As climate and society change, customizing buildings towards specific usage patterns and local weather conditions that might be obsolete within a few years, does not seem to be the smartest approach to building design. Facing the end of readily available highly efficient energy sources, such as oil and gas, we want to re-think the architectural environment towards a symbiotic habitat. The role of energy thus is not seen as a question of supply, but as one parameter among others that shapes the environment. A habitat relies on the physical, chemical and social interaction of different elements and organisms. The authors together with their students pursued a design research re-thinking the architectural environment towards a symbiotic habitat. Full-scale spatial prototypes as elements of such a habitat have been developed focusing on the interfaces between climate, people and other organisms, such as plankton, algae and flowers.

**Keywords:** Real-time interaction, Biologic architecture, Adaptability, Evolutionary algorithm

**INTRODUCTION**

This paper discusses the outcome of a seminar at Energy Design, a department of the Institute of Architecture of the University of Applied Arts Vienna. With the support of our Rector, Dr. Gerald Bast, within the last two years, the department could research in-depth into specific design questions related to energy and architecture, including the engineering of prototypical architectural models or fragments of architectural elements.

These two years of intense activities in teachings and (design) research were dedicated to understand the role of environmental forces as time-based influence on buildings rendering static concepts invalid. We are convinced that in the architectural design practice this aspect of change is massively underrated. Our goal was to explicitly investigate the design options yielded by an architectural design that is more conscious about the ever-changing physical and social reality. In art history a relation between architecture and music often has been discussed, being the notion of time versus space the strongest difference between the two disciplines. Some aphorism such as "Architektur ist erstarrte Musik" (Friedrich Wilhelm Joseph von Schelling), "Architektur ist steingewordene Musik" (Johann Wolfgang von Goethe), "Ar-
architektur ist gefrorene Musik” (Arthur Schopenhauer) show the strange desire to link these arts. However, besides some very formalized concepts such as the Avenue of the Sphinx in Luxor, where the position and the movement of the spectator was strictly given during religious rituals, architecture always failed to deliver the linear and composed experience music can provide. In 1928 Henrik Neugeboren proposes a Monument to Bach, a 3-dimensional system of musical notion. Figure 1 shows the desperate, not to say monumental, attempt to realize 4 measures from Bach’s fugue in E-flat minor. (Neugeboren, H. 1929)

An early attempt to use the transformation of a building to meet environmental forces is the Rotating Aluminium House in Snow Creek, Palms Springs, erected by aerospace engineer Floyd D’Angelo, depicted in Figure 2. This project is for its time especially mentionable, as “In order to rotate the home [...] D’Angelo adapted a device from his product company that was made to open and close aluminum loovers. Originally, D’Angelo powered the mechanical equipment through a photovoltaic cell on the roof which powered the system’s rotation arc.” [1]

The concepts of interactive architecture, as defined by Kas Oosterhuis (Oosterhuis, K. 2013) and his Hyperbody research institution so far had the clearest emphasize on time-based transformation as an architectural design driver.

The department of Energy Design was aimed at going one step further and investigate the meaning of interactive, transformable architecture in the context of climate, comfort and behavior. At the Institute of Architecture, thus two seminars have been set up that clearly pointed out our interest in ecologic strategies on the one hand and the conscious orchestration of time-based change on the other hand.

The first program was called Ecological Ballet. Fully functioning interactive models of scaled architectural projects were shown at the MAK - Austrian Museum of Applied Arts / Contemporary Art, Vienna, in October 2013. SolSeduction - A Phyto-Solar Dance-Floor was the second program, showing full scale interactive prototypes and one scaled model at Heiligkreuzer Hof, a show room of the University of
Applied Arts. The programs were framed by several guest lectures, such as Philippe Rahm, Francois Roche and Marco Poletto and Claudia Pasquero from ecoLogicStudio. Further, a workshop with guest critics Marco Poletto and Claudia Pasquero was held in the beginning of the second programme and a symposium on time, energy and architecture was organized as a final event, having Francois Roche and Marco Poletto, Claudia Pasquero and Brian Cody on the panel.

**METHODOLOGY**

There has to be a kind of disclaimer at the beginning of this paper: no energy balances have been calculated. Thus we fail to answer questions such as if the energy demand for transformation would not exceed what is gained by adaption. The seminar did not follow a strict scientific methodology as it should be expected in natural sciences. The context of the department of Energy Design is that of an architecture school at an art university. The methodology is what is discussed in the field of architecture under the term Design Research or Research by Design, a term specifically brought up in the context of architecture by Michael Hensel and the collaborative and interdisciplinary network he founded: OCEAN Design Research Association, a not-for-profit association focusing on research by design in architecture and urban design [2]. Of course, the methodology behind this term is still vague. David Leatherbarrow, professor of architecture at the University of Pennsylvania School of Design in Philadelphia, traces the modern approach to design research back to the 17th century and later to Le Corbusier and his atelier de la recherche patiente. He admits, that it seems odd to suggest that research could be undertaken in a [...] workshop, yet he points out the fact that scientific advances in our time often occur outside university settings. He finally concludes that design practice can be understood as a form of scientific research when both are seen as projective activities. Project making, so Leatherbarrow, requires a movement away from its own techniques toward conditions that are not of its own making, an eccentric procedure dedicated to the unseen potential of the world it seeks to remake (Hensel, M. 2013). It is this procedure we were after: the unseen potential of the world the projects seek to remake, the symbiotic habitat, that became the brief to our students. However, there is a less cloudy definition of what design research could be, at least as it is discussed in the field of Industrial Design. Trygve Fast and Haakon Faste state that design research is not a "kind" of research. Rather, research is a practice, and it is part of design practice. They find four categories of design research: Design of Research, Design through Research, Research on Design and Research through Design. In this context, our attempts were to follow the category Research through Design, a design activity that operates as research—whether intentionally or not (Faste, T., Faste, H. 2012).

**TECHNOLOGY**

The programs relied on different software and hardware components. Students were trained in Grasshopper, a graphical algorithm editor integrated with Rhino’s 3-D modeling tools. The Grasshopper plug-in Ladybug was used to analyze environmental data, the plug-in Firefly was used to link scripts to Arduino micro-controllers. Fritzing was used to understand and plan the configuration of the Arduino boards, the Arduino Software was used to finally program the micro-controllers. All software, besides Rhino 3D are open source software. The micro-controllers were equipped with a variety of sensors, depending on each individual approach. In the same manner the micro-controller was driving all the physical outputs, the students had to learn how to connect and control stepper motors, electromagnetic valves, servo and dc motors, bimetal, lights and sound. This approach to technology was a combination of content and aesthetics, as well as coding and hardware design for the development of working interactive prototypes.
SOL SEDUCTION - A PHYTO-SOLAR DANCE-FLOOR
The projects of Ecologic Ballet have been presented and discussed at the 10th European Conference on Product & Process Modeling in September 2014 (Sommer, B. et.al. 2014). One conclusion was that future work should address the realization of such concepts in 1:1 mock-ups. With SolSeduction a few mock-ups could be realized and were presented in an exhibition in November 2014 at the Heiligenkreuzer Hof in Vienna. The conceptual approach and task was deepened for this follow-up seminar.

The idea of buildings producing more energy as they need is widely discussed and projects are being realized, usually under the label Plus-Energie-Gebäude. However, this concept is problematic, if seen as a fundamental solution for the energy demand of buildings: North of the tropical and subtropical zones, where most developed countries are located and the total energy demand is highest, the production of solar electrical energy is more or less limited to the summer period, where demand e.g. for lighting is much higher in the winter season (Leibundgut, H. 2011). One alternative and further development could be the production of biomass as a way of chemically storing energy and transforming it to electricity and heat, when needed. The biomass production could be integrated in the building skin. A building with an algae bioreactor facade has first been developed to realization by the Austrian architecture office Splitterwerk in cooperation with Arup (Blaschitz, M. et.al. 2014). Taking up this approach, we want to re-think the architectural environment towards a symbiotic habitat. The role of energy thus is

Figure 3
Task diagram me by Bernhard Sommer.
not seen as a question of supply, but as one parameter among others that shapes the environment. A habitat, in our definition, relies on the physical, chemical and social interaction of different elements and organisms. Full-scale spatial prototypes, as elements of such a habitat, have been developed focussing on these interfaces between climate, people and other organisms, such as plankton and algae.

The prototypes were presented in the above mentioned exhibition. Each prototype was equipped with different sensors to enable them to interact with visitors and the physical conditions on site, re-acting and adapting in real-time. An exemplary responsive system loop as a guideline for the students to design the prototypes can be seen in Fig. 3.

**Luminiscent.Tracings.**
Students: Ola Mnich, Marko Margeta, Banafsheh Fahimipour, Nina Soltani, James Park

This habitat provides an artificial day zone and an artificial night zone. Bioluminescent organisms - *pyrocystis lunula* - help to orient in the darkness and accompany the visitors in the night zone providing an almost surreal atmosphere of water reflections and blue specular plankton light. The artificial vessels for the plankton are a combination of panels that provide the framework for clear cushion full with the mixture of water and nutrients and a kinetic hanging system that provides the motion for their transition from day to night. According to the movement of the visitors under the cushions, locally placed activators will produce the necessary turbulences to excite the plankton to release its glow. The movement of the visitor is traced by motion sensors that inform the respective areas to glow. This gives the audience a feeling of being followed by the light like one is followed by a curious animal. As the plankton needs a 12 hour cycles of daylight and darkness to be able to recharge its luminance, two different populations trade places every 12 hours. This change is driven by a mechanical clock, that slowly lowers and respectively raises the two sets of elements, so that the fluid with the plankton can flow freely from one zone to another. This full cycle occurs on 24 hours cycles making it barely visible for the visitors. The same mechanical clock also provides the a secondary motion tilting the panels gently back and forward to create a wave like effect to enhance the light reflections created by the habitat. (Fig. 4)

![Figure 4](image)
**Oxy.Clmn.**
Students: Noemi Polo, Moritz Hanshans, Artur Stashkevitsh, Arpapan Chantanakajornfung

Vessels of algae - *chlorella vulgaris* -, spread over the walls towards the ceiling. This algae vessels are interconnected with an air supply structure, a network of tubes and valves resembling a circulatory system. Interpolated with the algae there are also air reservoirs that inflate and deflate giving the a sense of breathing. The air supply system is mediated by several electromagnetic valves that will control the air circulation in the system. The algae consumes the CO2 that the visitors exhale giving back oxygen to the exhibition space. Using CO2 sensors the system is triggered by comparing the existing level in the room to the desire value. When this point is surpassed the system uses an air compressor to start the circulation of air form the room into to PVC inflatable reservoirs that will regulate the amount of air flowing into the algae vessels. When the air reservoirs reach the desire pressures, electromagnetic air valves will open the flow of air into the algae vessels, for them to process the CO2 and produce Oxygen in return. The organism also works as a new kind of ornament rich in detail and designed for the exhibition space.
This new type of ornamentation not only provides the space with clean air, but also gives the viewers a visual and musical performance. The sounds produced by the system are a combination electromagnetc valves clicking and clacking, the deep sound of the compressor serves as a humming musical base, on the other hand the bumbling sound of the air, being release in to the vessels containing the algae, adds to the orchestration a less mechanical sound. Moreover, for the exhibition, an array of light sensors were implemented to the system to facilitate the interaction between the visitors and the system. (Fig. 5)

**Dark.Matter.**
Student: Francois Gandon, Miro Straka, Venetia Alia, Jiaxing Lu, Annamaria Dobai

A kinetic wall four meters long by two meters high, made of twenty rotating vertical elements, follows the viewer and shivers as they approach and move in front of it. The elements are sharp points which rotate and face the viewers as they move closer and closer. When the points are rotated to their maximum being the closest to the viewer the start to shiver as if it was a fear reaction. At this moment the wall will release scents of various plants depending on the position of the expectation. This whole choreography of events creates an illusion of fear and self defense. The shivering also creates a kind of natural hissing, resembling the sound of reed in the wind, giving a voice to the installation. (Fig. 6)

**Drone.Synthesis.**
Student: Christian Anich, Daniel Rhomberg

This project is an instrument that is ruled by slime mould. Four satellite stations distributed in the exhibition space around the slime mould, house loudspeakers and ultrasonic proximity sensors. The activity of the sensor is visualized by a fading blue glowing light. The slime mould lives in a habitat, trying to reach nutrition, yet, avoiding light. LEDs in the mould habitat glow according to the activity and distribution of the people in the room. The activity is fed into a synthesizer, creating an ambient electronic sound. The slime mould can conduct electricity and is connected with the synthesizer. As it changes its growth pattern due to the LEDs, the slime mould start to modify the outcome of the musical composition. (Fig. 7)

**3R.House.**
Student: Rangel Karaivanov

This is the only scaled model in the exhibition. It involves a biomimetic principle rather than biologic organism. The model rotates around three axis, following a fitness goal of maximizing or minimizing the impact of solar radiation as well as redefining its
spaces according to space usage. This movement shows the continuous dance between the house itself finding its optimal position for its interaction with the environment and the user and his or hers usage needs. This scale model of the house is kinetically driven by a network or custom design gears and three stepper motor to provide the necessary accuracy for the graceful movement of the house. Weather data, as well local sensors can be streamed real-time into a Grasshopper script. As we see the 3d model reconfigure itself in front of us, the virtual 3d model is shown in a screen next to it. The digital model is represented in the script and the solar radiation levels on its surface are evaluated and described by a color gradient to visually illustrate the phenomenon. The best inclination and rotation angle of each axis is then calculated nearly in real-time by an evolutionary algorithm (Galapagos for Grasshopper). (Fig. 8)

**SEMINAR PROGRAMME OF SOLSEDUCTION**

The seminar started with an introduction and training of specific software skills. After four half-day training sessions, an intense workshop phase started with a concept storming day. These concepts were presented to guest critics Claudia Pasquero and Marco Poletto. Within three days, first prototypes were produced, one already involving pyrocystis lunula, one using chlorella vulgaris, another one using air movement as actuating force, Fig. 9.

In the following phase, besides further research, conceptual drawings and the development of structural details - functional schemes of each prototype were sketched. Exemplary, for luminiscant.tracings. one such diagramme is shown in Fig. 10.

A final flow chart of the actual built prototype is shown for oxy.clm. in Fig. 11. All projects were set up within five days at the exhibition venue. Building components were printed on site with a Witbox 3D-PLA-printer or lasercut, where 2D-elements were needed. The vessels were made of welded PVC. The exhibition opening was accompanied by a symposium on time, energy and architecture.
Figure 10
Diagramme by Ola Mnich, Marko Margeta, Banafsheh Fahimipour, Nina Soltani, James Park.

Figure 11
Diagramme by Galo Moncayo.
CONCLUSIONS
A wide variety of design options and new aesthetic experiences can be obtain by taking up new sustainable technical strategies. This potential lies completely open and architects should learn to use these new strategies as design drivers. From the present work, most promising seems the project oxy.clmn, as the algae significantly reproduced after two weeks of exhibition, although the exhibition room was not very well lit and although the exhibition took place in November. Compared with the realized The Algae House, from Splitterwerk / Arup, the project shows at least two steps forward: it combines the production of biomass with the cleaning of the indoor air and the algae does not need to be heated in winter.

ACKNOWLEDGEMENTS
The projects were made possible by extra funding from the rector of the University of Applied Arts Vienna, Gerald Bast. The development of the prototypes was accompanied by visiting critics Claudia Pasquero and Marco Poletto from UCL Bartlett / ecoLogicStudio.

The students involved showed commitment that exceeded what you can expect by far.

LINKS
Videos from the prototypes can be accessed online:
energy-design.tumblr.com

REFERENCES
Blaschitz, M, Wurm, J, Hemmrich, E, Arup, - and Splitterwerk, - 2014, Das Algenhaus / The Algae House, Niggli Verlag, Zürich
Faste, T and Faste, H 2012 'Demystifying “design research”: Design is not research, research is design,' Proceedings of the IDSA
Hensel, MU (eds) 2013, Design innovation for the built environment: Research by design and the renovation of practice, Routledge
Leibundgut, H 2011, : LowEx building design: für eine ZerOmission Architecture, vdf Hochschulverlag AG

Oosterhuis, K (eds) 2013, Hyperbody – the first decade of interactive architecture, JapSamBooks, Rotterdam
Sommer, B, Moncayo, G and Pont, U 2014 'Ecological ballet – a design research towards environmental-reactive, adaptive architectural design,' eWork and eBusiness in Architecture, Engineering and Construction, pp. 215-220