, and a *klima:aktiv passive house* has to reach at least 900 points. The tables including criteria and respective points can be found in the criteria catalogue at the *'klima:aktiv haus'* web platform [78].

'ÖGNI'

The *'Austrian Society for Sustainable Real Estate Management'* (*'Österreichische Gesellschaft für nachhaltige Immobilienwirtschaft', ÖGNI*) has been founded in April of 2009, and is a non-proft *'Non-Governmental Organization'* (*NGO*), with the purpose to expedite the sustainability of Austrian building culture and real estate management [80]. By a cooperation treaty that has been signed at the *'International congress and a trade fair for sustainable building CONSENSE 2009'* [81], the ÖGNI is linked to the *'German Sustainable Building Council' ('Deutschen Gesellschaft für Nachhaltiges Bauen', DGNB*) [82]. This cooperation aims to adopt the *'German Sustainable Building Certification'* of the *DGNB* to Austria, and in the future to further develop this system to a European certification system.

This *'German Sustainable Building Certification'* covers all relevant topics of sustainable construction, and awards outstanding buildings in the categories bronze, silver, and gold. Six subjects affect the evaluation: *ecology*, *economy*, *social-cultural* and *functional topics*, *techniques*, *processes*, and *location*. The certificate is based on the concept of integral planning that defines, at an early stage, the aims of sustainable construction. In this way, sustainable buildings can be designed based on the current state of technology, – and they can communicate their quality with this new certificate [82].

II.2.4 The *'Haus der Zukunft'* initiative

One of the ambitious aims of the European research framework programs is the abandonment of fossil fuels in the building sector within the next 25 to 50 years or so. By research and development, the basis for new and sustainable concepts, concerning building under construction and

renovation, shall be developed. Due to this, in 1999 the '*Austrian Federal Ministry of Transport, Innovation and Technology*' announced the research and technology program '*Haus der Zukunft*' ('*Building of Tomorrow*') [56]. The two main topics of the '*Haus der Zukunft*' programme, the *solar low-energy house* and the *passive house*, have later been extended by *ecological, economic, and social demands*.

'*Buildings of Tomorrow*' are new buildings or renovated old buildings that fulfil the following criteria:

- Clear reduction of use of energy and materials
- Enhanced implementation of renewable energy sources, especially solar energy
- Increased and efficient use of renewable and accordingly ecological building materials
- Consideration of social aspects and improvement of quality of life

As an output, the aim of the program was to research and develop marketable components, building parts, and building concepts for residential, commercial, or utility buildings, which to a great extent meet the above mentioned criteria. The generation of research proposals was done by broad national calls, whereas until the mid of 2009, six consecutive calls have been completed. From 700 proposals, 300 have been approved, and the '*Austrian Federal Ministry of Transport, Innovation and Technology*' has provided more than 35 million € of subsidies.

As given by the programme webpage, the first phase of '*Building of Tomorrow*' fostered essential developments in the field of sustainable building in Austria [56]:

- An increase of the scientific expertise in this field
- Austria exhibits the highest density of passive houses in the world
- Austrian companies were able to gain the technological leadership concerning sustainable building

- The adaption of housing subsidies to new developments in architecture have been supported
- The *'klima:aktiv haus'* programme (as given in chapter II.3.3) is based on the results of the first phase of the *'Haus der Zukunft'* programme.

The long-term vision of a *'Building of Tomorrow'* is to optimize the energetic efficiency of its construction and operation in a way that its greenhouse gas emissions are reduced to zero over its whole life-cycle. This requires the building to change from a consumer to a supplier of energy during its operational phase, which means that the building is designed as a *'Plus-energy-building'*.

By this, the second phase of the *'Haus der Zukunft'* programme, the *'Haus der Zukunft Plus'* (*'Building of Tomorrow Plus'*) programme deals with the development and fabrication of buildings that produce energy during their life of operation. Regarding to this focus, the four main thematic areas are [56]:

- Development of key-technologies
- Industrial implementation of innovative technologies
- Lead-projects concerning demonstration
- Strategy, Networking, and Education.

By this, the technological position of Austria regarding energy-efficient building construction and renovation, and increased use of renewable energy sources in architecture shall be strengthened on the one hand, and on the other hand these technologies and its' accompanying know-how shall be disseminated [56].

II.3 Biomimetics and biomimetic architecture

This chapter is divided into two parts. In the first part, the terminology of '*bionics*' or '*biomimetics*' is introduced, whereas examples for an academic- or more application-oriented classification are given. In the second part, methods by which "designs" or "inventions" from nature can be translated and transferred to the human world, and how they may be applied to technology or architecture, are given.

Different levels of biomimetic technologies as well as of mimicking behaviour can be defined. This makes an evaluation of the utilization of the potential of biomimetics in sustainable architecture rather difficult. Hence, to correctly evaluate the sustainability of a biomimetic approach, it has to be defined what may be appraised to be a sustainable building or specific building aspect on one hand, and what to be a valuable biomimetic approach to a building or a building aspect on the other hand. The first task has been addressed within chapters II.1 to II.2. To discuss the second task, in this chapter the concept of biomimetics and how it may be translated into architecture will be discussed. In chapter II.4, some ideas, concepts, and possible solutions of how biomimetics may be applied to obtain sustainable buildings, or to increase the sustainability of existing concepts or buildings, will be given.

II.3.1 Terms, definitions, and subfields

There is diverging information available about the creation of the term '*bionic*' (also known as '*biomimetics*', '*biomimicry*', '*bio-inspiration*', '*biognosis*', '*biologically inspired design*', and similar words and phrases implying reproduction, adaptation, or derivation from biology). Consistent is that it was introduced by Jack E. Steele around 1960. The term possibly originates from the Greek word '*βίον*' ('*bíon*'), meaning 'unit of life' and the

suffix '*-ic*', meaning 'like' or 'in the manner of', hence it may be translated as '*like life*'. However, some dictionaries or publications explain the word as being formed from '*biology*' and '*electronics*' or '*technics*' [7]. All these terms more or aim to denote it as a study that makes practical use of mechanisms and functions as present in biology or nature in engineering, design, chemistry, electronics, and so on.

In the German-speaking world, the according literature was strongly influenced by Werner Nachtigall, who interpreted the German term '*Bionik*' as a combination of the words '*Bio*logie' ('biology') and Tech*nik* ('technology' or 'technics') [83]. In English the term '*biomimetics*' is commonly used, and '*bionics*' is referred to the usage of robotics for the replacement or enhancement of living matter, tissue, body parts and organs with mechanical versions. The polymath Otto Schmidt introduced this term in the 1950s as a disregarded - but highly significant - converse to the standard view of biophysics [84]. In 1969, Schmitt used the term "*biomimetics*" in the title of a paper [85], and the word made its first public appearance in *Webster's Dictionary* in 1974, accompanied by the following definition:

> "*The study of the formation, structure, or function of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones*" [86].

However, the part '*mimetic*' suggests a mimicking of nature, and hence the term is controversial [7]. In this work, solely the term "*biomimetics*" is used (as long as this is applicable); possible different terms like '*bionics*', '*biomimicry*', or '*bionik*' will be used synonymously, without italic formatting and quotes.

In the ongoing scientific discussion, Nachtigall defined bionik and technical biology as disciplines that complement each other in the cycle of continuing scientific technical development and progress. Accordingly, the term bionik was agreed by '*The Association of German Engineers*' ('*Verein*

Deutscher Ingenieure', VDI [87]) in 1993, and extended by Werner Nachtigall in 1998:

> *"As a scientific discipline, bionics deals systematically with the technical execution and implementation of constructions, processes and developmental principles of biological systems. This also includes various forms of interaction between living and non-living elements and systems."* [88]

Websites like the German '*Biokon'* network, define bionik simply as:

> *"Decoding of 'inventions of animate nature' and their innovative implementation in technology" ("Entschlüsselung von 'Erfindungen der belebten Natur' und ihre innovative Umsetzung in die Technik."). [89]*

The '*Centre for Biomimetics'* in Reading defines biomimetics as:

> *"The abstraction of good design from nature."* [90]

In his comprehensive textbook *"Bionik: Grundlagen und Beispiele für Ingenieure und Naturwissenschaftler"* (*"Bionics: Basics and examples for engineers and Natural scientists"*, [91]) Werner Nachtigall topically divides bionik into 12 subfields [91]:

- *'Structure bionics'* ('Strukturbionik'): Structural elements, materials and surfaces
- *'Construction bionics'* ('Baubionik'): "Natural constructions", transform-able constructions, surfaces, etc.
- *'Climate bionics'* ('Klimabionik'): Passive ventilation, cooling and heating
- *'Structural bionics'* ('Konstruktionsbionik'): Constructional elements and mechanism
- *'Locomotion bionics'* ('Bewegungsbionik') Walking, swimming, and flying, as well as Interaction with the surrounding medium
- *'Device bionics'* ('Gerätebionik'): Overall constructions

- ‚*Anthropobionics*‘ (‘Mensch-Maschine-Interaktion‘, ‘Robotik‘): Human - machine interaction
- *‘Sensor bionics’* (‘Sensorbionik’): Sensors, detection and locating
- *‘Neuro-bionics’* (‘Neurobionik’): Data analysis, information processing
- *‘Process bionics’* (‘Verfahrensbionik’): Processes, conversions, transactions, etc.
- ‘Organizational bionics’ (‘Organisationsbionik’): Relationships in biological systems
- *‘Evolutionary bionics’* (‘Evolutionsbionik’): Evolution techniques, and - strategies.

This classification should be seen as an academic approach, whereas the individual subfields may partly overlap, as for example the subfields *‘construction bionics’* and *‘climate bionics’*, and are partly comprised wider or narrower. Hence, many examples utilizing one or more of the above given biomimetic approaches may be allocated to more than one subfield.

Biomimetic approaches are integrated in industry already, or are considered to be applied in the near future. The *‘Biomimetics Network for Industrial Sustainability’*, *BIONIS*, tries to promote the application of biomimetics in products and services, and classifies biomimetic into - application-oriented - focus areas [92]:

- Energy and resource efficiency
- Elimination and control of hazardous substances
- Use of renewable and biodegradable materials
- Added functionality in materials and structures
- Biomedical & Pharmaceutical applications
- Architecture and design, intelligent buildings
- Biologically inspired decision-making, optimisation strategies
- Robotics, fluid dynamics, flying, swimming, drag
- Materials & lightweight structures
- Sensors, information processing, communications

- Packaging
- Surfaces.

Some of the previously given subfields from W. Nachtigall, namely [91]:

- *'Structure bionics'* ('Strukturbionik'): Structural elements, materials and surfaces
- *'Construction bionics'* ('Baubionik'): "Natural constructions", transform-able constructions, surfaces, etc.
- *'Climate bionics'* ('Klimabionik'): Passive ventilation, cooling and heating
- *'Structural bionics'* ('Konstruktionsbionik'): Constructional elements and mechanism,

or focus areas derived from *BIONIS* [92]:

- Energy and resource efficiency
- Elimination and control of hazardous substances
- Use of renewable and biodegradable materials
- Added functionality in materials and structures
- Architecture and design, intelligent buildings
- Materials & lightweight structures
- Surfaces

may especially be applied to sustainable architecture, and are primarily relevant for this work.

II.3.2. Abstraction, translation, and transfer

Abstraction and translation

In her book *"Biomimicry: Innovation Inspired by Nature"* [93] Janine Benyus tried to summarize and categorize the main trends and principles of current biomimetic investigation, by which a multitude of disciplines - from

engineering to agriculture - analyze and evaluate the designs and processes found in nature [93,94]:

1. *'Nature as Model'*: Biomimicry is a science that studies nature's models and emulates or takes inspiration from their designs and processes to solve human problems.
2. *'Nature as Measure':* Biomimicry uses an ecological standard to judge the "rightness" of our innovations. After 3.8 billion years of evolution, nature has learned, what works, what is appropriate, and what lasts.
3. *'Nature as Mentor':* Biomimicry is a holistic way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it.

In the book *"Natural constructions"* (*"Natürliche Konstruktionen"*) [95] from 1985, Frei Otto relates form, structure and function by:

"Constructions possess a shape or (geometrical) form and an inner structure. Form and structure come into being by way of a common developmental process, depending on physical and chemical laws or human creative power." [95]

Juri Lebedew found a very similar explanation:

"In nature, the principle of integration of function+form+structure is effective, and is adapted to the existence and interrelation with the environment." [96]

By this, Petra Gruber concludes that:

"The existing object always embodies both process and result. The integrity of form, structure and function in nature makes purely morphological translations worthless." [97]

This is a very important conclusion for this study, because since from the beginning of the 21st century - especially triggered by new and powerful computer-aided design (CAD) systems - the design and construction of

buildings that mimic natural or biological forms began to mature, but this does not automatically mean that such buildings are "*closer to natural*".

Human design capabilities, materials, manufacturing and construction methods are different from those found in nature, and as such do not always translate from one to another in an efficient manner [94]. Thus, a concept will become much more robust, if we are able to distil innovative design and manufacturing inspiration (with regard to the current manufacturing techniques available) from natural phenomena rather than strictly attempting to mimic them [98]. The natural phenomenon should be translated into a technological application by an independent development or re-invention that passes a couple of abstraction-, and modification processes [99].

Transfer

Transferring nature to engineering can be performed by different concepts. Following the book "*Biomimetics*", edited by Yoseph Bar Cohen, "*approaching nature in engineering terms needs to sort biological capabilities along technical categories using a top-down structure or vice versa*" [100].

- The '*top down approac*h' (also known as '*biology influencing design'* [101]) is mainly based on foregoing basic research studies to find possible natural (e.g. biological) models or concepts, which are then used to elaborate a specific technical solution. The natural or biological knowledge influences the human solution.

- The '*bottom up approach'* (also known as '*design looking to biology'* [101]) starts with a specific technical problem, and research studies are done to find possible solutions in nature for an analogous problem. Possible findings are then applied into the search for a solution of the specific problem.

Top down approach / Biology influencing design

Probably the most famous example for this concept is the scientific analysis of the lotus flower, which is able to self-clean it's leafs by a special surface-texturing and water. This analysis led to many design innovations, including Sto's *Lotusan paint* enabling surfaces to be self-cleaning (see also figure II-4) [13].

Citing studies by Vogel [102], and later by Vincent and co-authors [84], similarities between human design solutions and tactics used by other species have a surprisingly small overlap, if considering they exist in the same context and with the same available resources [13]. Therefore, biology may influence humans in ways that might be outside a predetermined design problem, resulting in previously not considered approaches to design solutions. Hence, such an approach to biomimetic design may involve the potential for true shifts in the way humans design, and what is focused on as a solution to a problem [103]. A disadvantage with this approach is that biological research has to be conducted and then identified as relevant to a design context, whereas biologists and ecologists have to be able to recognise the potential of their research for novel applications [13].

Bottom up approach / Design looking to biology:

This concept requires designers to identify problems, their initial goals and parameters, and biologists to hereon match these to organisms that have solved similar issues. A famous example of such an approach is *Daimler Chrysler*'s prototype *Bionic Car* (see figure II-5) [13].

Figure II-4: Self-cleaning lotus flower (two left images) and principle of Sto's Lotusan paint (two right images) (adapted from [13]).

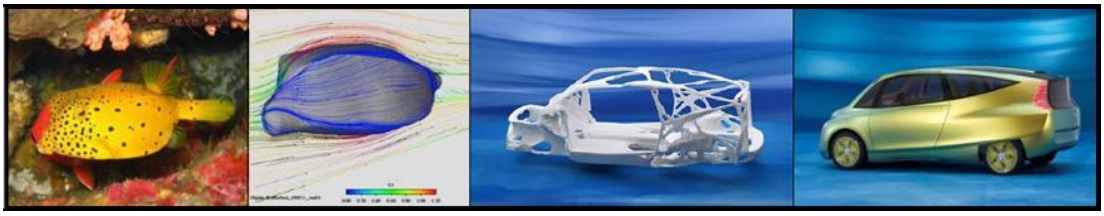

Figure II-5: DaimlerChrysler's prototype *Bionic Car* (two right image), which was inspired by the box fish (two left images) and tree growth patterns (adapted from [13]).

In looking to create a large volume, small wheel base car, the design for the car was based on the surprisingly aerodynamic box fish, giving the design its box-like shape [13]. The chassis and structure of the car are also biomimetic, having been designed based upon modelling of trees, which are able to grow in a way that minimises stress concentrations. The resulting structure looks almost skeletal, as material is allocated only to the places where it is most needed [84]. As Maibritt Pedersen Zari points out [13]:

> *"...possible implications of architectural design, where biological analogues are matched with human identified design problems, are that the fundamental approach to solving a given problem, and the issue of how buildings relate to each other and the ecosystems they are part of, is not examined. The underlying causes of a non-sustainable or even degenerative built environment are not therefore necessarily addressed with such an approach."*

Addressing this point at *Daimler Chrysler*'s *Bionic Car* (see figure II-5,) the car itself is not a new approach to transport. It is more efficient in terms of fuel use due to its aerodynamic body. It is also more material-efficient by using the minimum amount of material for the structure of the car due to the mimicking of tree growth patterns. In conclusion, small improvements have been made to an existing technology, without a re-examination of the idea of the car itself as an answer to personal transport. According to Zari [13]:

> *"Designers are able to research potential biomimetic solutions without an in depth scientific understanding or even collaboration with a biologist or ecologist […] With a limited scientific understanding however, translation*

of such biological knowledge […] remains at a shallow level. It is for example easy to mimic forms and certain mechanical aspects of organisms, but difficult to mimic other aspects, such as chemical processes without scientific collaboration."

But despite these disadvantages, such an approach might be a way to begin transitioning the built environment from an unsustainable to an efficient and effective paradigm [104].

In contrast, it is argued that a shift from a building policy that ultimately is degenerating ecosystems to one, which regenerates and restores local environments, will not be possible by a gradual process of improvements but will in fact require a fundamental rethinking of how architectural design is approached [11,105].

Stochastic approach:

Stochastic approaches may be performed by the use of large databases, which collect as much different phenomena from nature as possible, to access the desired information. The European Space Agency (ESA) for example uses a 'biomimetics database' to look for suitable role models from nature, while ordering them as follows [106]:

- Structures and materials
- Mechanisms and processes
- Behaviour and control
- Sensors and communication
- Generative biomimicry.

In the case of the application of biomimetics to architecture, we hereby may have to change the scale, the medium, or the time dimension, as Petra Gruber summarized in a scheme that is shown in figure II-6 [107]. This figure bridges the gap to the next chapter, in which the fundamentals of the biomimetic application to sustainable architecture are introduced.

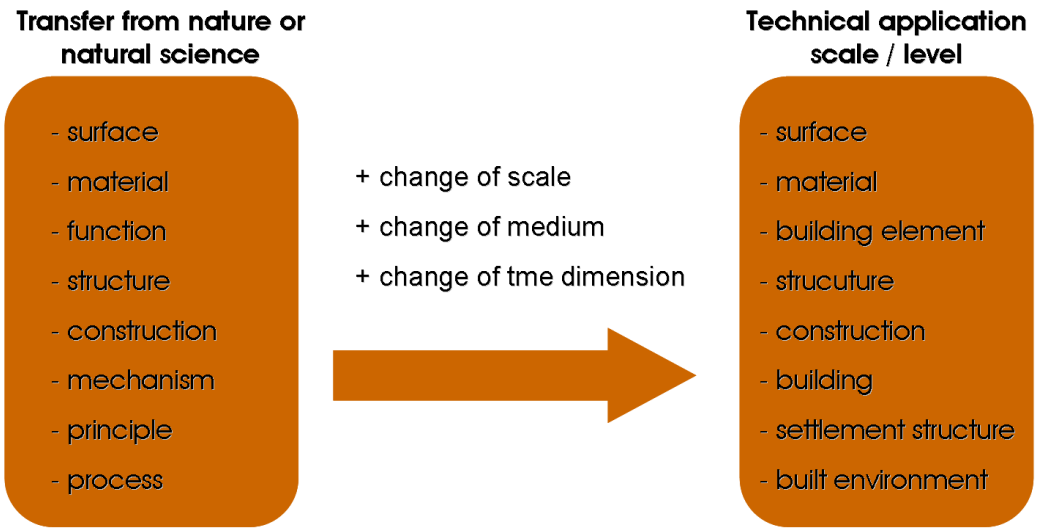

Figure II-6: Possible transfers of various natural constructions, structures, materials, processes, or information into technical applications (adapted from [97]).

The main attraction of this biomimetic approach for architects is that it raises the prospect of closer integration of form and function (with regard to a holistic building design) [108]. At a deeper level, according to George Jeronimidis of the University of Reading, architects are drawn to the field,

> "*...because we are all part of the same biology. The urge to build in closer sympathy with nature is a genuinely biological, and not merely a romantic urge.*" [109]

II.4 Applying biomimetics to sustainable architecture

In the field of sustainable architecture, various forms of biomimetic or bio-inspired design are discussed by researchers and professionals [10,11]. Hereby it is consistently concluded that the widespread and practical application of biomimetics as an architectural design method remains largely unrealised, as demonstrated by the small number of built case studies [12,13].

Biomimicry is often described as a tool to increase the sustainability of human designed products, materials, and the built environment [110]. However, many biomimetic technologies or materials are not inherently more sustainable than conventional equivalents, and may not have been initially designed in this intention [111].

Most examples of biomimicry are 'organism biomimetic', and while this may be inspirational to produce novel architectural designs [109], the option for buildings is to mimic natural processes. They may function like an ecosystem; and thus have the potential to achieve sustainability by using regenerative systems [11]. Hence, it is suggested that, if biomimicry is to be conceived as a way to increase the sustainability of an architectural project, mimicking of general ecosystem principles should be incorporated into the design at the earliest stage, and used as an evaluative tool throughout the design process [101].

The different levels of biomimetic approaches and technologies broaden the potential of biomimetics to be applied in buildings or more specifically in sustainable architecture. Consequently, to correctly account the sustainability potential of a biomimetic approach to architecture, it has to be defined, what is appraised to be a sustainable building or specific sustainable architectural aspect on one hand, and what is to be a valuable biomimetic approach to a building or an architectural aspect on the other hand. The first item has been answered within chapters II.1 to II.2. The concept of biomimetics and how it may be translated to architecture has been elaborated in chapter II.3. In the following chapter, ideas, concepts, and

possible solutions how biomimetics may be successfully applied to obtain sustainable buildings or to increase the sustainability of existing concepts are explained.

II.4.1 Ideas and concepts

Levels of biomimetics (biomimicry):

Three levels of biomimetics, which are typically given as *'form'*, *'process'* and *'ecosystem'*, may be applied to a design problem [101]. *Form* and *process* are aspects of an organism or ecosystem that could be mimicked, whereas *ecosystem* could be studied to look for specific aspects to mimic.

Maibritt Pedersen Zari [13] tries to deliver a framework for understanding the application of biomimicry, while redefining these different levels. She also attempts to clarify the potential of biomimetics as a tool to increase the regenerative capacity of the built environment, and defines three levels of biomimicry, which are categorized by their aspect of *'bio'* that has been *'mimicked'*: *'organism'*, *'behaviour'* and *'ecosystem'* [13].

- The ***'organism level'*** refers to a specific organism like a plant or animal, and may involve mimicking part of or the whole organism.
- The ***'behaviour level'*** may include translating an aspect of how an organism behaves, or relates to a larger context.
- The ***'ecosystem level'*** refers to mimicking of whole ecosystems and the common principles that allow them to successfully function.

Within each of these levels, *five additional* possible dimensions to the mimicry exist. The design may be biomimetic for example in terms of [13]:

- *'Form'* (What it looks like)
- *'Material'* (What it is made out of)
- *'Construction'* (How it is made)
- *'Process'* (How it works)
- *'Function'* (What it is able to do).

The differences between each kind of biomimicry are described in table II-2 and are exemplified by looking at how different aspects of a termite, or a ecosystem a termite is part of could be mimicked [13]. It has to be noted that each kind of biomimicry is not mutually exclusive, and overlaps between different kinds of biomimicry are expected to exist.

Species of living organisms have typically been evolving for millions of years; they have adapted to constant changes over time, and hence these organisms may have already developed energy- and/or material-effectiveness. An example is the mimicry of the Namibian desert (*'Stenocara'*) beetle [112]. The beetle captures moisture from the swift moving fog in the desert by tilting its body into the wind. Droplets form on the alternating hydrophilic – hydrophobic rough surface of the beetle's back and wings and roll down into its mouth [113].

Matthew Parks from KSS Architects demonstrates **process biomimicry at the organism level** inspired by the beetle, with his proposed fog-catcher design for the *Hydrological Centre* for the *University of Namibia* (see figure II-7) [114].

A more specific **material biomimicry at the organism level** has also been discussed, where the surface of the beetle has been studied and mimicked to be used for other potential applications, such as to clear fog or to improve dehumidification [115,116].

Mimicking an organism alone however, without also mimicking how it is able to participate and contribute to the ecosystem, may produce designs that remain conventional or even below average in terms of environmental impact [111]. While this method may result in new and innovative building technologies or materials, methods to increase sustainability are not necessarily explored [13].

In **behaviour level biomimicry**, it is not the organism itself that is mimicked, but its behaviour, whereas it may be possible to mimic the relationships between organisms or species in a similar way [13]. A great number of organisms tend to operate within 'ecological capacity' of a specific place and within limits of energy and material availability. These limits and pressures

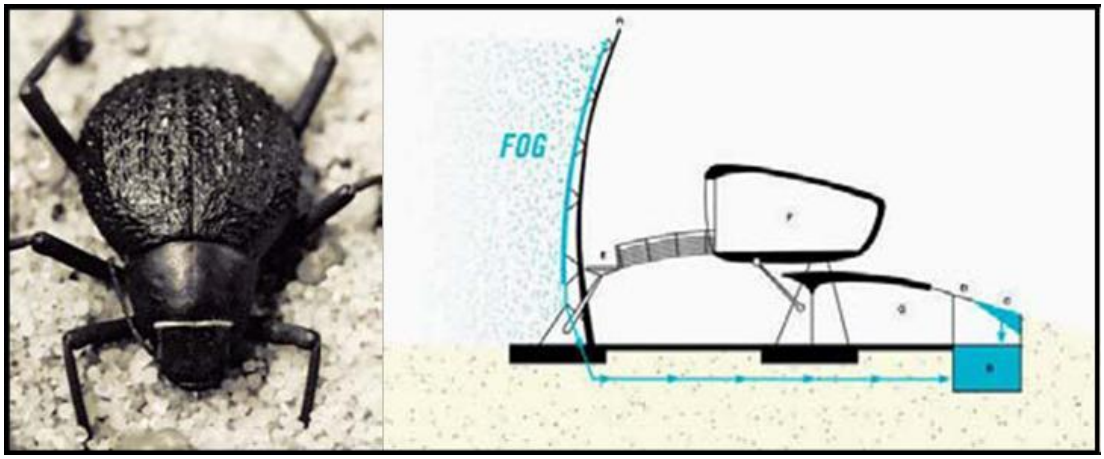

Figure II-7: Proposed hydrological centre for the University of Namibia (right image) and the '*Stenocara*' beetle (left image) (Please note the change in scale; adapted from [13]).

Table II-2: Levels and dimensions for the Application of Biomimicry (From [13]).

Level of Biomimicry		*Example - A building that mimics termites:*
Organism level (Mimicry of a specific organism)	*form*	The building looks like a termite.
	material	The building is made from the same material as a termite; a material that mimics termite exoskeleton / skin for example.
	construction	The building is made in the same way as a termite; it goes through various growth cycles for example.
	process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta-genomics for example.
	function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.
Behaviour level (Mimicry of how an organism behaves or relates to its larger context)	*form*	The building looks like it was made by a termite; a replica of a termite mound for example.
	material	The building is made from the same materials that a termite builds with; using digested fine soil as the primary material for example.
	construction	The building is made in the same way that a termite would build in; piling earth in certain places at certain times for example.
	process	The building works in the same way as a termite mound would; by careful orientation, shape, materials selection and natural ventilation for example, or it mimics how termites work together.
	function	The building functions in the same way that it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example (fig. 6). It may also function in the same way that a termite mound does in a larger context.
Ecosystem level (Mimicry of an ecosystem)	*form*	The building looks like an ecosystem (a termite would live in).
	material	The building is made from the same kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium for example.
	construction	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used for example.
	process	The building works in the same way as a (termite) ecosystem; it captures and converts energy from the sun, and stores water for example.
	function	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilising the relationships between processes; it is able to participate in the hydrological, carbon, nitrogen cycles etc in a similar way to an ecosystem for example.

create ecological niche adaptations, and lead to well-adapted organism behaviours and relationship patterns between organisms or species [111].

Ecosystem engineers, which are organisms that are able to directly or indirectly control the flow of resources and who may cause changes in biotic or abiotic (non living) materials or systems [117,118], alter habitats either through their own structure (e.g. corals) or by mechanical or other means (e.g. beavers and woodpeckers). Humans are undoubtedly effective ecosystem engineers, but may gain valuable insights by looking at how other species are able to change their environment while creating more capacity for life [13].

Architectural examples of **process and function biomimicry at the behaviour level** are demonstrated by the *Eastgate Building* in Harare, Zimbabwe, and the *CH2 Building* in Melbourne, Australia (see also figure II-8). Both buildings are partly based on passive ventilation techniques and temperature regulation as observed in termite mounds. The *CH2 Building* uses water, which is mined (and cleaned) from the sewers beneath, in a similar manner how certain termite species use the proximity of aquifer water as an evaporative cooling mechanism [13]. But not every organism exhibits a behaviour that is suitable to mimic, and it may be more appropriate to mimic a specific construction that may increase the sustainability and regenerative capacity of a human building, rather than mimic social or economic spheres without careful consideration [13].

The **mimicking of ecosystems** is an integral part of biomimicry as described by Benyus [93] and Vincent [84], and the importance of architectural design based on an understanding of ecology is also discussed by researchers advocating a shift to regenerative design [11]. An advantage of designing at this level of biomimicry is that it can be used in conjunction with other levels of biomimicry (organism and behaviour) [13]. A further advantage of an ecosystem based biomimetic approach is that it is applicable to a range of temporal and spatial scales, and can serve as an initial benchmark or goal for what constitutes truly sustainable [111].

Even though, the author is not aware of any architectural examples that demonstrate ecosystem based biomimicry at process or function level, there

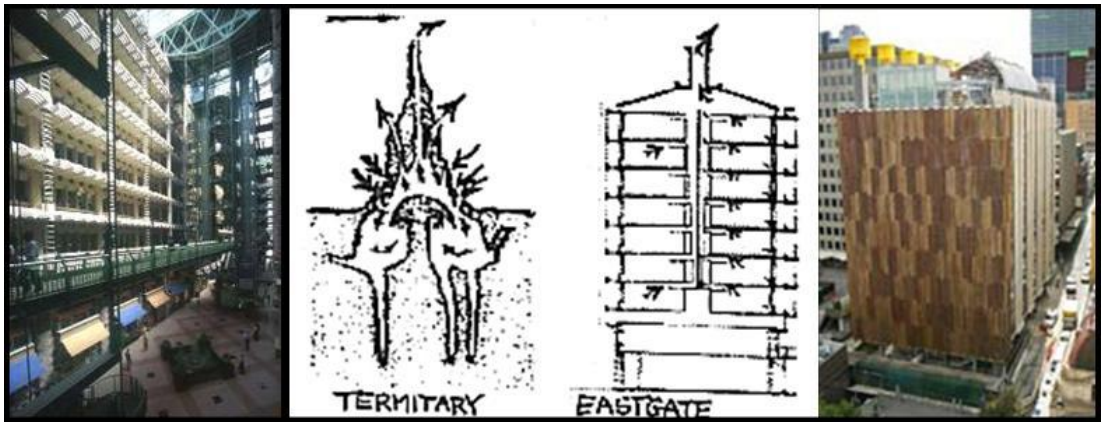

Figure II-8: *Eastgate Building* in Harare, Zimbabwe (most left and second right image), schematic of termite mound (second left image), and *CH2 Building* in Melbourne, Australia (most right image) (Please note the change in scale; adapted from [13]).

are proposed projects that display aspects of such an approach. An example is the *Lloyd Crossing Project* proposed for Portland, Oregon, which uses estimations of how the ecosystem that existed on the site before its development functioned to set goals for the project's ecological long-term performance (see figure II-9) [13].

Ecosystem based biomimicry can operate at both a **metaphoric level** and at a **practical functional level**. At a metaphoric level, general ecosystem principles (based on how most ecosystems work) are able to be applied [93,104], and if a built environment is expected to behave like an ecosystem - even if only at the level of metaphor - its environmental performance may increase [119]. At a functional level, ecosystem mimicry could mean that the design of a built environment is able to participate in a reinforcing rather than damaging way in the major biogeochemical material cycles of the planet (hydrological, carbon, nitrogen, etc.) [13].

But such an approach challenges conventional architectural design thinking, particularly the typical boundaries of a building site and time scales a design may operate in [13]. The difficulty in understanding and modelling ecosystems may be that the mimicking of nature in human designs is one dimensional and non-complex [120]. But this does not suggest that mimicking of ecosystems is impossible, particularly when one takes into account that biological knowledge may be doubling every 5 years [93].

Figure II-9: *Lloyd Crossing Project*, Portland, USA (adapted from [13]).

II.4.2 Buildings' aspects: Materials, envelope, and environmental considerations

In the previous chapter, theoretical and rather abstract concepts and ideas of applying biomimetics to sustainable architecture have been introduced.

In the following chapter buildings' aspects like materials, envelope, and environmental considerations, and how these aspects may be approached by biomimetics to increase the sustainability of the related building(s), are addressed; based on the work of Godfraud John and co-authors [16].

According to John and co-authors, sustainable building involves considering the whole life of buildings, taking environmental quality, functional quality, and future values into account [16]. Sustainable building design is therefore the thoughtful integration of architecture with electrical, mechanical and structural engineering resources. Following the '*Biomimetics Network for Industrial Sustainability*' there are four main targets for applying biomimetics to industrial sustainability [15], which may also be sufficient for building technology:

1. Energy and resource efficiency
2. Elimination and control of hazardous substances

3. Use of renewable and biological materials
4. Added functionality in materials and structures.

However, there are a number of challenges that have to be faced while interpreting and understanding biomimetics from the perspective of buildings: The design may have to satisfy complex code requirements; the linear nature of today's commonly used structural materials; or the way that construction industry develops things separately and then joins these together [17]. Design and functions present in plants and animals have evolved over millions of years, and these long lead times do not fit easily with the more frenetic pace of the engineering world today [17]. But to dismiss the solutions that nature has found would be foolish and arrogant [16]. The time scale may be different, but design constraints and objectives are similar: functionality, optimisation and economy of scale effectiveness.

In the following, the various aspects of sustainability will be addressed while concentrating primarily on those related to building materials properties, building envelope, and environmental considerations.

Building materials properties

Building materials have to serve their intended function not only when newly installed but also for some acceptable length of time, which may vary from only a few years as in the case of paints to the life of the building. The durability or the useful life of a material in place always has to be related to the particular conditions involved. Most building materials are complex in their chemical and physical nature [16]; and even though the chemical nature is seldom meaningful to the user, it determines the reactivity of a material to other materials and to some elements of the environment. It is especially significant that small changes in composition (even trace amounts of some substances as in the case of metal alloys) can have a profound influence on the resulting properties. The impact of ultraviolet radiation on organic materials can be appraised, if it is known that organic molecules have bonds that may be broken or changed due to solar radiation [121].

In structural design, the engineering properties of a material are given in terms of the bulk material, while assuming that the material is homogenous and isotropic on a scale that is significant in the proposed design. But this approach does not allow to understand the materials behaviour, since at this scale the relevant issues that determine the response of the material itself cannot be evaluated. Concerning a steel bridge for example, it may carry a certain load, but it may fail in time, if one element is overstressed. To understand the physical and mechanical behaviour of a material it is necessary to analyze the material on a micro-structure scale, such as morphological or crystalline structure and grain size, porosity, chemical bonding, etc.

Nearly all load bearing materials in nature are fibrous composites of some kind or another, offering a wide area of application and design flexibility. They provide greater opportunities for added functionality, because there is no obvious dividing line between material and structure [16]. Still, a major problem with fibres is that they are most efficient, if under tensile stress, either as central structures (ropes, cables, tendons, silk threads in spider's web), or as reinforcement in composite materials (membrane structures) in biaxial tension. Nature provides four solutions to this problem: (i) Pre-stress of the fibre in tension so that they hardly ever experience compressive loads, (ii) introduce mineral phases intimately connected to the fibres to help carry compression, (iii) heavily cross-link the fibre network to increase lateral stability, and (iv) change the fibre orientation so that compressive loads along fibres are avoided [122].

It is interesting to note that biological materials, if compared to engineering materials, are of small amount, and they don't have any especially outstanding characteristics, such as a particularly high Young's modulus, tensile strength, or toughness [16]. Hence, they may not be classified as '*high-performance materials*', even though they have much lower densities than most engineering materials. The key within the success of these materials lies within the way how they are combined to operate, and not within their intrinsic properties.

The exact prediction of a material's performance requires a complete understanding of the material's properties, the processes involved in the

interaction of the material with its environment, and the environmental factors to which it will be subjected. The experience with traditional materials over many years allows to predict the performance of an equal material under equal conditions. Still, if new materials are to be considered, or when traditional materials are to be used in an untested situation, the ability to predict may be greatly limited unless the fundamental factors involved are understood. Hence, the basic exercise of judgement in design should be a combination of experience and analysis [123].

Careful selection of environmental sustainable building materials is the easiest way for architects to begin incorporating sustainable design principles in buildings [16]. Natural materials are generally lower in embodied energy and toxicity than man-made materials. They require less processing, and are less damaging to the environment. If such low-embodied energy natural materials are incorporated into building products, the products become more sustainable [16].

Re-materialisation in the industrial world refers to chemical recycling that adds value to materials, allowing them to be used again and again in high-quality products. This process suggests a design strategy aimed at maximising the positive effects of materials and energy, and participating in the Earth's abundant materials flow cycle [16]. '*Nylon 6*' for example can be chemically recycled into the raw material '*Caprolactum*', which can be used to make generation after generation of high-quality carpet fibre. The process virtually eliminates waste and saves energy, and hence the significance of the re-materialisation of '*Nylon 6*' is enormous, suggesting a new model for material flow [124].

Building envelope

The building envelope comprises all building components that separate indoor from outdoor, which basically are the exterior walls, the roof, floors, windows, and doors. In addition to a desired appearance, the envelope has to act as a protection to the local climate (e.g. against solar radiation, temperature extremes, vaporous or liquid moisture, dust, wind) and to the exterior (e.g. against noise, fire, animals, and even human intrusion).

Moreover, it may be required to transmit light (window), while suitably contributing to the form and aesthetics of the building. Historically, designs for buildings' exterior walls have evolved slowly, keeping pace with gradual changes in social and economic patterns, and environmental requirements [17,125]. Nowadays, triggered by the advances concerning structural engineering, computer modelling, automated production, and new materials, a large number of new designs is possible. Unfortunately, some are being adopted without adequate consideration; and the evaluation by '*trial by use – methods*' of the past is no longer adequate [16]. Nevertheless, due to the advances in building science and technology during the last decades, it is now possible to systematically analyse the performance of wall designs, which provides a basis for the development of improved designs.

Determination of the requirements due to outdoor environmental considerations and indoor desires and needs is essentially the first step in exterior wall design. Inevitably, at this stage, some aspects of the building services become involved, to adjust the desired indoor situation. Day-lighting characteristics, artificial lighting, relative indoor humidity, heating and cooling requirements are related to the barrier characteristics of the wall, considering the local climatic conditions. Such manipulation however, requires an understanding of the pertinent properties of materials and the phenomena that operate within the walls [125].

New building regulations in various countries drastically reduce the required *U-values* of walls, floors, and so on [16]. While such building regulations often concentrate on insulation, they do not address the thermal mass of the construction. In general, heat capacity and thermal conductivity increase with density, and heavyweight building materials such as concrete blocks, brickwork, or stone can absorb large amounts of heat, whereas lightweight materials, such as timber, insulation, or plasterboard are not able to absorb that much heat. But to be effective, the mass needs to be well connected or 'coupled' with the space, because the effectiveness depends on mass and coupled area [126,127]. In addition, also the temporal response

is of high interest since thermal mass acts and reacts rather slowly, influencing heating and cooling needs and cycles.

Environmental considerations

There is an increasing recognition that buildings cannot be designed without considering their social impact on the environment.

Since buildings are responsible for half of the nation's energy demand and hence carbon dioxide emissions, the design, construction and operation of buildings is vitally important for people, now and in the future [16]. The environmental effects of other pollutants such as smoke, fumes, chemicals, and noise is also an issue. This of course applies to the entire building stock of old and new buildings [17], and the internal environment plays a crucial role too, since people living and working in buildings should experience a good sense of well-being and optimal productivity [128].

Buildings filter the passage of light, air, sound and energy between the inside and outside environments [16]. The link between them is provided by windows, which have to fulfil the need for natural light, contact with the outside world, and the sense of time. The environment inside buildings is linked to the outside by entrances (or exits), windows and chimneys. Issues of sustainability will force us to consider buildings in relationship to towns and cities, and the evaluation of building performance will involve the quality of indoor environments.

The architect Ken Yeang is one of the pioneers in the field of biomimetic sustainable architecture, whereas his designs follow the theme of an '*urban ecosystem*' (see also chapter II.4.1: '*ecosystem level biomimicry*'), a holistic design solution that deals actively with pedestrian flows, plant growth and the equilibrium of energy, water and waste [16]. Yeang believes that all architecture ought to respond ecologically to the natural environment as a whole [16]. There are certain issues that continually recur in Yeang's work, and these may be reduced to two points: wind and solar orientation. The wind is known as the '*compass project*' and the solar as the '*sunpath projects*' [129]. Designs for the '*compass projects*' are fragmented, and display numerous openings to make thorough natural ventilation possible,

while ensuring that the ventilation is as effective as possible. Furthermore, a variety of innovative ideas such as wind-wing walls, aerodynamic surfaces and roof-level *'sky courts'* to suck in the air are used. Yeang's *'sunpath buildings'*, like the compass designs use natural ventilation wherever possible. The overall design is, however, dictated by the sun, whereas the whole structure is related to the diurnal and annual course of the sun. Buildings gain a micro-climate changing in accordance with the time and the outdoor conditions [130].

People in different countries have adapted to different levels of temperature, in climates where the diurnal range may be in the order of 17 °C. There are many ways in which man has adapted to climate, whether it is the use of covered tents commonly found in hot countries, arranging streets in a way that buildings are close together, or the use of cloisters or verandas around the courtyard of buildings to offer shade. What appears evident is the attempt to balance basic needs in an as simple as possible way, but also in a design that is pleasing to the eye [14].

The paper of Godfraud John and co-authors [16] additionally covers the two building's aspects *'Sensors, monitoring and feedback systems'* and *'Team integration and functionality'*. These aspects will not be treated in detail in this work but for the sake of completeness, in the following will shortly be summarized.

With a very high signal to noise ratio and a negligible error coefficient, digital systems have massively replaced old analogue devices. Still, those systems do not have the information capacity of natural **biologic sensors** which are entirely analogue. Biological sensors, operating at the complex nature-animal interface, process gigantic volumes of information in real time, and have also the remarkable capability to operate as multifunctional devices. Presently the sensors within buildings are simple and not all multi-functional. In Formula 1 motor racing, each car carries about 1.5 km of wiring that pulls data from approximately 120 sensors that are located around the

body of the car, providing essential information about performance, orientation or load [131]. The building industry is yet to achieve this level of monitoring and feedback, and such technology can be utilised by the industry for effective sustainable solutions.

A building is a complex product, with the applied technology involving almost every facet of pure and applied science, and its design and construction requiring the involvement of various disciplines and trades. Hence, for a successful application, it has to be understood by owners, architects, engineers, contractors, material suppliers and operators. It is clear, therefore, that participants in the building industry require assistance in matching available technology with the specific problems encountered in their day-to-day activities. And all too often, the problem is not with the aims but with the methods we use to achieve them, while in the same way as in nature, the boundary between materials and structure is blurred. The study of biological systems to understand those aspects of design, which might be useful for our purposes, requires a **team integration** of all the disciplines above. The main reason for this is that biological structures are often multifunctional, and if we do not understand the various **functions**, how they are controlled and integrated, it will be difficult to extract any lessons [17].

PART III:

INVESTIGATION AND DISCUSSION

"It is easy to be misled or seduced by technology and to think that if we assemble enough eco-gadgetry… in one single building that this can automatically be considered ecological architecture."

Ken Yeang

III.1 INVESTIGATION

Part III of this work is divided into two main chapters: 1. Investigation and 2. Discussion. Chapter III.1 will explain the work methodology, and contains a catalogue that comprises identified Austrian buildings that appear to best fulfil the combinatory approach of sustainable and biomimetic architecture.

Here, it has to be anticipated that the number of adequate Austrian examples is very low. Following the strict definition of *'The Association of German Engineers'* (*'Verein Deutscher Ingenieure'*, VDI [87]) and Werner Nachtigal: "... *bionics deals systematically with the technical execution and implementation of constructions, processes and developmental principles of biological systems. This also includes various forms of interaction between living and non-living elements and systems.*" [83], almost no Austrian building would fulfil the requirements to be called *'biomimetic'*. In contrast, following the less stringent definition of the *'Centre for Biomimetics'* in Reading defining biomimetics as "*the abstraction of good design from nature*" [90], a wider scope can be gathered. Hence, within this work a commitment to strict definitions as been made by the *VDI* and Werner Nachtigal does not appear to be meaningful. The most appropriate examples of Austrian buildings that appear to fulfil the criteria of sustainable architecture and follow a *biomimetic concept in a broader sense* will be identified and indexed.

In chapter III.2, showcase buildings that allowed obtaining sufficient information will be discussed in detail regarding both, their sustainability as well as their biomimetic approach.

III.1.1 Methodology

Basically, the methodology of this work is based on a comprehensive investigation on Austrian architecture to identify sustainable buildings all over the country. The result of this study is summarized in a catalogue in chapter III.1.2. The most important aspects of sustainable architecture have already

been described in chapter II.1. As the OECD project '*Sustainable buildings*' [14] identified five objectives for sustainable buildings,

1. Resource efficiency
2. Energy efficiency (including reduction of greenhouse gas emissions)
3. Pollution prevention (including abatement of indoor air quality and noise)
4. Harmonisation with environment
5. Integrated and systemic approaches.

at least one – but ideally of course all - of these criteria should be fulfilled in order to index a building '*sustainable*'. In a first step, the evaluation of the respective building is dependent on the information provided by the related client or responsible architect. In a second step, well suited and documented showcase buildings, which provided sufficient necessary information (annual energy demand, applied building materials, building evaluation, etc.), are investigated in detail to – at least qualitatively and, if possible quantitatively – evaluate their sustainability. This is done by means of evaluation by the most important Austrian ecological coefficients or building certificates as introduced in chapter II.2.3, or by project-related information from literature and web pages.

Additionally, these showcase buildings are discussed regarding their utilization of biomimetics to achieve or improve their sustainability. The type of this approach will be assigned by following the '*Biomimetics Network for Industrial Sustainability*', who defined four targets for applying biomimetics to industrial sustainability, which may to a certain extent also be sufficient for building technology [15]:

1. Energy and resource efficiency
2. Elimination and control of hazardous substances
3. Use of renewable and biological materials
4. Added functionality in materials and structures.

Thereby, the focus will be set on three items of buildings' aspects (see chapter II.4.2), and the building should at least address one these related to:

- Building material properties
- Building envelope
- Environmental considerations,

III.1.2 Catalogue of sustainable Austrian architecture

On the following pages, 32 appropriate Austrian building examples are summarized. The buildings are indexed by a number, and besides the building name information is given on: Building location, start/end year of building/project phase, building type, architect/planner, client, and property management. These 32 buildings have been identified by a comprehensive internet research focused on databases like the '*Haus der Zukunkt*'-platform [65] or on web pages of recognized architects in the field, a continuous print media research, the visit of a symposium, as well as on various discussions.

The second catalogue comprises eight showcase buildings that are discussed in more detail in chapter III.2. These showcases have been selected due to their thematic and conceptual suitability, as well as due to the availability and accessibility to the required information. Fortunately, these eight buildings give an excellent overview of the current developments in Austria. Moreover, since these buildings mostly have a strong innovative and scientific character, the relevant information has been made publicly available. Still, it is important to note that these eight buildings must not be attributed to represent the best suited Austrian examples currently existing.

It is important to note that this thesis does not embody a representative overview on past and present sustainable building in Austria. The focus during investigation was to identify buildings that could be attributed to apply a biomimetic approach as given by the definitions of the *VDI* and W. Nachtigall [88] or the *Centre of Biometics* [90], *and* by this, increase or support the sustainability of this building. Still, possible well-suited Austrian examples may not have been covered within this work, due to a lack of public or openly available information.

Table III-1: Sustainable Austrian architecture

#	Name	Location	Year	Building Type	Architect/Planner	Client	Property Management
[1]	S-House	Böheimkirchen, Lower Austria	2004 -2005	Office/ open to public	Mag. Georg Scheicher, Architekten Scheicher ZT GmbH	Gruppe Angepasste Technologie, TU Wien (Dr. Wimmer)	Gruppe Angepasste Technologie, TU Wien (Dr. Wimmer)
[2]	Ökopark Hartberg	Hartberg, Styria	1997 -today	Business/ Public	Peter Zinganel, Graz	Ökoplan Umweltdienst-leistungen GmbH	Oekopark Errichtungs GmbH
[3]	Büro/Werksgebäude, Company '*Natur und Lehm*'	Tattendorf, Lower Austria	2002 -2006	Office building/ open to public	Georg W. Reinberg	Company *Natur und Lehm*	Company *Natur und Lehm*
[4]	Wohnhaus	Vienna, Vienna	2003 -2006	Residential	Georg W. Reinberg	GEWOG	GEWOG
[5]	Büro und Werkstätten '*Biotop*'	Weidling, Lower Austria	2004 -2006	Office building/ Workshop	Georg W. Reinberg	Company Biotop	Company Biotop
[6]	Salzburg Arena	Salzburg, Salzburg	2002 -2003	Public	Engel und Zimmermann Architekten	Messezentrum Salzburg GmbH	Messezentrum Salzburg GmbH
[7]	*Kunsthaus Graz*	Graz, Styria	2001 -2004	Public	Peter Cook & Colin Fournier	Landesmuseum Joanneum	Landesmuseum Joanneum, Graz
[8]	Rogner-Bad Blumau	Bad Blumau, Styria	1993 -1997	Business	F. Hunderwasser	Rogner-Bad Blumau, Hotel & Spa	Rogner-Bad Blumau, Hotel & Spa
[9]	Hundertwasser-Haus Wien	Vienna, Vienna	1977 -1986	Public/ Residential/ Business	F. Hunderwasser; J. Krawina; P. Pelikan	City of Vienna	Hundertwasser-Krawina Haus; City of Vienna
[10]	Autobahnrasthaus Bad Fischau	Bad Fischau, Lower Austria	1989 -1990	Business	F. Hunderwasser	WIGAST	Tourast (Autogrill) Bad Fischau
[11]	Wohnpark Sandgrubenweg	Bregenz, Vorarlberg	2006 -2010	Residential	Wolfgang Ritsch; Gerhard Hörburger;	Rhomberg Bau GmbH	Rhomberg Bau GmbH

	Bregenz				Helmut Kuess; Norbert Schweitzer		
[12]	Volksschule Hermagor	Hermagor, Carinthia	2003 -2004	Public (school)	Architekten Ronacher	Stadtgemeinde Hermagor-Pressegger See	Stadtgemeinde Hermagor-Pressegger See
[13]	Arche des Waldes	Mariazell, Styria	-2004 -2005	Business/ open to public	Architekten Ronacher	Schwebebahnen Mariazell GmbH	Schwebebahnen Mariazell GmbH
[14]	Wohn/Bürohaus Architekten Ronacher	Khünburg, Carinithia	-1992 -2005	Residental /Business	Architekten Ronacher	Architekten Ronacher	Architekten Ronacher
[15]	"Die Grube"	Breitebrunn, Burgenland	1971 -today	Public/ Art	Peter Noever	-	-
[16]	Erdefunkstelle Aflenz	Aflenz Kurort, Styria	1976 -1980	Business	Gustav Peichl	Post- und Telegraphen-direktion Steiermark	Post- und Telegraphen-direktion Steiermark
[17]	Wohnpark Grüne Schanze Wien 21	Vienna, Vienna	2004 -2009	Residental	Cuubuus architects	Familienhilfe Bau- und Siedlungs-gesellschaft mbH, 1150 Wien	Familienhilfe Bau- und Siedlungs-gesellschaften
[18]	Siedlung "Naturnahes Wohnen", Wien 22	Vienna, Vienna	1994 -1996	Residental	Treberspurg & Partner Architekten	Stadt Wien, MA 24	Stadt Wien, MA 24
[19]	SolarCity Linz Pichling	Pichling, Linz, Upper Austria	1992 -2009	Residental/Public	Treberspurg & Partner ZT; Helmut Schimek; Michael Loudon; Auer+Weber+Partner; Atelier Dreiseitl	EBS WohnungsGmbH Linz	EBS WohnungsGmbH Linz
[20]	Alpiner Stützpunkt Schiestlhaus	Hochschwab, Styria	-2004 -2005	Public	ARGE pos architekten; Treberspurg & Partner ZT	Österreichischer Touristenclub	Österreichischer Touristenclub
[21]	Wohnprojekt, Stadlau,	Vienna, Vienna	1988 -1991	Residental	Arge Architekten Reinberg - Treberspurg	Hausbau-Howe Generalunternehme	Hausbau-Howe Generalunternehmen

	Kamillenweg				- Raith	n	
[22]	Wohnhaus Schützenstraße	Innsbruck, Tyrol	2006 -2006	Residental	Helmut Reitter	WE Wohnungseigentum GmbH, Innsbruck	WE Wohnungseigen-tum GmbH, Innsbruck
[23]	Passivwohnhaus L. - E.	Feldkirch, Vorarlberg	- -2003	Residental	Walter Unterrainer	Family Ess Längle	Family Ess Längle
[24]	Doppelpassiv-wohnhaus H. - R.	Bregenz, Vorarlberg	1995-1996		Walter Unterrainer	Family H., Family R.	Family H., Family R.
[25]	Gemeinde-zentrum Ludesch	Ludesch, Vorarlberg	2004 -2005	Public	Architekten Hermann Kaufmann	Gemeinde Ludesch Immobilienverwaltungs GmbH & Co KEG	Gemeinde Ludesch Immobilien-verwaltungs GmbH
[26]	Solarschule Dafins	Zwischenwasser/Dafins, Vorarlberg	1989 -1990	Public (school)	Architekten Hermann Kaufmann; Walter Unterrainer; S. Larsen	Gemeinde Zwischenwasser	Gemeinde Zwischenwasser
[27]	Olpererhütte Zillertaler Alpen	Zillertaler Alpen Tyrol,	2006 -2007	Business/ Public	Architekten Hermann Kaufmann	DAV Deutscher Alpenverein	DAV Deutscher Alpenverein
[28]	*OMV H2-Ausstellungshaus*	Schwechat, Lower Austria	1997 -today	Business/ Public	Greg Lynn - m form; Dr. Martin Treberspurg	OMV AG	Not built yet!
[29]	*SOL4* Büro- und Seminarzentrum Eichkogel	Mödling, Lower Austria	2003 -2005	Business	SOLAR 4 YOU Consulting GesmbH	SOL4 Büro- und Seminarzentrum; Ing. Klaus KIESSLER	Medilikke Immobilien und Bauträger GesmbH
[30]	Biohof Achleitner	Eferding, Upper Austria	2003-2005	Business	Büro Bmst. Ing. Eduard B. Preisack MAS	Günter Achleitner, Biohof Achleitner GmbH	Günter Achleitner, Biohof Achleitner GmbH
[31]	ChristophorusHaus	Stadl-Paura, Upper Austria	2002-2003	Business	Arch. Dipl. Ing. Albert Paul Böhm, Arch. Mg. Helmut Frohnwieser	BBM - Beschaffungsbetrieb der MIVA	BBM - Beschaffungsbetrieb der MIVA
[32]	ENERGYbase	Vienna, Vienna	2006-2008	Business / Public	pos Architekten; KWI Engineers; AIT – Austrian Institute of Technology	Wiener Wirtschafts-förderungsfonds	Wiener Wirtschafts-förderungsfonds

Table III-2: Showcase buildings

#	Name	Location	Year	Building Type	Architect/Planner	Client	Property Management
[1]	S-House	Böheimkirchen, Lower Austria	2004 -2005	Office/ open to public	Mag. Georg Scheicher, Architekten Scheicher ZT GmbH	Gruppe Angepasste Technologie, TU Wien (Dr. Wimmer)	Gruppe Angepasste Technologie, TU Wien (Dr. Wimmer)
[2]	Ökopark Hartberg	Hartberg, Styria	1997- today	Business/ Public	Peter Zinganel, Graz	Ökoplan Umweltdienst-leistungen GmbH	Oekopark Errichtungs GmbH
[3]	Büro-, und Werks-gebäude, Company '*Natur und Lehm*'	Tattendorf, Lower Austria	2002 -2006	Office building/ Workshop; open to public	Georg W. Reinberg	Company *Natur und Lehm*	Company *Natur und Lehm*
[7]	*Kunsthaus Graz*	Graz, Styria	2001 -2004	Public	Peter Cook & Colin Fournier	Landesmuseum Joanneum	Landesmuseum Joanneum, Graz
[8]	Rogner-Bad Blumau	Bad Blumau, Styria	1993 -1997	Business	F. Hunderwasser	Rogner-Bad Blumau, Hotel & Spa	Rogner-Bad Blumau, Hotel & Spa
[25]	Gemeinde-zentrum Ludesch	Ludesch, Vorarlberg	2004 -2005	Public	Architekten Hermann Kaufmann	Gemeinde Ludesch Immobilienverwaltungs GmbH & Co KEG	Gemeinde Ludesch Immobilien-verwaltungs GmbH
[29]	*SOL4* Büro- und Seminarzentrum Eichkogel	Mödling, Lower Austria	2003 -2005	Business	SOLAR 4 YOU Consulting GesmbH	SOL4 Büro- und Seminarzentrum; Ing. Klaus KIESSLER Ges.m.b.H.	Medilikke Immobilien und Bauträger GesmbH
[30]	Biohof Achleitner	Eferding, Upper Austria	2003-2005	Business	Büro Bmst. Ing. Eduard B. Preisack MAS	Günter Achleitner, Biohof Achleitner H	Günter Achleitner, Biohof Achleitner H

III.2 DISCUSSION OF SHOWCASE BUILDINGS

In the following, the eight showcase buildings as identified and indexed in the previous chapter are discussed. This will be made in three parts: First of all, the building will be introduced, second the degree of the sustainability of the building will be analyzed (see chapter III.1.1), and third, the utilization of biomimetics to achieve/improve this sustainability will be evaluated (see chapter III.1.1). By a concluding synopsis the eight buildings will be summarized and benchmarked (as far as this is possible).

III.2.1 [1] *S-House*

At the becoming of this work, the *S-House*, a project within the '*Haus der Zukunft*' initiative, is maybe the most appropriate example in sustainable Austrian architecture that uses and applies renewable building materials as well as biomimetic methods. It combines the energy standard of the passive house technology (less than 15 kWh/m²a) with the use of renewable resources.

Figure III-1: S-House in Böheimkirchen, Austria (From: http:\\www.s-house.at).

The *S-House* is intended to function as a centre for renewable resources and sustainable technologies, and a permanent exhibition shows the developed components and constructions for the *S-House*, as well as the variety of applications of biogenous building materials [132].

Regarding the **sustainability** of the building, the *S-House* aims to thoroughly address all four objectives for sustainable buildings as identified within the OECD project '*Sustainable buildings*' [14], and demonstrates sustainable building with a physical example open to the public. It serves the following points [132]:

- Sustainable planning (e.g. by use of innocuous and non-toxic building materials)
- Economic efficiency of sustainable construction: during planning already the whole life cycle of the building (construction, use, removal deconstruction) is taken into account and the negative impact on the environment is minimized
- Minimized consumption of energy (specific heating demand: 6.1 kWh/m²a) and resources
- Use of regional building materials made of renewable resources
- CO_2 neutrality
- Environmentally sound solutions for a healthy room climate
- Testing of long-term functionality
- Easy separation of building materials during deconstruction and plans for recycling and reuse (end of life concept)
- Dissemination of sustainable building technologies based on renewable resources by an exhibition hosted in the demonstration building and by other means.

The construction of the straw-wall causes an ecological footprint of only 2364 (m²a/m² wall) as a compared to a conventional wall construction that consumes 24915 (m²a/m² wall) [132]. Moreover, wall-constructions with other insulating materials (e.g. hemp, flax, wool, cellulose) were integrated; different ecological surface materials and various natural surface treatment

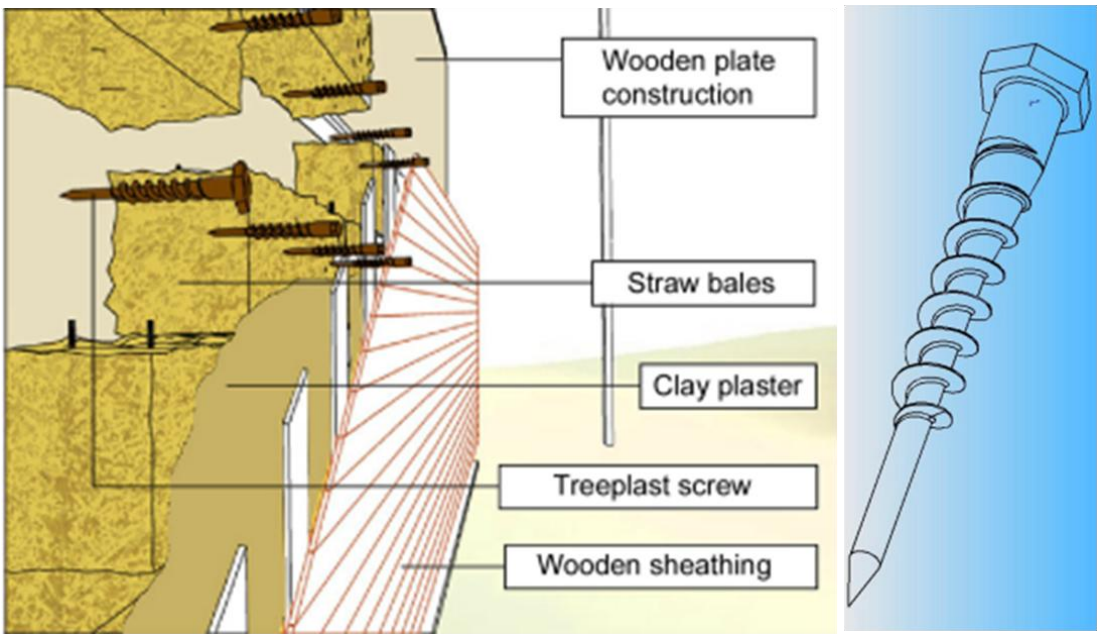

Figure III-2: Model of the wall of the S-House showing the various layers (left image) including the *Treeplast screws* (larger scaled model in right image) for mounting various items to straw bale constructions (From [133]).

agents (lacquers, waxes, scumbles) were applied [132]. The wall construction of the *S-House* consists of the layers shown in the figure III-2: An inner wooden plate construction, the straw bales, clay plaster, and a wooden sheathing. This sheathing is mounted to the straw bales by *Treeplast screws*, which have been especially developed for the *S-House* (see figure III-2) [133].

Referring the sustainability of the *S-House* to the six competing logics of Guy and Farmer [27], the holistic concept of a consequent use of natural and renewable resources combined with its health- and dissemination aspects, its concept is based on a '*light-version*' of the *eco-centric* logic, but also on the *eco-cultural* and *eco-medical* logics (see chapter II.2.2).

The development of these screws represents the true **utilization of biomimetics** to improve the sustainability of the building: The shape of the 365 mm long screw was optimized after biomimetic criteria to achieve optimum strength while minimizing the use of material. After a method developed by Claus Matthek, the shape of the screw has been optimized by referring to the growth of trees, thus reducing occurring tensile and bending stresses. With consequent natural building not only the shape of a device is

important but also the material of use. Therefore an eco-design process was used to develop an environmentally sound solution, using the lignin-based biopolymer *Arboform*. It is made of renewable resources, biodegradable, and water proof. This leads to a thermal bridge free wall construction free of any metal joining elements.

The *Treeplast screws* are optimized regarding *resource efficiency*, they make use of renewable and biological materials, and they add functionality to a construction. Hence, they successfully meet the targets as defined by the '*Biomimetics Network for Industrial Sustainability*' [15] (see chapter III.1.1).

Moreover, besides the development of the biomimetic screws, the consequent use of natural and renewable resources throughout the whole building can be attributed to a consistent biomimetic approach regarding the buildings' aspects *Building material properties* and *Environmental considerations*.

III.2.2 [2] *Ökopark Hartberg*

Even though the *Ökopark Hartberg* is not a single building but more a thematic and practical concept that offers an infrastructural and some kind of ideological environment for companies, research institutions, and visitors, it is worth to be discussed in this section (Figure III-3 shows the map). The *Ökopark Hartberg* - officially opened in 1998 - is an '*eco-park*' that combines the areas *business*, *science*, and *adventure* [134]:

1. **Business Park**: The economic fundament of the overall project offers a business environment for companies that deal with the production of trade of environmental or ecological goods, products, or services. The settlement is limited to small and medium busines with the goal to strengthen the local value chain. Since the opening already 30 such companies created more than 200 jobs. Every office/commercial building is heated and cooled CO_2-neutrally.

2. **Science Park**: It delivers a network for commercial research and development (R&D) projects, whereas the R&D institutions locally work together with their commercial partners. Business, science, and promotion are brought together with the goal to support every company with *'its own R&D department'* on demand.

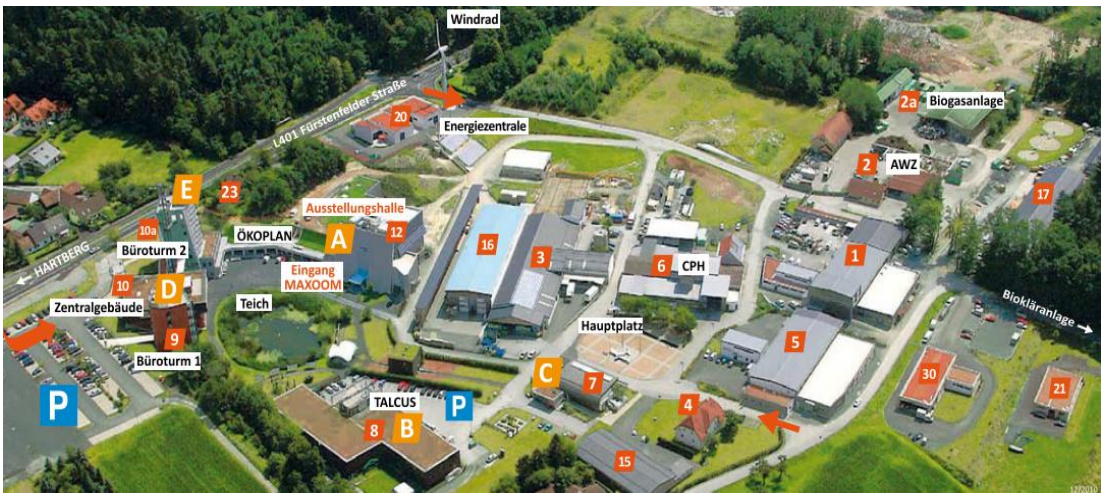

Figure III-3: Map of the *Ökopark Hartberg*, Austria, showing among other things: [2] Biogas plant, [6] CPH cellulose sound-insulation material production, [9+10] Office towers, [12] Exhibition hall and cinema, and main place (between [6] and [7]), [20] power station with wind generator (From [135]).

3. **Adventure Park**: A spacious and decentralized '*Science Center*' that disseminates ecological topics and natural sciences. This is achieved by an large-scale cinema, permanent and temporary exhibitions, events, and '*glassy companies*'. Around 20.000 visitors per year are counted.

Beside of these three pillars, the '*eco-park*' offers an educational program including thematic workshops, the '*DAVINCI-school*', and the society '*Bionik Austria*' that has its office at the site [135].

The **sustainability** of the *Ökopark Hartberg* is based on all three aspects: '*economy*', '*ecology*', and '*society*'.

It practices a circular flow economy including an autarkic and decentralised energy supply concept. Electricity, heating and cooling of the whole site is generated CO_2-neutrally by heating and refrigeration plants, as well as by power plants based on biogas, photovoltaics, biomass, and wind; 2500 MWh heating energy, 2100 MWh electricity, and 110 MWh cooling energy are generated per year. Additionally, waste management, sewage management, and the utilization of rainwater are part of this ecological closed loop.

Moreover, the *Ökopark Hartberg* makes an important contribution towards a sustainable society: Its public concept demonstrates environmental technologies and production processes, and gives an insight into related research and development. In combination with thematic exhibitions it aims to sensitize in particular young people in terms of an environmental and sustainable consciousness.

The *Ökopark* Hartberg is a conglomerate of various buildings that together as a whole form the idea of an ecological and sustainable village. The conceptual idea/logic behind has definitely *eco-cultural*, but also *eco-technical* aspects [27] (see chapter II.2.2).

Unfortunately, due to a lack of accessible information it was not possible to investigate the issues of single buildings within the site. In sustainability-terms this is not really a problem, since the park also functions as a whole. But

in terms of the **utilization of biomimetics** regarding a defined aspect of a single building this is problematic. Regarding this fact, a specific biomimetic approach regarding *building materials*, *building envelope* or *environmental considerations* of buildings within the site could not be identified.

Nevertheless, biomimetics is one thematic focus of the park: The society '*Bionik Austria*' has its office at the site [135], an exhibition called '*Bionik – Weisheit der Natur*' ('*Bionics – Wisdom of nature*') has been organized, and currently the first Austrian '*bionic park*' is realized.

Moreover, companies like the *CPH GmbH & Co KG* located at the eco-park are developing acoustic noise absorber products based on natural and renewable cellulose materials.

III.2.3 [3] Office building and workshop, company *'Natur und Lehm'*

Supported by the *'Haus der Zukunft'*-initiative, the office building and workshop of the company *'Natur und Lehm'* (see figure III-4) was intended to combine energy-efficient passive house technology (less than 15 kWh/m²a) with sustainable clay-building. The building, which is not only an office building but also a seminar house, showroom, and research facility, acts as a prototype for the industrial production of clay-passive house building-modules. With the knowledge that has been gained during this project, the newly developed wood/straw/clay passive house technology was intended to be further optimized to get a cost-effective building technology outside urban agglomeration regions [136].

Pre-fabricated and up to 3 x 9 m² wide building segments (composed of two thermally insulated wood beam structures that respectively have a wood boarding and are plastered with clay and filled with a straw insulation; figure III-5) have been developed. The southward oriented building uses solar energy by thermal collectors as well as passive heating, which enable to use only a small bio-ethane oven for additional heating. Moreover, innovative concepts like a grass-roof that works as an arid habitat, a humid habitat, and nesting sites for bats have been realized.

Figure III-4: Office building and workshop company *'Natur und Lehm'*, Tattendorf, Austria (© Peter Kytlica; from: http:\\ www.reinberg.net).

The building was awarded the *'Austrian Building Price 2006'* (Special price for sustainability in office building).

The building comprehensively addresses the three aspects of **sustainability**, *'economy'*, *'ecology'*, and *'society.' In terms of ecology* and as a building, it entirely addresses the four objectives for sustainable buildings of the OECD [14]. Through the project aim to make this building technology cost-effective, it fulfils an economical aspect, and as a physically accessible demonstration object, it makes an important social contribution.

The availability of the nearby railway tracks made the CO_2-friendly transport of all building components possible, strongly affecting the ecological balance and the sustainability of the construction site. Within the whole building no synthetic volatile organic compounds have been used.

The sustainability of the used building materials as well as of the whole building (including construction and user issues) have been quantified by the *IBO Vienna* and *ÖGNB*, respectively. The ecological evaluation on the basis of the *OI3-index* by the *IBO Vienna* led to a rating of the $OI3_{TGH}$-value of 0 points (out of 100 points, see also chapter II.2.3). The summary of this evaluation is given in figure III-6. At the evaluation tool *'TQB'* (as merchandised by the *ÖGNB*, see also chapter II.2.3) it achieved an excellent or maximum rating of +5 or almost +5 in every category. The summary of this evaluation is given in figure III-7, and more details are given in the certification [137].

Figure III-5: Model of wood/straw/clay building segment, with the cross section from inside to the outside composed of: 1.5 cm of clay-plaster, 0.1 cm clay-fleece, 3 cm horizontal wood boarding, 40 cm straw insulation, 2 cm horizontal wood boarding, 0.1 cm clay-fleece, 7 cm bio-fibre clay, and again 1 cm bio-fibre clay (From [136]).

Referring the sustainability of this building to the six competing logics of Guy and Farmer [27] (see chapter II.2.2), its *eco-centric, eco-cultural* and *eco-medical* concept is similar to that of the *S-House, based on* a consequent use of natural and renewable resources, and health- and dissemination aspects.

Projektbezeichnung:	Lehm-Passiv Bürohaus Tattendorf
Eigentümer:	
Verwalter:	
Baujahr:	
Gemeinde:	Tattendorf
Nutzfläche des Gebäudes:	m²
Beheizbare Bruttogeschossfläche:	416 m²
Anzahl der Geschosse:	2
Bauweise:	Leichtbau
Außenwände:	Holzriegelkonstruktion mit 40cm Strohdämmung
Decken:	Dübelbaumdecke mit Lehmsteinen
Dach:	Gründach mit innen 66cm Strohdämmung
Fenster:	Holz
Heizwärmebedarf:	4992 kWh/a
Spez. Heizwärmebedarf:	12 kWh/(m²a)
PEI_{ges} // PEI_{TGH}/KOF	516241,9 MJ // 299,7 MJ/m²
GWP_{ges} // GWP_{TGH}/KOF	-173365,5 kg CO_2 eq. // -172,8 kg CO_2 eq./m²
AP_{ges} // AP_{TGH}/KOF	248,9 kg SO_2 eq. // 0,1516 kg SO_2 eq./m²
$OI3_{TGH}$ // $OI3_{TGH-lc}$	**0,00 //**

Figure III-6: Ecological building evaluation office building and workshop company *'Natur und Lehm', IBO Vienna* (From [136]).

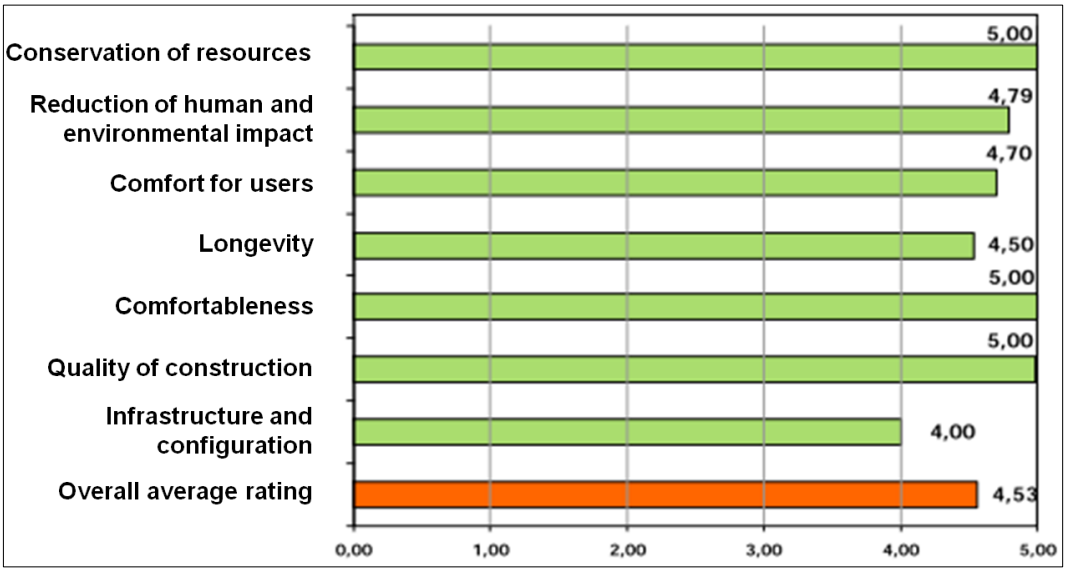

Figure III-7: *'TQB'* building evaluation Office building and workshop company *'Natur und Lehm', ARGE TQB, ÖGNB* (Adapted from [137]).

In terms of the **utilization of biomimetics**, this project does not go as far as the *S-House* (see III.2.1) by implementing completely new biomimetic developments like the *Treeplast screws* into the construction. A specific and true biomimetic approach in terms of a (technical) development regarding the buildings' aspects *building material properties, building envelope* or *environmental considerations* could not be identified. Nevertheless, the consequent use of natural and renewable resources throughout the whole building may be attributed to a consistent biomimetic approach regarding the aspects *building material properties* and *environmental considerations*.

III.2.4 [7] Kunsthaus Graz

The *Kunsthaus Graz* (see figure III-8) is an art museum specialized on contemporary art of the last four decades, and was built as part of the *European Capital of Culture* celebrations in 2003. The responsible architects *spacelab* (Peter Cook and Colin Fournier) called their design '*Friendly Alien*', since regarding form and material *"it consciously stands out from the surrounding baroque roof landscape, but nevertheless integrates the façade of the 1847 iron house"* [138]. In contrast to the modernist cubic approach, which is regularly used for the museums or exhibition facilities, the architects used the so-called *blob architecture*. The 60 m wide biomorphic construction has an acrylic glass outer '*skin*' *with* '*nozzles*' that provide natural lightning.

The main eastern façade, the so-called '*BIX Façade*' is based on a concept of the Berlin-based architects *realities:united*. BIX is a matrix of 930 fluorescent lamps integrated into the acrylic glass *skin*. Through the possibility to individually adjust the lamp's brightness at an infinite variability of 20 frames per second, images, films and animations can be displayed (see figure III-9).

Figure III-8: *Kunsthaus Graz*, Austria (From: http://www.wikipedia.com; © Creative Commons: Attribution-Share Alike 2.5 Generic license).

Even though the *Kunsthaus Graz* has most likely not been built to demand a great deal of its **sustainability**, the building has been selected for a good reason. The sustainability - or more generally the environmentally friendliness – of a building is often referred to its formal appearance, and biomorphic buildings are often - unintentionally or not – perceived as environmentally friendly. Architects often use these issues, also in combination with biomimetic designs, to '*sell*' their building as *eco-* or *green architecture*. The ideas behind can be often referred to be *eco-aesthetic* and *eco-technical* (see chapter II.2.2), still the sustainability of the approach has to be questioned

In the case of the *Kunsthaus Graz* this was surely not the intention behind this design; still it illustrates the most appropriate example in Austrian architecture to discuss this issue. Unfortunately, it was not possible to get information on any performed evaluation of the building regarding its sustainability or environmental impact, as well as on information on significant numbers like yearly energy demand or similar. Hence, we can only roughly estimate the sustainability of the buildings' envelope. The biomorphic form is generated by about 1.500 three-dimensional formed acrylic glass panels, which are punctually attached to an insulated steel-ridge construction by stainless steel mounts [138]. In a cross section from the outside to the inside, the shell construction is composed of: acrylic glass / air layer / foam-glass insulation / F30 steel panels with rock-wool insulation / back-ventilation [139]. The reflecting solar glass reduces heating in summer.

Figure III-9: *BIX façade, eastern* façade of the *Kunsthaus Graz*, Austria (From: http://www.museum-joanneum.at; © LMJ Graz/Nicolas Lackner).

The north-oriented nozzles provide natural lighting during the day, whereas the lighting intensity can be controlled by the varying the orientation of some of the nozzles. Nevertheless, the *OI3-index* of rock-wool insulation is with a value of 72.8 very bad [140], and the value for the foam-glass insulation (roughly about 44, since the material in [140] is most likely not identical) is better but still far away from environmentally friendly. An *OI3-index* for acrylic glass has not been found, but the values of the OI_{AP} (the eco-indicator for the '*Acidification Potential*' and the OI_{PEIne} (the eco-indicator for the 'Primary Energy Input' non-renewable (energies)) are very high as compared to other materials [141].

In conclusion, the building envelope of the *Kunsthaus Graz* cannot be confirmed as to be sustainable. Taking technological development and structure of the construction into account, its insulation properties can be assumed to be good. In addition, the compactness of the biomorphic form (if neglecting the nozzles) and the lighting concept help to reduce the yearly energy demand. But on the other hand, no clear sustainable thought within the overall building concept can be identified, and the building materials are not ecologically sound.

The biomorphic form of the building may indicate a **biomimetic approach** towards the *building envelope*. But no clear technological development or purpose, and much less an adaption from a natural archetype, pattern, or similar, can be found. Hence, this approach most likely simply reproduces natural shapes, based on the iconographic concepts of *blob architecture*, and cannot be identified to be biomimetic. Moreover, a noticeable impact of this formal approach on the sustainability of the building cannot be noticed, neither quantitatively nor qualitatively.

III.2.5 [8] *Rogner-Bad Blumau*

The *Rogner-Bad Blumau* (see figure III-10) was built between 1993 and 1997 on an about 40 ha wide site, and consists of several hot spring thermal water pools, a hotel complex, several restaurants, a health center, and a beauty- and wellness areal. The architectural concept strictly follows the philosophy of F. Hundertwasser: Organic lines and building forms that integrate themselves into the surrounding nature, grass roofs, golden domes, 330 different colored and unique columns, 2400 different unique windows, and uniquely colored façades. It „*realizes a unique overall picture following the philosophy and architecture of Friedensreich Hundertwasser in harmony with nature*" [142].

Sustainability is the central (marketing) concept of the hot springs village *Rogner-Bad Blumau*. This is emphasised by the publication of its own '*Sustainability Report*' [142]. This report covers many aspects like business philosophy, tourism, region, and human and natural resources, but does not cover the buildings itself in details, such as applied materials or building site.

Figure III-10: *Rogner-Bad Blumau*, in Bad Blumau Styria (From [143]).

In terms of tourism, the business is regularly awarded the '*Österreichisches Umweltzeichen*' ('*Austrian Ecolevel*'[1]) [144], that comprises an overall assessment by '*must-*' and '*should-criteria*' of the tourism company in terms of: (i) society and information, (ii) mobility and traffic, (iii) food, kitchen and service, (iv) laundry, hygiene and chemistry, (v) building construction, equipment, and indoor- and outdoor facilities, (vi) energy supply, (vii) waste, water, and sewage, and (viii) air quality and noise [142].

Due to the lack of information a thorough analysis of the sustainability regarding the *buildings' materials*, *envelope*, and *environmental considerations* is not possible. Nevertheless, the buildings have been built after F. Hundertwasser's concepts that are based on ecological and organic building in harmony with nature, which may be referred to the *eco-social concept* of of Guy and Farmer [27] (see chapter II.2.2). All buildings have a biomorphic form that exhibits geometric compactness, which in general is energetically favourable. In addition, they have a green roof, which can (i) reduce heating and energy consumption (by adding mass and thermal resistance), (ii) reduce cooling demand (by evaporative cooling), (iii) mitigate possible drain-peaks, (iv) create natural habitats, (v) filter pollutants and carbon dioxide out of the air and pollutants and heavy metals out of rainwater, and (vi) improve sound insulation [145].

The hot spring in Bad Blumau has a temperature of 100 °C and escapes from the soil at 60 litres per second. Since 2001, the hotel complex uses its own geothermal power plant delivering 250 kW of energy. In a first step, electrical energy is generated (4.300 kWh per day, which accounts for about 30% of the yearly demand can be met), and in a second step, heat for the whole hotel and thermal bath complex is generated by a plate heat exchanger. Since 2004, also the exhalable CO_2 is captured (about 34 tons per day) and utilized for water treatment or sold. Finally, the water is re-injected into another spring, closing the cycle. This water cycle including electricity, heat, and CO_2 generation is shown in figure III-11.

Other measures to save energy or resources are: (i) air infiltration heat recovery, (ii) controlled room heating by a central control room as well as

[1] *by the way designed by F. Hundertwasser*

motion sensors, (iii) sewage water for plantation and bathing pond, (iv) controlled waste recycling, (v) recycling of grease and oil, and (vi) the use of ecological cleaning agents for kitchen and laundry.

The heating and cooling demand of a building is related to its surface area exposed to the ambient. Hence, compact buildings with a high volume to surface area ratio and a reduced number of corners and edges are favorable in terms of a reduction of the energy demand. Regarding this issue, buildings that have an organic or biomorphic - as in the case of the hot spring valley Bad Blumau - can be called *sustainable*. The question whether this can be seen as a **biomimetic approach** is difficult to answer, since such forms have always been there and cannot be seen as a technical development in a biomimetic context; the situation concerning the green roofs is very similar. Nevertheless, the application of biomorphic forms in

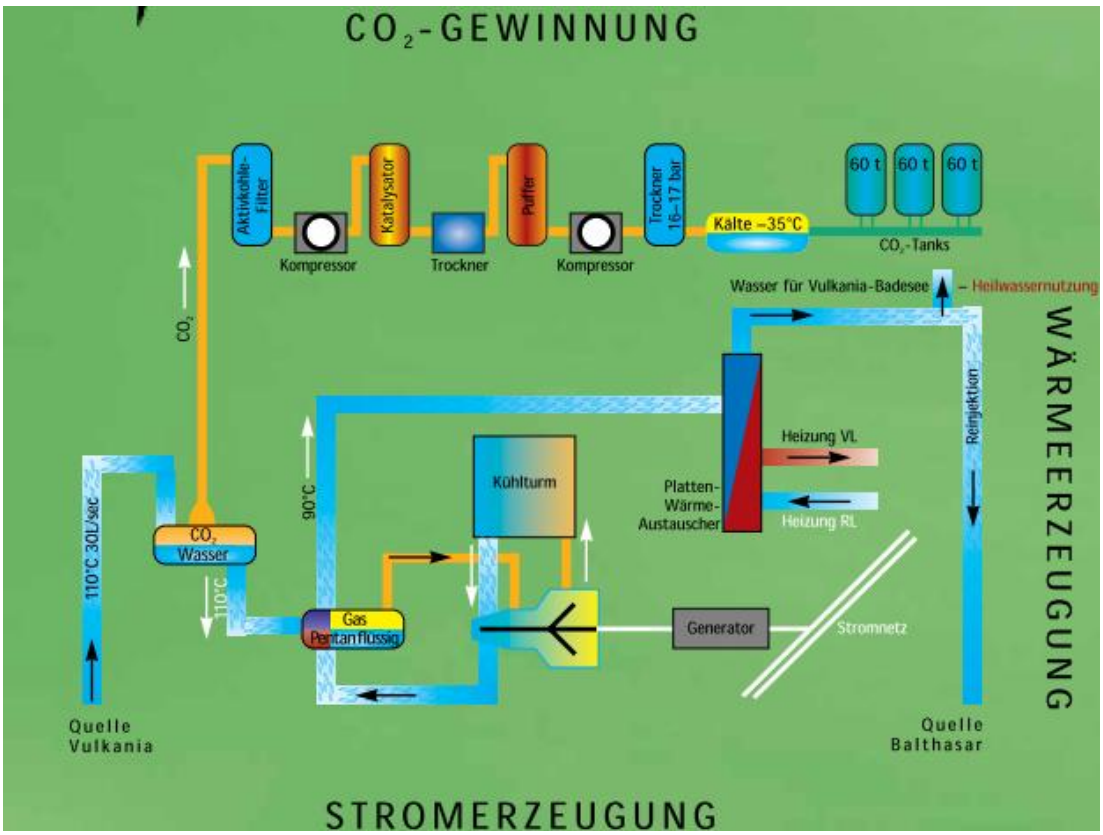

Figure III-11: Hot spring water cycle including electricity (*'Stromerzeugung'*), heat (*'Wärmeerzeugung'*), and CO_2 generation (*'CO_2-Gewinnung'*) of the hotel- and thermal bath complex Bad Blumau (From [142]).

combination with green roofing in terms of a – intentional or unintentional – sustainable building may be seen as the implementation of nature-oriented building that is not simply based on purely morphological translations but in a broader sense biomimetic contexts based on biological principles or cycles.

III.2.6 [25] *Community center Ludesch*

The village Ludesch is an *e5-community* (*'e5-Gemeinde'* [146]) with the aim to use available energy, natural and material resources as sustainable as possible. The *community center Ludesch* (see figure III-12) was realized as a show case project within the *'Haus der Zukunft'* programme [56]. It was intended to fulfil passive house criteria on one hand, and set new standards regarding material consumption, sanitation, and ecological building on the other hand. One specific aim was to lower the specific primary energy use of the construction (*'built energy'*) to less than 18 kWh/m²a, as compared to 35 kWh/m²a for *'conventional'* passive houses; and at the same time reduce the ecological impact of the construction (global warming potential, primary energy input, acidification) to half the amount of *'standard'* buildings [147]. In addition, the sustainability of the building was planned and realized in terms of various social (e.g. community center, library, etc.), and economical aspects (e.g. reduced operating costs, regional value creation), including the complete project planning and tender phases.

Figure III-12: *Community center Ludesch* and its areaway roofed by the photovoltaic system (From [147]).

The *community center Ludesch* was realized as an '*ecological timber construction', which* considers the whole life-cycle of the materials, and is characterized by (i) minimization of material consumption, (ii) reduction of embodied energy, (iii) pollution prevention, and (iv) recyclability of used materials. In comparison to '*conventional'* timber constructions, '*ecological timber construction'* is characterized by: (i) the utilization of wood from sustainably used local/regional forests, (ii) naturally dried wood, or technically dried by environmental sound methods, (iii) natural finished timber products, (iv) constructive wood preservation for expanded lifetime and reduced maintenance, (v) constructive fastener, and (vi) low-emission bonding and surface coating, and (vi) improved project management [147].

The demonstration project *community center Ludesch* developed important knowledge regarding the planning and realization of eco-efficient and sustainable building in Austria. The concept of **sustainability** was addressed in full extent by the application of an '*ecological timber construction'* enabling to fully meet the actual needs of the building's users while neither imposing a subsequent use for future generations nor leaving possible recycling issues [147].

By the intelligent use of ecological materials, synergies between optimized functionality and prevention of environmental or disposal problems could be realized. In terms of the '*ecological timber construction'*, this has been/is shown with the help of a full lifecycle [147]:

1. **Raw material:** The natural growth of wood absorbs CO_2 from the atmosphere (negative global warming potential) which is stored over the whole lifespan. It is an abundant renewable resource, manufactured by using low energy input and creating low pollution. Only wood from sustainably and local/regional forests was used.
2. **Transport:** The exclusive use of timber from local/regional forests strongly reduces the ecological impact due to traffic during construction.
3. **Manufacturing/Construction:** The wood was dried naturally or technically by environmental sound methods. Natural finished timber,

constructive fastener (screws and dowels), low-emission bonding, and surface coating reduced pollution and environmental impact.

4. **Utilisation:** Natural finished timber exhibits a very good buffering of humidity. The use of environmentally and hygienic sound materials, solvents, paints and finisher has a positive impact on user and environment.
5. **Recycling/Disposal:** A life-cycle of at least 40 years for the softwood and 75 years for the hardwood is expected. The construction is fully removable and the natural finished wood fully reusable. Cell- and timber materials can be recycled, e.g. in the brick industry; also combustion for heating is possible.

Besides the wood construction, the whole building (materials and construction) has been analyzed and ecologically optimized on the basis of the above given life-cycle. Figure III-13 summarizes all applied measures, whereas a detailed description can be found in [147].

Standard	umgesetzte ökologische Alternative
Wandaufbauten	
GK-Bauplatte	Holzbeplankung aus regionaler Weißtanne
OSB-Platten	Weißtannen-Diagonalschalung (regionales Weißtannenvollholz), 3-Schichtplatten
Metallständer	Baulatten (regionales Weißtannenvollholz)
Mineralwolle-Dämmung	Schafwolle-Dämmung, Zelluloseflocken
Böden und Decken	
Kunstharz-Versiegelung	Naturöl-Versiegelung, Linoleum
Spanplatten	Industrieparkett
Mineralwolle	Schafwolle
2-lagige Bitumenabdichtung	Flexible Polyolefine verschweißt
EPS 25 Dämmplatten	Perliteschüttung
Brettschichtholz bzw. Leimbinder	Massivholzbalkenlage (sägerau)
Fenster und Türen	
Holz/Alu	Passivhaustaugliche Holzfenster und –türen aus regionaler Weißtanne
PU-Schaum (Ortschaum)	Stopfwolle (Schafwolle)
Allgemein	
PVC-Baustoffe	Polyolefine-Baustoffe, EPDM, Faserbetonleisten, verzinkte E-Trassen
Verklebte Befestigungen	Mechanische Befestigungen
Chemischer Holzschutz und Beschichtungen	Konstruktiver Holzschutz
Lösemittelhaltige Beschichtungen	Wasserverdünnbare Beschichtungen

Figure III-13: Standard solutions (*'Standard'*) and ecological alternatives (*'umgesetzte ökologische Alternative'*) for building parts and materials, as applied at the community center Ludesch. The different categories comprehend wood construction (*'Wandaufbauten'*), floors and ceilings (*'Böden und Decken'*), doors and windows (*'Fenster und Türen'*), and general (*'Allgemein'*) (From [147]).

Every material and building part has been evaluated on the basis of the *OI3-index* by the *IBO Vienna* (see also chapter II.2.3). The summary of the overall evaluation and for every single of the three buildings ('*House A*, *B*, and *C*') of the community centre is given in figure III-14; again, the detailed description can be found in [147]. The values are consistently in the lowest (best) third (0 to 100 points).

Another key implementation of the community centre is the 350 m² wide partly translucent photovoltaic system that roofs the areaway and village square (see figure III-15). 120 glass/glass modules, incorporating 12.5 cm² wide mono-crystalline silicon translucent full-square cells, deliver up to 17.5 kWp peak performance, and are intended to produce about 350.000 kWh electrical energy in 20 years. By the use of the partly translucent modules, the square is shaded without getting darkened.

Gemeindezentrum Ludesch	OI3-Indikator = 30,65 Punkte
Haus A	OI3-Indikator = 26,04 Punkte
Haus B	OI3-Indikator = 31,15 Punkte
Haus C	OI3-Indikator = 32,20 Punkte

Figure III-14: *IBO OI3* ecological building evaluation of the community center Ludesch and for every of its three buildings ('*Haus A,B,C*')(From [147]).

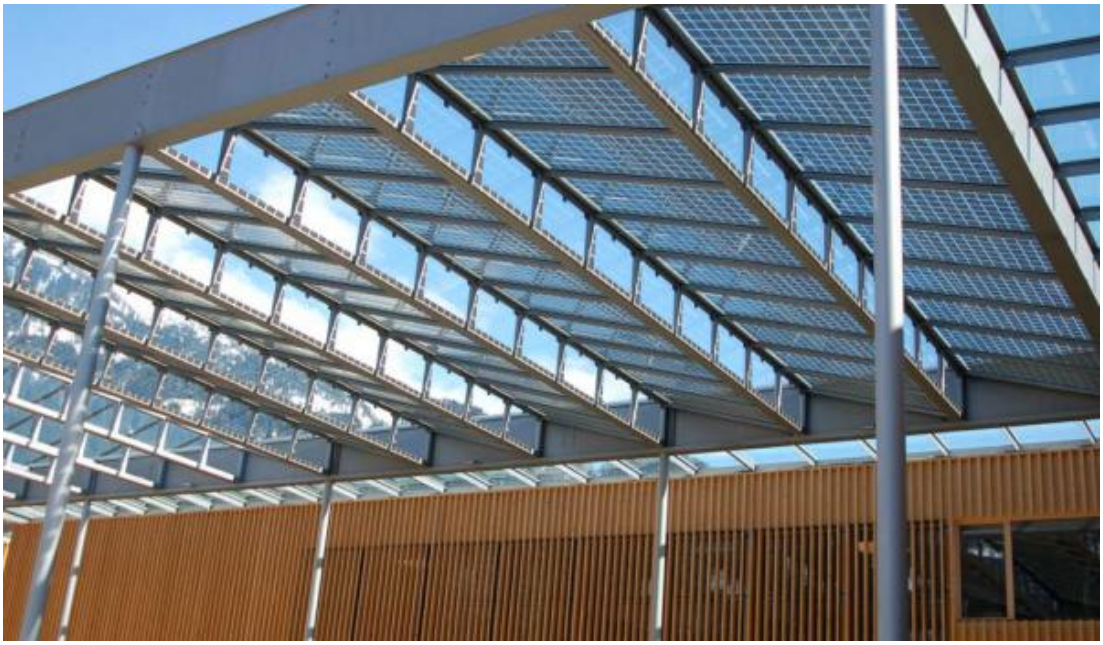

Figure III-15: The about 350 m² wide partly translucent photovoltaic system roofing the village square of Ludesch (From [147]).

Besides the functional and ecological achievements of the project, social aspects (like the creation of an ecological and sustainable community place that can be used as demonstration building), and economical aspects (like the creation and strengthen of regional value and the awareness that the building could be realized by adding only 1.9% to the costs for the use of the ecological materials), have been addressed.

Referring the sustainability of this building to the six competing logics of Guy and Farmer [27] (see chapter II.2.2), its *eco-centric* (not in full depth!), *eco-cultural* and *eco-medical* concept is very similar to that of the *S-House, based on* a consequent use of natural and renewable resources combined with its health- and dissemination aspects.

In terms of the **utilization of biomimetics**, this project is also similar to the *S-House* (see III.2.1) or the company building *'Natur & Lehm'* (see III.2.3), even though it does not go as far as the *S-House* by implementing completely new biomimetic developments like the *Treeplast screws* into the construction. A specific and true biomimetic approach in terms of a (technical) development regarding the buildings' aspects *building material properties, building envelope* or *environmental considerations* could not be identified. Nevertheless, the consequent use of natural and renewable resources throughout the whole building may be attributed to a consistent biomimetic approach regarding the aspects *building material properties* and *environmental considerations*.

Moreover, a fully and comprehensively executed *'ecological timber construction'* may – intentionally or unintentionally - be referred to the mimicry of an ecosystem based on full biological cycles of materials or other resources.

III.2.7 [29] *SOL4 Office- and Seminar-Centre Eichkogel*

The *SOL4* in Eichkogel (see figure III-16) is an office- and seminar-centre as well as a competence centre for advanced standards in ecological development, construction and workplace design [148]. It was intended and realized as an exemplary pilot project in a new semi-urban district for the sustainable construction of a working and living environment, and supported by the *'Haus der Zukunft'* programme [56].

The technologies and design objectives implemented in the project sought to maximize *'green' surfaces* (e.g., green roof systems, open infiltration surfaces, etc.), and environmentally sound construction materials have been used as extensively as possible. Social aspects have been taken account of by including relax areas and other social spaces. Finally, the overall ecological performance of the building is monitored and continually analyzed with total quality assessment methods.

The building primarily addresses the **sustainability** aspects *'ecology'* and *'society.'* In terms of building materials, environmentally friendly materials have been used as extensively as possible. The load-bearing structure is made of locally engineered materials used for the first time [149]: Cement-

Figure III-16 *SOL4 Office- and Seminar-Centre Eichkogel* (From: [148]; ©Thomas Kirschner).

free concrete and brick masonry with optimized storage capacity (see figure III-17, left image); the thermal envelope is made of: mineral foam insulation, prefabricated structural panels made of straw and oriented-strand board (OSB), and a photovoltaic cladding system (see figure III-17, right image). High-performance windows with multiple glazing were installed and equipped with an advanced shutter system. In addition, non-ceramic clay bricks were used as interior office walls. The heating demand of the building was intended to reach passive house standard (< 15 kWh/m²a).

The facility's energy management system optimizes ventilation and air conditioning by means of a closed-loop heat distribution circuit with ground-coupled and ventilation heat exchangers. Vertical boreholes enable earth-to-air cooling, that is, passive cooling by concrete core activation in the panels of the roof construction. The photovoltaic system in the upper part of the building covers the remaining energy demand of the mechanical systems [149]. It involves three photovoltaic facades (east, south, and west) and was calculated to deliver ~17000 kWh of electrical energy per year [148].

Social aspects played an important role during the planning and building phase, as well as during the useful life. Project partners and associates were brought together in common infrastructure and seminar program for tenants.

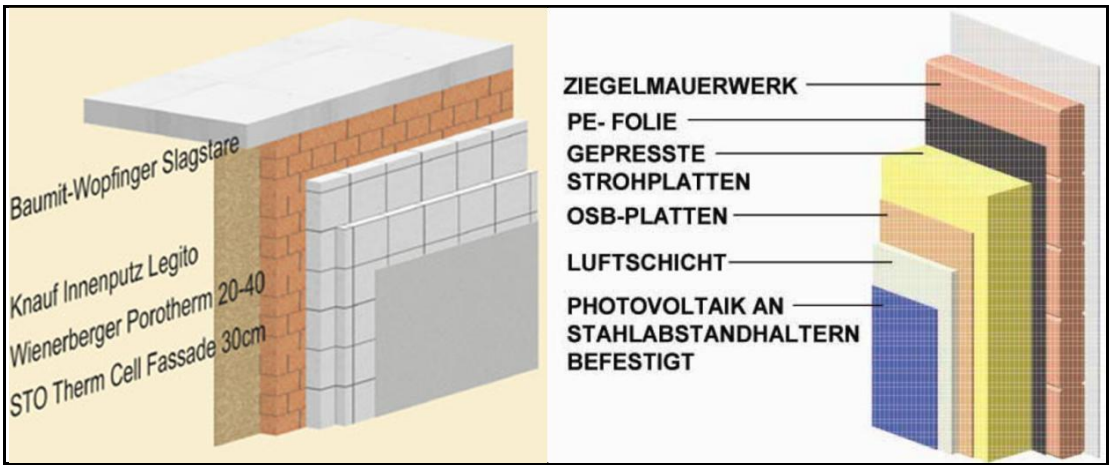

Figure III-17: Left image: Cement-free concrete (*'Baumit-Wopfinger Slagstare'*) in combination with interior stucco (*'Knauf Innenputz Legito'*), brick masonry (*'Wienerberger Porotherm'*), and mineral foam board (*'STO Therm cell Fassade'*. **Right image:** Brick masonry (*'Ziegelmauerwerk'*), polyethylene foil (*'PE-Folie'*), pressed straw panel (*'Gepresste Strohplatten'*), OSB board (*'OSB-Platten'*), air layer (*'Luftschicht'*), and photovoltaic cladding system (*'Photovoltaik'*) (From [149]).

The resulting living and working environment includes relax areas and other social spaces. The necessary understanding of ecological construction technologies was provided to the involved craftsmen in accompanying professional training programs.

The sustainability of the building has been evaluated by the '*ÖCN Ökopass*', which is based on the '*IBO Ökopass*' (see also chapter II.2.3) and by '*TQB*' (see also chapter II.2.3). Regarding the '*ÖCN Ökopass', the building achieved* 901 out of 1000 possible points. The summary of the report is given in figure III-18, the detailed report is given in [149]. Concerning '*TQB*' it achieved excellent ratings in all categories, with an overall rating of 4.21 (out of 5.0). The summary of this evaluation is given in figure III-19, and more details are given in the certification [150].

In terms to the six competing logics of Guy and Farmer [27] (see chapter II.2.2), and in terms of the **utilization of biomimetics**, this project is similar to the community center Ludesch (see III.2.6) or the company building '*Natur & Lehm*' (see III.2.3); though, it may not go as far as the community center Ludesch in terms of natural and biological building materials. Again, a specific and true biomimetic approach in terms of a (technical) development regarding the buildings' aspects *Building material properties, Building envelope* or *Environmental considerations* could not be identified.

BAUBEFUND			Erreichte Punkte	Maximal erreichbare Punkte
Infrastruktur			36	50 max
Unterlagen bei Standort	I1	Öffentlicher Verkehr	15	15
	I2	Geschäfte des täglichen Bedarfes	16	16
	I3	Stromleitung	5	5
	I4	Ortskernverdichtung	0	14
Behaglichkeit			150	150 max
Unterlagen bei Bauphysik	B1	Wärme im Winter	30	30
	B2	Kühle im Sommer	30	30
	B3	Schall	40	40
	B4	Luftdichtheit	50	50
Energie			450	450 max
Unterlagen bei Bauphysik	E1	Gesamtenergiekonzept	280	350
	E2	Warmwasser	50	50
	E3	Stromverbrauch	50	50
Gesundheit			200	200 max
Unterlagen bei Baustoffen	G1	VOC	90	90
Unterlagen bei Baustoffen	G2	Formaldehyd	50	50
	G3	Radon	30	30
Unterlagen bei Elektroplänen	G4	Elektromagnetische Felder	30	30
Umwelt			76	150 max
Unterlagen bei Haustechnik	U1	Wassernutzung	21	50
Unterlagen bei Baustoffen	U 2	Baustoffwahl	55	100

Objektdaten: SOL4
Art: Bürogebäude
Adresse: 2340 Mödling
Strasse: Guntramsdorferstraße 103

Errichtungsjahr: 2004/2005
Bruttogeschoßfläche: 3257 m²
Wert HWB: 33.040 kWh/a // 10,1 kWh/m²a
Wert Luftdichtigkeit: n_{50}< 0,6

ÖBC ausgezeichnetes Gebäude:
mehr als 750 Punkte

Erreichte Punkte: 901

Figure III-18: Summary '*ÖCN Ökopass*' of *SOL4* office- and seminar-centre Eichkogel (From [149]).

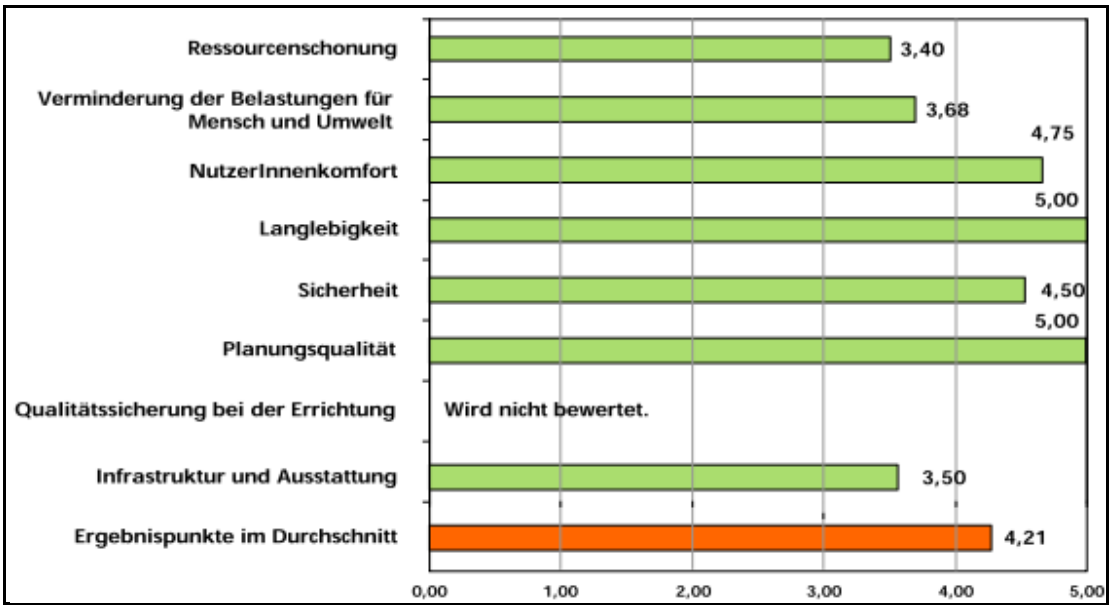

Figure III-19: *'TQB'* evaluation of planning phase of the *SOL4* office- and seminar-centre Eichkogel (From [149]); (For the English translation see figure III-7).

III.2.8 [30] *Biohof Achleitner*

The principles of the *Biohof Achleitner* (see figure III-20) are based on sustainable approaches regarding the construction of the central marketing-, storage- and operations/logistics building, including a bio-supermarket and a bio-restaurant. The approaches include (i) the use of renewable building materials, (ii) use of renewable energies and solar cooling, (iii), the use of plants for air conditioning, and (iv) a gas station providing bio-fuel made of sunflowers for the company's car pool [151].

The intended aims of the *Biohof Achleitner* were – besides the communicated concept "*to aim for an diversified workspace in a liveable environment and to supply the customers with healthy food and valuable bio-products*" [151] - the demonstrating of the usage of straw (mainly grown on the field of the biofarm) as insulation material for a commercially used building (logistic centre with an area of 1780 m²), and air conditioning and accompanied improvement the indoor climate by using plants [151].

Since this building, or rather its concept regarding **sustainability** is very similar to these of the *S-House* (see III.2.1) or the office building and workshop of the company '*Natur und Lehm*' (see III.2.3), in the following, we will only cover the main issues and unique features of this project.

Figure III-20: *Biohof Achleitner* (From [151]).

The building aims to cover the aspects, '*economy*', '*ecology*', and '*society.*' The ecological and social issues are most likely also driven by an economic motivation in terms of visitors and positive marketing effects.

The *Biohof Achleitner* applies straw that has been mainly grown on the field of the biofarm as insulation material for the walls and the ceiling of its logistic centre. This application is demonstrated by a rear ventilated glass construction that has been newly developed, and uses only a minimum amount of constructive steel parts. The architectural effect of the wall is shown in figure III-21, and details on the construction are given in figure III-22. The overall construction achieves an u-value of 0,114 W/m²K, as calculated during a complete building simulation performed by the *Donau-Universität Krems* [151]. This institution also monitors the building during use, and the thermal characteristic of the building are better than calculated [151].

Figure III-21: Rear ventilated glass/straw wall at the *Biohof Achleitner* (From [151]).

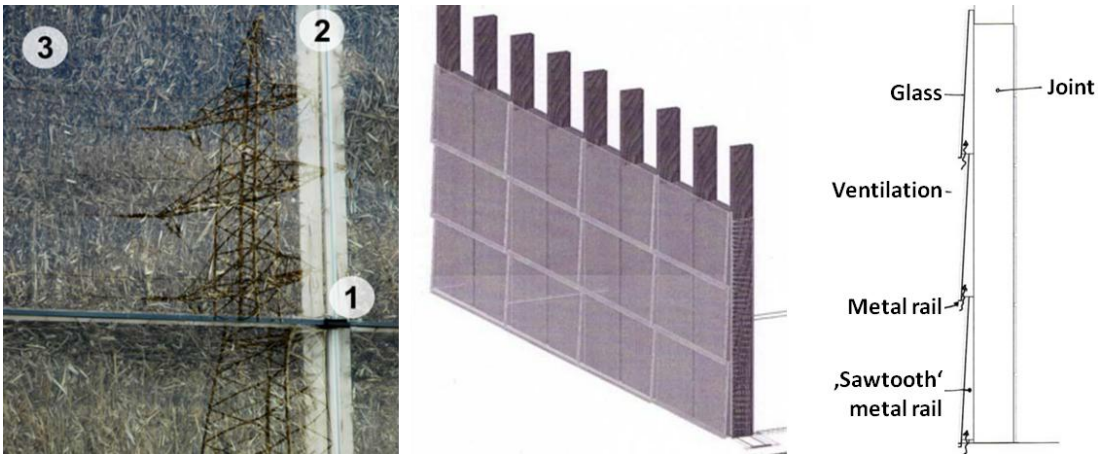

Figure III-22: Construction details of the rear ventilated glass/straw wall as shown in figure III-21. In the left image (1) depicts the metal holder, (2) the wood beam/joint, and (3) the straw insulation. The middle image is a drawing of the construction, and the right image sketches the cross-section of it (From [151]).

An additional characteristic is the extensive use of plants for air conditioning, supported by Jürgen Frantz, former head of the botanic garden of the *University of Thübingen* and the planning group *agsn*. Details on the exact planning and planting of the various plants, as well on the watering and the lighting concept and gardens are given in [151]. The office area, the supermarket, and the restaurant achieve passive house standard, heating and cooling is provided by a heat pump, which is electrified by a photovoltaic system that additionally delivers electrical energy to the building.

The building rose huge visitor traffic (customers, seminar participants, excursions): about 10000 visitors followed the guided tours due to the opening of the building.

In terms to the six competing logics of Guy and Farmer [27] (see chapter II.2.2), and in terms of the **utilization of biomimetics**, this project again is similar to the *S-House* (see III.2.1) or the company building '*Natur & Lehm*' (see III.2.3). In contrast to the *S-House*, no specific and true biomimetic approach in terms of a (technical) development regarding the buildings' aspects *Building material properties, Building envelope* or *Environmental considerations* could not be identified. .

III.2.9 Synopsis of showcase buildings

Table III-3: Benchmarking of showcase buildings

#	Name	Main issues	(Degree of) sustainability	Utilization of biomimetics
[1]	*S-House*	• Sustain. planning • Renew. Materials • Open to public	• Straw-wall: ecolog. footprint: 2364 m²a/m² • Consequent use of natural & renew. res. • Dissemination of sustainable building	• Biomimetic development of *Treeplast screws* • Consistent biomimetic approach regarding *building materials* & *environm. considerations*
[2]	*Ökopark Hartberg*	• Business, science & adventure park • *'Bionik Austria'*	• Circular flow economy • Public concept including exhibitions • Ecological and sustainable village	• Biomimetics is one thematic focus • Society *'Bionik Austria'* is located here • Exhibition *'Bionics – Wisdom of nature'*
[3]	Office building and workshop company *'Natur und Lehm'*	• Passive house • Sust. clay-building • Prototype for in-dustr. production	• *IBO OI3$_{TGH}$*-value: 0 points (out of 100) • *ÖGNB 'TQB'* overall rating: 4.53 (out of 5) • Consequent use of natural & renew. res. • Health- and dissemination aspects	• No *'true'* biomimetic approach in terms of a (technical) development • Consistent biomimetic approach regarding *building materials* & *environm. considerations*
[7]	*Kunsthaus Graz*	• Art museum • Biomorphic form • *'BIX Façade'*	• Oriented nozzles provide natural lighting • *OI3-index* of rock-wool insulation: 72.8 • Biomorphic form reduces energy demand	• Biomorphic form may indicate a biomimetic approach towards the *building envelope* • Simple reproduction of natural shapes
[8]	*Rogner-Bad Blumau*	• Hot spring village • Tourism • Organic forms	• Sustainab. is central (marketing) concept • Publication of *'Sustainability Report'* • Regular awarded the *'Austrian Ecolevel'*	• Biomorphic/Organic forms in combination with green roofing may – intentionally or not – be based on biological principles or cycles.
[25]	*Community center Ludesch*	• *'e5 community'* • Passive house • Social & eco-nomical aspects	• *'Ecological timber construction'* • *IBO OI3* building evaluation: 30.65 points • Full building analyzed & ecolog. optimized • 350 m² wide partly translucent PV system	• Biomimetic approach regarding *building materials* & *environm. considerations* • *'Ecological timber construction'* may be referred to mimicry of ecosystem
[29]	*SOL4 Office- and Seminar-Centre Eichkogel*	• Seminar-centre • Passive house • Pilot project	• Panels made of straw and strand board • *ÖGNB 'TQB'* overall rating: 4.21 (out of 5) • *'ÖCN Ökopass'*: 901 points (out of 1000)	• No *'true'* biomimetic approach in terms of a (technical) development • Tendency regarding *building materials*
[30]	*Biohof Achleitner*	• Marketing-, storage- & logistics building,	• Straw grown on the biofarm; straw/glass construction with U-value of 0,114 W/m²K • Extensive use of plants for air conditioning	• No *'true'* biomimetic approach in terms of a (technical) development • Tendencies regarding *building materials*

PART IV:

SUMMARY
AND CONCLUSION

"The urge to build in closer sympathy with nature is a genuinely biological, and not merely a romantic urge."

Hugh Aldersey-Williams

IV.1 Summary and conclusion

In the EU, 40 % of the total final energy consumption of the residential sector is used for space heating, 25 % for domestic hot water and 11 % for electricity [52]. In the US, buildings account for 39 % of total energy use, 12 % of the total water consumption, and 68 % of total electricity consumption, and 38 % of the carbon dioxide emissions [26].

These figures imposingly illustrate the need to develop building practices for the existing building stock and for new buildings, which aim for integral quality. But these figures do not only reflect the urgency to act, they also state the enormous potential of **sustainable architecture** involving ecological (environmental), economic, and social benefits. Thus, the rational use of natural resources and appropriate management of the building stock, the improvement of energy efficiency, the prevention of pollution, the harmonisation with the environment, and the application of integrated and systemic approaches will contribute to save scarce resources, reduce energy consumption, and improve environmental quality and living standards.

In **Austria**, almost 40% of the final use of energy are attributable to the building sector [56], and by signing the *'Kyoto protocol'*, Austria committed itself to reduce greenhouse gas emissions by 13 % as compared to 1990 until 2012 [61], a goal that will most likely be not met. The highest emission growth rates in Austria are documented for traffic, which is directly linked with territorial buildings structures [62].

In 2002 the EU approved the *'Energy Performance of Buildings Directive (EPBD)'*. In Austria the conversion of the *'EU Energy Performance Certificate'* into national law is to a large extend within the obligation of the federal states. Nevertheless, there is a will to develop countrywide building regulations, which are developed by the *'Austrian Institute for Healthy and Ecological Building' ('IBO')*. Several ecological coefficients and building certificates exist in Austria, such as the *'OI3-Index', the 'IBO-Ökopass'*, *'Total*

Quality Building (TQB)', or the *'klima:aktiv haus'*. The most important national research and technology program is the *'Haus der Zukunft'* (*'Building of Tomorrow'*) initiative [56] that comprehends three main categories: the *solar low-energy house,* the *passive house*, and *ecological, economic, and social demands.*

Sustainable architecture can but does not implicatory have to be achieved by applying biomimetic approaches or methods. From a scientific perspective, the approach or method has to be categorized and evaluated, first in terms of biomimetics, and second in terms of sustainability.

The definition of the concept of **bionics or biomimetics** reaches from a very strict and technical one, specifying it as *"a scientific discipline that systematically deals with the technical execution and implementation of constructions, processes and developmental principles of biological systems"* (as defined by *'The Association of German Engineers'* (*'VDI'*) and W. Nachtigall [88]), to a much smoother and artistic one, that sees it as *"the abstraction of good design from nature",* as given by the *'Centre for Biomimetics'* [90].

Transferring natural concepts to engineering can be done by a *'top down approach'* that is mainly based on foregoing basic research studies to find possible natural (e.g. biological) models or concepts, which are then used to elaborate a specific technical solution; or by a *'bottom up approach'* that starts with a specific technical problem, and research studies are done to find possible solutions in nature for an analogous problem. Three levels of biomimetics, which can be defined as *'organism'*, *'behaviour'* and *'ecosystem',* may be applied to a design problem, and within each of these levels the design may be biomimetic in terms of *form*, *material*, *construction*, *process*, or *function* [13101].

Dividing a building into its aspects *'materials'*, *'envelope'*, and *'environmental considerations'* helps to identify biomimetics approaches and evaluate them regarding their impact on the sustainability of a building. By applying biomimetics to building technology, the sustainability of the building may be achieved or improved by *energy and resource efficiency*, the *elimination and control of hazardous substances*, the *use of renewable*

and biological materials, and/or an *added functionality in materials and structures*.

Based on a comprehensive **investigation on Austrian architecture**, 32 sustainable buildings all over the country have been identified and summarized in a catalogue. Following, eight well suited and documented showcase buildings, which provided the necessary information (annual energy demand, applied building materials, building evaluation, etc.), have been investigated in detail to – at least qualitatively and, if possible quantitatively – evaluate their sustainability. Nevertheless, this thesis does not give a representative overview on past and present sustainable building in Austria. The focus during investigation was to identify buildings that could be attributed to apply a biomimetic concept or approach (in agreement with the definitions of the *VDI* and W. Nachtigall [88] or the *Centre of Biometics* in Reading [9090]), and by this increase or support the building's sustainability.

The **sustainability** of most investigated **showcase buildings** can be exemplary discussed on the basis of the *S-House* in Böheimkirchen. It aims to thoroughly address all objectives for sustainable building [14], and has a strong demonstrative and public character. It serves the whole building cycle, from a sustainable planning phase regarding CO_2 neutrality and environmentally sound solutions for a healthy room climate, an economic efficient construction with the use of regional building materials made of renewable resources, a minimized consumption of energy and resources during use, and an end-of-life concept including easy separation of building materials during deconstruction and plans for recycling and reuse. Moreover, dissemination of sustainable building technologies is a key issue to sensitize the public. [132].

Referring the sustainability of the *S-House* to the six competing logics as elaborated by Guy and Farmer [27] (see chapter II.2.2), the holistic concept of a consequent use of natural and renewable resources combined with its health- and dissemination aspects, its concept is based on a '*light-version*' of the *eco-centric* logic, but also on *eco-cultural* and *eco-medical* logics.

According to the investigated showcase buildings, the office building and workshop of the company *Natur und Lehm*, the *community center Ludesch,* the *SOL4 Office- and Seminar-Centre Eichkogel*, and the *Biohof Achleitner* follow very similar concepts and ideas (even though they all have their peculiarities): All these buildings apply materials that are preferentially renewable and natural such as clay, timber, and straw, combined with increased reuse and recycling. They emphasize on the locality of their location, try to mainly use local materials, and an appropriate formal response to climatic and microclimatic conditions. The design strategy draws inspiration from indigenous and vernacular building approaches (see for example [152]). Concerning health issues, they focus a critical attention on the interior of buildings that meet physical, biological, and spiritual human needs. Of course, not all buildings address all these issues, and not to the same extent. Some buildings, as for example the *community center Ludesch* and the *SOL4 Office- and Seminar-Centre Eichkogel* use different integrative approaches also including *techno-rational concepts*.

The *Ökopark Hartberg* is a conglomerate of various buildings that together as a whole form the idea of an ecological and sustainable village. It practices a circular flow economy including an autarkic and decentralised energy supply concept. Its public concept demonstrates environmental technologies and production processes, and gives an insight into related research and development. The conceptual idea/logic behind has definitely *eco-cultural* but also *eco-technical* aspects [27]. *Eco-cultural* aspects are not as deep as in the above given examples; in contrast to that, *eco-technical* approaches implementing science, technology, and management are more pronounced.

On the contrary, the hot springs village *Rogner-Bad Blumau* combines such an *eco-technical* approach with an *eco-social* one, and to a certain extend also make use of *eco-centric* and *eco-cultural* ideas [27]. The related buildings have been built after F. Hundertwasser's concepts based on ecological and organic building in harmony with nature [142]. The buildings' biomorphic forms exhibit geometric compactness, which is energetically favourable, and the implementation of green roofs mitigate environmental impacts [145].

Also the *Kunsthaus Graz* shows a biomorphic form, even though it this has most likely not been realized to demand a great deal of the building's sustainability (in contrast, see chapter II.2.2: *eco-aesthetic* logic [27]). Rather it shall create exciting architecture as it is commonly used in currently built museums or exhibition centres utilizing either *box*- or *blob*-geometries (see for example [153]). Nevertheless, the *Kunsthaus Graz* exhibits some energy-efficient approaches, such as its insulation properties, the compactness of the form, and the lighting concept. Though, this has to be demanded from building built in the 21st century, and in terms of sustainability the overall building concept is not sufficient.

Concerning the **utilization of biomimetics** in terms of the sustainability of the above summarized showcase buildings, first of all the presence of a biomimetic approach had to be identified, depending on the definition of biomimetics: the strict and technical one of the *VDI* and W. Nachtigall [88] or the smoother and more artistic one of the '*Centre for Biomimetics*' [90]).

Following the first one, the development of the *Treeplast screws* of the *S-House* may represent the only '*true*' biomimetic approach to sustainable architecture in Austria. The shape of the screws was optimized after a method developed by C. Matthek referring to the growth of trees to achieve optimum strength while minimizing the use of material. In addition, an eco-design process was used to develop an environmentally sound material from which the screws are made of, using the renewable and biodegradable, lignin-based biopolymer *Arboform*.

Though, if sensitizing the society towards sustainable architecture (and more precisely towards natural and environmentally sound building), an interpretation on basis of the definition as given by the '*Centre for Biomimetics*' appears to be more adequate. Hence, the consequent use of natural and renewable resources as in the case of the *S-House* – but also in the office building and workshop of the company '*Natur und Lehm*', the *community center Ludesch,* the *SOL4 Office- and Seminar-Centre Eichkogel*, and the *Biohof Achleitner –,* can be attributed to a consistent biomimetic approach regarding the buildings' aspects *building material properties* and *environmental considerations*.

In general, mainly the *building materials* aspect is addressed within the investigated buildings. In nature the synergy of form and function that is based on a combined growth or evolution process often leads to a concrete optimization or additional value of a shape and/or a material. In contrast, human building is still mainly a sequential process – even if this is more and more reduced –, and hence a biogenic material or a biomorphic form very often does not fulfil the envisaged properties. Nevertheless, using natural materials or designing biogenic material is still the most straightforward approach in terms of human building, and hence this aspect is the most favoured one. Here, addressing and meeting *environmental considerations* very often goes hand in hand.

The application of biomorphic building envelopes, as demonstrated at the *Kunsthaus Graz* or the buildings of the *Rogner Bad Blumau,* is more difficult in terms of a sustainably valuable biomimetic application. In terms of heating demand per area of building envelope, such buildings usually exhibit an advantageous (since minimized) surface per volume ratio. Nevertheless, as long as the material of the envelope is not optimized in terms of material usage and type, the impact on the sustainability is small. Green roofs as in the case of the *Rogner Bad Blumau* can clearly improve this issue; nevertheless the extensive use of grass, plants and trees with the building envelope is very often problematic in terms of user acceptance and building construction methodology.

There are a number of **challenges** that have to be faced while **applying biomimetics to buildings**, such as the linear nature of most of today's used building materials, or the way a building is commonly constructed by manufacturing things separately and then joining these together. Form and function as present in plants and animals have evolved over millions of years, and often develop during days, months or years. These time scales have to be harmonized with human engineering to improve functionality, and/or optimize economy and efficiency.

In many cases, the correct interpretation and categorization of an intentional or unintentional biomimetic approach is difficult: A fully and comprehensively executed '*ecological timber construction*' may be referred

to the '*mimicry of an ecosystem based on full biological cycles of resources*', or simply to '*sustainable sylviculture*'.

If a biomimetic approach or application meets the strictest definition in terms of "*systematically dealing with the technical execution and implementation of constructions, processes and developmental principles of biological systems*", or, if "*the urge to build in closer sympathy with nature is a genuinely biological, and not merely a romantic urge*" are not the questions that are to be answered by this work. This work shows with the help of built examples how *truly sustainable building* in Austria can be executed, and of what kind the *most biomimetic-like* methods and approaches are, to achieve this. These buildings to a certain and individual extent '*implemented nature*' in terms of their materials, envelope, and/or environmental aspects, aiming to – intentionally or not – create architecture that "*meet the needs of the present without compromising the ability of future generations to meet their own needs.*"

PART V:

REFERENCES
AND APPENDIX

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V.2 APPENDIX

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V.2.3 Curriculum Vitae

Dr. Dipl. Ing. Stephan Abermann

Nationality	Austria
Date of birth	14.10.1978
Place of birth	Innsbruck, Austria

Education

2007 – today	Vienna University of Technology, Institute of Architectural Sciences, Department of Building Physics and Building Ecology, Austria: • Master Program Building Science and Technology
2004 – 2007	Vienna University of Technology, Faculty of Electrical Engineering and Information Technology, Institute for Solid State Electronics, Austria: • Doctoral (referred to "PhD") program in Engineering Sciences; Title/Topic of Thesis: "High-k/Metal-gate Devices for Future CMOS Technology"
1997 – 2003	University of Leoben, Austria: • Degree Program Materials Science

Professional Experience

2010 – today	Austria Institute of Technology (AIT), Energy Department, Austria: • Researcher on new concepts and technologies in photovoltaics
2007 – 2010	Vienna University of Technology, Faculty of Electrical Engineering and Information Technology, Institute for Solid State Electronics, Austria: • University-Assistant / Project-Assistant
2004 – 2007	Vienna University of Technology, Institute of Architectural Sciences, Department of Building Physics and Building Ecology, Austria: • Project-Assistant
2001 – 2003	University of Leoben, Austria: • Tutorial Assistant

Selected Publications

[1] Ion bombardment induced morphology modifications on self-organized semiconductor surfaces
Author(s): Hofer C, Abermann S, Teichert C, et al.
Source: NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B Volume: 216 Pages: 178-184 Published: FEB 2004

[2] Technology and performance of InAlN/AlN/GaN HEMTs with gate insulation and current collapse suppression using ZrO2 or HfO2
Author(s): Kuzmik J, Pozzovivo G, Abermann S, et al.
Source: IEEE TRANSACTIONS ON ELECTRON DEVICES Volume: 55 Issue: 3 Pages: 937-941 Published: MAR 2008

[3] MOCVD of HfO2 and ZrO2 high-k gate dielectrics for InAlN/AlN/GaN MOS-HEMTs
Author(s): Abermann S, Pozzovivo G, Kuzmik J, et al.
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[4] Lanthanum-Zirconate and Lanthanum-Aluminate Based High-kappa Dielectric Stacks on Silicon Substrates
Author(s): Abermann S, Henkel C, Bethge O, et al.
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[5] Impact of Al-, Ni-, TiN-, and Mo-metal gates on MOCVD-grown HfO2 and ZrO2 high-k dielectrics
Author(s): Abermann S, Efavi J, Sjoblom G, et al.
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[6] Processing and evaluation of metal gate/high-kappa/Si capacitors incorporating Al, Ni, TiN, and Mo as metal gate, and ZrO2 and HfO2 as high-kappa dielectric
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[10] Impact of Germanium Surface Conditioning and ALD-growth Temperature on Al2O3/ZrO2 High-k Dielectric Stacks
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[12] Technology and performance of InAlN/AlN/GaN HEMTs with gate insulation and current collapse suppression using ZrO2 or HfO2
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