Wood as a Primary Medium to Eco-Systemic Performance:

A Case Study in Systemic Approach to Architectural Performance

Doctoral Thesis by Marie Davidová, MArch.

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I, Marie Davidová, hereby confirm that the work in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated

The present research considers **wood** as a study material for a wider question on architecture's environmental[1] interaction. It aims to explore its potential for **eco-systemic**[2] **performances**[3] and **atmospheres**[4] as well as to broaden the discussion on this problem area by accessing the **public space** and **professional practice** calls. My project researches such interactions through practical experiments as well as theoretical reflections, including examinations of other scientific, design, artistic and crafts disciplines. It honestly discusses the successes as well as the failures and weak points to develop a strong background for **eco-systemic collaborative design-research practice**.

The methodology **Research by Design**[5] while **full scale prototyping** is covered by the **Systems Oriented Design**[6] to interpret and develop complex environmental relations. While doing so, this work also claims develop the **methodology** itself and to **generate theory through experimental practice**. The fusion of these **process based** fields led to the ratification of new design field: **Systemic Approach to Architectural Performance**[7].

This is an **article based thesis**[8], where the texts of the articles have been shortened of the parts

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[1] 'Environment is physical and biological surroundings of an organism. The environment covers non-living (abiotic) factors such as temperature, soil, atmosphere and radiation, and also living (biotic) organisms such as plants, microorganisms and animals.' (Oxford University Press, 2004)

[2] Ecosystem was described by Allen and Roberts as an ecological system inside the system that includes the geophysical part. (T. F. H. Allen & Roberts, 1993)

[3] Leatherbarrow is explaining the performance view on construction: '…when the preparations of well-designed construction are seen to be inevitably inadequate, when the finished work is understood to be necessarily incomplete, because the world of which it is part is recognized as a field of forces that will, over time and unpredictably, re-qualify what design and construction had pre-qualified.' (Leatherbarrow, 2013)

[4] 'Quality in architecture . . . is to me when a building manages to move me. What on earth is it that moves me? How can I get it into my own work? . . . How do people design things with such a beautiful, natural presence, things that move me every single time. One word for it is Atmosphere.' (Zumthor, 2006a)

[5] 'Research by Design is any kind of inquiry in which design is a substantial part of the research process. In research by design, the architectural design process forms a pathway through which new insights, knowledge, practices or products come into being. Research by design generates critical inquiry through design work that may include realized projects, proposals, possible realities or alternatives. Research by design produces forms of output and discourse proper to disciplinary practice, verbal and non-verbal that make it discussable, accessible and useful to peers and others. Research by design is validated through peer review by panels of experts who collectively cover the range of disciplinary competencies addressed by the work.' (ResEAAErch, 2017)

[6] Systems Oriented Design: 'an approach to learn how to better cope with very complex issues as designers. The approach is influenced and inspired by modern systems thinking and systems practice and inspired by generative diagramming. Design practice, systems thinking, systems practice, design thinking, information visualisation, diagramming, GIGA-mapping, research by design, research through design, design for complexity, sustainability.' (Sevaldson, 2013c)

[7] The notion of Systemic Approach to Architectural Performance was first expressed by me in 2016 as a title for collaborative project among me, Birger Sevaldson, Michael Hensel and Miloš Florián that was fusing Performance Oriented Architecture and Systems Oriented Design. This project was supported by EEA and Norway Grants as a bilateral partnership program between the Faculty of Art and Architecture at the Technical University of Liberec and the Oslo School of Architecture and Design (Davidová, 2016k, 2016l). The project's continuation among the same design - researchers participants for the bilateral partnership between the CTU in Prague and the Oslo School of Architecture and Design has been recently submitted for funding to the same donor.

[8] *PhD Thesis Requirements at CTU in Prague:* '1. A dissertation is the result of solving a particular scientific or artistic task; PhD student demonstrates the ability to work independently in a creative way and it must contain original authorship of the dissertation published results of scientific or artistic work or results accepted for publication; 2. A general theme or themes of dissertation are offered during the admissions procedure on the basis of the future supervisor, followed by the recommendation of the head of the training department and the consent of the Scientific Committee. A more specific definition of the topic within the thematic area is possible upon an agreement between the supervisor and the candidate; 3. The title of the dissertation, including its load is set at the latest at the end of the study unit on the basis of the submitted studies and debates on the topic of dissertation under – see Art. 27 paragraph. 7th; 4. The dissertation can be recognized and accepted as a set of

mentioned elsewhere in the work and underwent through language check. These serve as an addendum covered with an exegesis. Most of the repeating images were removed from the articles. If there is an exception this is reasoned through its important relation to the present text.

All substantial contributions are mentioned within the text and/or summarized in the Thanks chapter. To mention the main **institutions** and **practice/NGO's** respectively, this **research has been collaboratively developed** at the Faculty of Architecture at the Czech Technical University in Prague, the Faculty of Art and Architecture at the Technical University of Liberec, Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences in Prague, the Academy of Art, Architecture and Design in Prague, the Architectural Institute Prague, the Oslo School of Architecture and Design, the University of Chemistry and Technology in Prague, the Faculty of Civil Engineering the Czech Technical University in Prague, Collaborative Collective, Defio, Oximoron, re.code.nature, CooLAND, Experis SDKM and reSITE.

This work is a second, **revised edition** of the thesis, when the first, work in progress, publication called ***Wood as a Primary Medium to Architectural Performance: A Case Study in Performance Oriented Architecture Approached through Systems Oriented Design*** (Davidová, 2016m) served as a **tool to receive broader feedback** from its readers. The first publication was kindly supported by **EEA and Norway Grants** through the project **Systemic Approach to Architectural Performance**, was printed on paper with 100% of recycled fibre. This edition was **reviewed by a gender equal team** and is to be defended in front of a **gender equal selection of opponents**. The work itself is dedicated to our **Biosphere**[9].

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publications or manuscripts joint by an integrating text; 5. dissertation is written in Czech, Slovak or English. Applicants may, with the agreement of the President of the Scientific Committee, submit a dissertation in one of the other world languages. Other formal requirements for dissertation is specified by the dean of the faculty. If the work does not meet these formal requirements it may be not accepted by department for science and research for further proceedings. In case of doubt the decision is concluded by the Dean. (Konvalinka, 2015)

>> *PhD Thesis Requirements at FA CTU in Prague:* **'**Formal and Content of State doctoral examinations, dissertation and its defence is specified in the requirements and recommendations for additional SER CTU.' (Lábus, 2016)

>> *Additional PhD Thesis Requirements and Recommendations by SER CTU:* 'Also dissertation as a set of publications or accepted manuscripts joined by integrating text can be recognized. Dissertation is written in Czech, Slovak or English language… …Dissertation has the following formalities and obligatorily includes: 1. The cover or first page: marking the university, the faculty and supervising department, dissertation title, 'Doctoral Thesis' title, name of the PhD candidate, the year of submission, supervisor's name, study program, field of study; 2. In the introductory part: target of the dissertation and an overview of the current state of the science issues (with references to literature); 3. In the final part: overview of results, including the original dissertation doctoral student contribution (i.e. a brief overview of the results of dissertation and how to improve the current situation), the conclusions for future the advancement of science or for implementation in practice; 4. One-page abstract in English.' (Fialová, 2016)

[9] Biosphere is 'irregularly shaped envelope of the earth's air, water, and land encompassing the heights and depths at which living things exist. The biosphere is a closed and self-regulating system (see ecology), sustained by grand-scale cycles of energy and of materials—in particular, carbon, oxygen, nitrogen, certain minerals, and water. The fundamental recycling processes are photosynthesis, respiration, and the fixing of nitrogen by certain bacteria. Disruption of basic ecological activities in the biosphere can result from pollution.' (Lagasse & Columbia University, 2016)

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2 Thanks

First I would like to offer my sincere gratitude to my supervisors, Miloš Florián from the Faculty of Architecture at the Czech Technical University (FA CTU) studio FLO|W, Birger Sevaldson from the Oslo School of Architecture and Design (AHO) and Ocean Design Research Association and Zdeněk Fránek from the Faculty of Art and Architecture at the Technical University of Liberec (FUA TUL) and Fránek Architects, for providing great support and inspiration during my work. A special thanks to Birger for very precisely reviewing both versions of the thesis.

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3 Introduction

This research by design[10] is seeking answers to the question of what is a solid pine wood's environmental interaction and how it can be used in **Performance Oriented Architecture**[11] applied in **Czech locations**. This is looked upon from **Systems Oriented Design**[12] perspective. By integrating these fields from **eco-systemic perspective**, the work leads to the ratification of a new design field: **Systemic Approach to Architectural Performance**. Therefore, the case study demanded larger complexity of investigation as one cannot divide the field into fragments. This is obvious when it comes to discussion on eco-systems. Ulanowitz describes that *'ecosystems'*[13] behave in ways that are very different from the systems described by other sciences, i.e. evolutionary theory, ethology, mechanics, thermodynamics, etc. And that the ability of aggregated mechanical constructs, otherwise known as *'eco-systems models*', to predict the behaviour of ensemble eco-systems is notoriously poor. (Ulanowicz, 1999). Therefore, he also discusses *'Ecosystems Phenomenology'*[14] (Ulanowicz, 1988). The importance of performance of the whole is also discussed by Gestalt Psychology (Wertheimer, Koffka, Köhler and others)[15]. With the understanding of above mentioned, several full scale prototypes, their production and application in architectural and *'urban design'*[16] and eco-systems, design processes and the methodology itself were all interpreted through practice as fused ever evolving biotic as well as abiotic co-design, being the design-research process and the result in the same time.

This **multiple approach** to generate **rich thesis** is reasoned from observations of a reductionist's architectural design applications, that were also criticised i.e. by Hemmersam and Morrison[17] in relation to local specificity (Hemmersam & Morrison, 2016), the core of this thesis. In the last few decades, a large amount of computer generated designs inspired by material, biological or social systems i.e. have been built. These attempts often failed to engage the main field of their inspirations, the material, the

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[10] For the reason, that the work is *'research by design'* authored or co-authored by me from the position of project leader, there is a large auto-referencing appearance. This necessity is also supported by the fact, that there is no similar research in the location. As the work is local-specific and there is no other author in the field and location, auto-referencing was unavoidable.

[11] 'Performance-oriented Architecture, a subset of Performance-oriented Design, that engages the key concepts 'non-discrete architectures' and 'non-anthropocentric architectures'. The former seeks for a higher level integration of architecture and environment that are locally specific and intensely embedded in their setting. The latter aims for an integration of ecology and urban ecology considerations on the scale of architecture.' (Hensel, 2015c)

[12] Systems Oriented Design: 'The designerly way to work with systems: The main mission of Systems Oriented Design is to build the designers own interpretation and implementation of systems thinking so that systems thinking can fully benefit from design thinking and practice and so that design thinking and practice can fully benefit from systems thinking.' (Sevaldson, 2013b)

[13] 'By ecosystem we mean a view that explicitly includes the geophysical part of an ecological system inside the system.' (T. F. H. Allen & Roberts, 1993)

[14] Ecosystems Phenomenology is contrasting analytical processes that are dissecting that which is whole, probing that which is small, and looking for causes in component parts (Ulanowicz, 1988).

[15] Wertheimer, Koffka, Köhler did not claim that the whole is more than the sum of its parts but that objects and relations are experienced differently than collection of sensations, parts or pieces (Ash, 1998).

[16] 'Urban design is about making connections between people and places, movement and urban form, nature and the built fabric. Urban design draws together the many strands of place-making, environmental stewardship, social equity and economic viability into the creation of places with distinct beauty and identity.' (UrbanDesign.org, 2017)

[17] Hemmersam and Morrison reject the modernist 'result of abstract utopian ideas' and propose 'moving beyond the reductivism' through 'methodology involving transect walks, with the purpose of mapping the peculiarities of cultural landscapes…. [this] includes the ephemeral and emergent, but also digital, dimensions of urban landscapes, and results in a complex reflexive method of critically reading and writing, of moving and locating, of seeing and picturing place mapping.' (Hemmersam & Morrison, 2016) This work is addressed to Arctic climatic location. Therefore, it is very relevant for this thesis, as it is discussing the expected weather extremes in discussed location in reference to its adaptation.

biological and the social systems themselves in real life, thus not achieving any real life performance. For this reason, and because there is not enough research in related areas, the research had to investigate and bring more multi-layered acquisitions to the fields. Architectural and Urban Design are being commonly understood as the most complex disciplines – so must be the research by design in these disciplines. Therefore, to conclude with acquisitions to only three major fields seems to be reduced to a minimum. These cover:

a) **the methodology:** MINI-maps, Processing Performance of the Whole, Performance of the Whole, Rich Design Research Public Space, Feedback Looping of Final Prototypes, Time Based Eco-Systemic Co-Design, Practice Generated Theory (see Methodology Research Acquisitions section);

b) **the material research:** Life Cycle Based Eco-Systemic Material Selection, Force-Hygroscopicity Relations, Time-Based Force-Hygroscopicity Relations, Angle Cut-Fibre Direction Hygroscopicity Performance, Sugar and Amyl Free, Biological De-Re-Sorption Relation, MC-Cut Hygroscopicity Relation, Material-Design Life Cycle, Introduction of Solid Wood Responsivity to POA (see Material Research Acquisitions section);

c) **architectural and urban design field:** Responsive Solid Wood's Application, Performance Based Beauty – Beauty's Performance, Embodied Architectural Performance, Boundary Conditions Crossing, Onion Principle, Eco-Systemic Environmental Interaction Principle, Trans-Co-Design, Local Climatic Adaptation

(see Architectural and Urban Design Research Acquisitions section).

Inspired by the performance of traditional architecture from locations with more extreme climate histories, this case study mainly focuses on performative potentials of solid pine wood cut in tangential section; to be precise – its cup warping – and particularly how this might be applicable in the specific climatic conditions of Czechia. With today's climatic change in our region, there is a necessity to search for the adaptation of our local architecture in different places where such conditions have been already present.

3.1 Theme

The **Czech National Strategy for Climate Change Adaptation** document clearly states that it is necessary to promote research and development of new materials and technology in reference to anticipated effects of climate change, such as strong gusty winds, extreme rainfall or snow totals or temperature extremes. The main issue in the urban environment mentioned is humidity extremes – long periods of very dry weather or extreme rains (Czech Republic Ministry of the Environment & Czech Hydrometeorological Institute, 2015). In regards to this issue, the architecture is not considered. It is important to note that architects and urbanists were excluded from the document preparation. This research claims that the experimental field of architecture and urban design may bring new perspectives to the discussion, joining climatic, material and biotic (including social), sciences. However, this investigation does not stop with **material** and **experimental architecture** alone but expands to social architecture across **biotic and abiotic interactions and processes**. This is necessary to investigate how such material technologies can become a realistic contribution to architecture and built environment in its eco-systemic performance. Such was investigated through practice – individual and collaborative GIGA-mapping[18] and full scale prototyping, both exposed to public space or a highly -biotic environment for interaction (see Figure 1). Furthermore, this acquired data and registering from vernacular architecture were examined by collaborative trans-disciplinary practice project application.

Figure 1: Research Prototypes that Are Moderating its Micro-Climatic Ambient Environments through Material-Environment Interaction Causing Sorption or Evaporation followed by Warping, from the left to right a) pereSITE Pavilion during the Public Lecture and Discussion on the Design-Research at reSITE Festival (photo: Pedersen 2013); b) Loop Pavilion Tested by My Self for Its Opportunistic Use – Posing at the Press Conference before the EnviroCity's Festival Release (photo: Exner 2014, from Exner, 2014, with the courtesy of City Council of Prague); c) Ray 2 Prototype in Sunny Summer Weather after Three Years of Being Exposed to Highly Biotic and Abiotic Conditions next to a Forest Hillside for its Environmental Interaction – notice algae distribution along the grain of the panels (photo: Davidová 2016); d) Ray 3 Prototype Getting into its Narrow State during an Increase of Relative Humidity, thus Sorption of the Material (photo: Davidová 2016)

The work covers *'down to earth'* exemplification of two sub-projects resulting in four built prototypes: Performative Screens Ray and Environmental Summer Pavilions, where prototypes Ray 2, Ray 3, pareSITE and LOOP pavilions (see Figure 1) benefit from each other's ideas, observations and design results. The Ray project that was inspired by Norwegian traditional panelling and Oriental screens called 'mashrabīyas'[19] is proposing a screen that is airing and improving the environment by evaporating humidity in warm, dry weather while being resistant and sorping moisture in high relative humidity. The pavilions were mainly focused on moderating *'urban heat islands'* (Wong, Hogan, Rosenberg, & Denny, 2016) through circulation of evaporated humid air such as in 'mashrabīyas', while using the idea from

[18] 'A Gigamap is characterized by: • Designerly construction of a rich picture of a real life situation • Mixing information types and kinds e.g. images, graphics, texts, and other media • Mixing sources of information • Myriadic quality: including large amounts of information • Crossing scales, from large scale to small scale (microscope, telescope, wide angle views) • Combining and relating categorically different entities • Covering wide fields • Digging into details • Combining, interpolating and criticizing systems models • Boundary construction, critique, and adjustment.' (Sevaldson, 2012a)

[19] 'Mashrabīyas' are wooden oriental screens moderating, among others, humidity micro-climatic conditions exchange across interior and exterior (Fathy, 1986). These can be appearing in different layers, either as a permeable envelope in direct contact with the exterior, or as a second layer of enclosable 'kishks' (Fakouch et al., 2004).

Norwegian traditional panelling of warping for humid air movement generation. These architectures were improving/may improve outdoor-indoor climatic comfort by providing shading and wind sheltering but also sorping moisture in high relative humidity level that occurs mainly at nights, while evaporating it on hot summer afternoons, when the relative humidity is on average the lowest. According to Banham, humidity has been the most pestiferous, subtle and elusive of control for most of architectural history, either too much or too little of it in certain climatic conditions (Banham, 2009). These prototypes wish to take this discussion further through not control but its moderation practice, applied for the location with both extremes and their increase expectations, as stated in Czech National Strategy for Climate Change Adaptation (Czech Republic Ministry of the Environment & Czech Hydrometeorological Institute, 2015).

3.2 Design-Research Inspirations, Motivations and Practice

This research on solid wood cut in a tangential section (see Figure 3) was greatly inspired by contemporary research on **ply-wood and laminates**, conducted by Michael Hensel, Achim Menges and others and research of **Sustainable Environment Association** (Hensel, 2011b) co-founded by Michael Hensel, Defne Sunguroğlu Hensel and Birger Sevaldson that recently joined the Ocean Design Research Association (Hensel, 2015b). In the September/October 2015 issue of Architectural Design it was revealed that the research at the Institute of Computational Design at the University of Stuttgart led by Achim Menges is also planning to take the direction of research on solid wood cut in tangential section (Menges & Reichert, 2015). This work has not yet been published.[20]

Implementing the ***'Bottom-Up'*** approach starting with the material research, the ***'Top-Down'*** method was also applied through the combination of ongoing speculations about possible applications, in addition to the separate mission of the pavilions in being public architectural performative objects through which other observations started. At the same time, the need for such performative capacities was discussed several times through many projects in my collaborative practice design-research network, **Collaborative Collective**[21] (Collaborative Collective, 2012). The most threshold example of this work is shown in the DCA2016 paper, Ray 3: The Performative Envelope (Davidová, 2016g). Though the project På Vei (Collaborative Collective, 2011) is not situated in the Czech Republic but rather Norway, the relevance of this possible application was so important that it was included into this otherwise very site-specific, thesis. The Practice Application Discussion covers research of ***'non-discrete spaces'*** (Hensel, 2012c) in the context of my work and traditional architecture in Norway. The Norwegian traditional architecture investigation and its relation to presented work is discussed in the paper for the Relating Systems Thinking and Design 5 conference: Socio-Environmental Relations of Non-Discrete Spaces and Architectures: Systemic Approach to Performative Wood (Davidová, 2016i). Its practice application is exemplified on competition entry by transdisciplinary[22] collaboration of Collaborative Collective, Experis SDKM and CooLAND for administration centre of the Forests of the Czech Republic: Responsive Transformer[23], discussed in the paper for International Design Conference: Design Evolution [Education and Practice]: Responsive Transformer: The Bio-Robotic Adaptive Architecture (Davidová, Zatloukal, & Zímová, 2017). This project proposes *'heterogeneous architectural space'* (Hensel, Hight, & Menges, 2009), organized in **layers of onion peels** (Davidová, 2016g, 2016i, 2016m).

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[20] The authors referred in this paragraph are founders and key figures within the research fields of this thesis. For this reason, they are also widely quoted throughout the text.

[21] Collaborative Collective is a collective of architects, designers and friends, first conceived in 2008 as an open platform for sharing ideas and pursuing personal agendas. After this first formation broke up, the team without its establishing founder got rise to different platform called EDIT!. This platform also, deservedly, refers to the former Collaborative Collective's work. In 2011 Krištof Hanzlík, the former founder of the previous platform, and me ratified a design-research network practice with this name under the agreement of the former platform members. This network already started with its own physical office, while outsourcing external transdisciplinary collaborators. In 2012, me, Krištof Hanzlík and Martin Gaberle founded and registered an NGO with the same title as a civic association for science, research and development within the architectural field.

[22] Transdisciplinarity, as opposed to Interdisciplinarity refers to equality of the involved disciplines. There is no more master architect within an *'architectural project'*. While practicing transdisciplinary design-research, all involved agents participate through their agendas and thus also gain equal outcomes.

[23] Transformation: '1. the act or process of transforming. 2. the state of being transformed; 3. change in form, appearance, nature, or character; 4. Theatre: a seemingly miraculous change in the appearance of scenery or actors in view of the audience; 5. Logic: Also called transform. one of a set of algebraic formulas used to express the relations between elements, sets, etc., that form parts of a given system; 6. Mathematics: the act, process, or result of transforming or mapping. function (def 4a); 7. Linguistics: transformational rule. the process by which deep structures are converted into surface structures using transformational rules; 8. Genetics: the transfer of genetic material from one cell to another resulting in a genetic change in the recipient cell; 9. a wig or hairpiece for a woman.' (Dictionary.com, 2017)

For the research project's purposes, a sister **NGO** of the same name as the practice network, Collaborative Collective, was established in conjunction with my colleagues from the practice. The 'Research by Design' thus joins not only academy with practice, but also an investigation on how radical architectural research by design can be organized in the format of the NGOs. This part is a crucial research tool that opens access from academic research to public and other non- scientific professions. As Leatherbarrow puts it: *'to understand architecture's performative character, we cannot rely on transparent and objective description alone, or on techniques of quantification and measurement.'* (Leatherbarrow, 2009), therefore i.e. event oriented artistic professions were invited to the project. This was elaborated in DCA2016 paper: NGO, Practice and University Driven Research by Design on Performative Wood, co-authored with Birger Sevaldson (Davidová & Sevaldson, 2016b).

Besides literature studies on different topics like ecology, forestry, dendrology, wood material science and technology, climatology, algology, mycology, architectural theory, history and conservation, today's research in the field of responsive wood, environmental art, urban design and landscape architecture, etc. the project's main research approach is based on Research by Design, that was featured as solid ground already in 2010 in a special issue of FORMakademisk (Morrison & Sevaldson, 2010), with 1:1 Scale prototyping and practical experiments directing towards sustainable applications in architecture and urban design. This research mode has been synchronised with the methodology Systems Oriented Design (Sevaldson, 2013b, 2013c, 2017b). The approach helped to maintain an overall focus of the project and to address the systemic implications and connections. This also implied development of the methodology through its application into the specific design needs. Throughout the process, the GIGA-maps (Sevaldson, 2012a) were tools for this transdisciplinary project that was mapping hard data together with tacit and subliminal knowledge and experiences, targeting the architectural and urban design practice. While Michael Hensel and Fredrik Nilsson comment on the recent shift from building theory to inform practice to research through design agency (Hensel & Nilsson, 2016), this work claims to build the theory though design-research practice and performance.

3.3 The Structure of the Thesis

The thesis first **chronologically positions my prototypes** (see 5.1) into the perspective of other research that has been done in the field and **reasons why the root of solid wood has been taken through LCA** (see 5.2) comparison, modelled for the Czech Republic's environment on the example of one of the prototypes.

The methodology chapter (see 6) introduces approaches and/or development in all the methodologies involved. This covers Systems Oriented Design, Research by Design through full scale prototyping, as well as transdisciplinary cooperation in the project. The last subchapter called 'Systemic Approach to Architectural Performance: The Media Mix in Creative Design Process' (see 6.4) discusses and introduces visions for merging digital design tools with prototyping, while handling different interrelated large amount of data as a designer in relation to GIGA-mapping for *'co-design'* (Sanders & Stappers, 2008; Szebeko & Tan, 2010) and *'Time Based Design'* (Sevaldson, 2004, 2017b). The research also covers the full scale prototypes observations that are also discussed in this chapter.

The chapter on material (see 7) covers the study of forests of the placement of the research for selecting species related to closer observation of the material and its environmental interactions, including the concept of weathering (Kudless, 2009; Mostafavi & Leatherbarrow, 1993).

The prototyping chapter (see 8), following the speculations discussion and introduction, explains each prototype subproject in detail. This is divided not chronologically but by the two main projects subchapters Environmental Summer Pavilions and Ray. All of these prototypes are interlinked, one informing the other.

The thesis discusses the **research's application** (see 9), taking its role in biotic, as well as abiotic environmental perspective in reference to climatic change in the targeted location. It places the research case study into the context of larger range of different options of exterior-interior boundary conditions that I have experienced in my practice or earlier in my studies, arguing for relevance of this application in practice that is exemplified on Responsive Transformer project. Some of the elaborated topics here are already proposing new explorations rather than fully closing the discussion.

The closing chapter (see 10) offers the summary of acquisitions in methodology, material research, and architectural and urban design and envisions its interpretation into outcomes in architectural and urban design practice and research.

This is an article-based thesis that covers edited, published or submitted articles in a role of addendum glued together with exegesis that is richly referenced in my other articles that were not selected for full text. The selection of full articles was adapted to the suitability to different chapters of the thesis, such as methodology and specific projects' developments and explanations.

3.3.1 The articles cover

3.3.1.1 Articles on method of selection of the used material and methodology

Davidová, M., & Kočí, V. (2016). Choosing the Material for Environment Responsive Screen Ray: The LCA Comparison. In N. Guimaraes, A. Paio, S. Oliveira, F. C. Osorio, & M. J. Oliveira (Eds.), *Architecture In-Play 2016* (pp. 78–84). Lisbon: ISCTE - University Institute of Lisbon.

Davidová, M. (2014b). Generating the Design Process with GIGA-map: The Development of the Loop Pavilion. In B. Sevaldson & P. Jones (Eds.), Relating Systems Thinking and Design 2014 Symposium Proceedings (pp. 1–11). Oslo: AHO.

Davidová, M., & Sevaldson, B. (2016a). 1:1, A Transdisciplinary Prototyping Studio. In J. Slyk & L. Bazerra (Eds.), ASK.the.Conference 2016 (pp. 302–308). Warszaw: Warszaw University of Technology, Faculty

of Architecture.

Davidová, M., & Sevaldson, B. (2016b). NGO, Practice and University Driven Research By Design on Performative Wood. In M. S. Uddin & M. Sahin (Eds.), 2016 DCA European Conference: Iclusiveness in Design (pp. 509–517). Istanbul: Özyeğin University.

And recent article for FORMakademisk's systemic design III special issue: Davidová, M (2016). Systemic Approach to Architectural Performance: The Media Mix in Creative Design Process that is in reviewing process.

3.3.1.2 Papers on separate subprojects' prototypes

Davidová, M., Šichman, M., & Gsandtner, M. (2013). Material Performance of Solid Wood : Paresite , The Environmental Summer Pavilion. In E. M. Thompson (Ed.), Fusion – Proceedings of the 32nd eCAADe Conference – Volume 2 (Vol. 2, pp. 139–144). Newcastle upon Tyne: Department of Architecture and Built Environment, Faculty of Engineering and Environment, Newcastle upon Tyne.

Davidová, M., & Prokop, Š. (2016). Advances in Material Performance of Solid Wood: Loop, the Environmental Summer Pavilion II. In M. S. Uddin & M. Sahin (Eds.), 2016 DCA European Conferencen: Iclusiveness in Design (pp. 501–507). Istanbul: Özyeğin University.

Davidová, M. (2016b). Ray 3: The Performative Envelope. In M. S. Uddin & M. Sahin (Eds.), 2016 DCA European Conference (pp. 519-525). Istanbul: Özyeğin University.

3.3.1.3 Papers discussing the research's application

Davidová, M. (2016). Socio-Environmental Relations of Non-Discrete Spaces and Architectures: Systemic Approach to Performative Wood. In P. Jones & B. Sevaldson (Eds.), *Relating Systems Thinking and Design 2016 Symposium Proceedings* (pp. 1–17). Toronto: Systemic Design Research Network.

Davidová, M., Zatloukal, J., & Zímová, K. (2017). Responsive Transformer: The Bio-Robotic Adaptive Architecture. In F. Mahbub, S. Uddin, & M. A. Khan (Eds.), International Design Conference: DESIGN EVOLUTION [Education and Practice] (p. 1-8). Karachi: Indus Valley School of Art and Architecture.

3.3.2 The referenced articles within the field mainly cover

Davidová, M. (2009). Exploring Environmental Dimensions : On Sustainability as an Architectural Problem ; Why It Is Not Enough To Discuss Space and Time Only. In Nordes 2009 – Engaging Artifacts (pp. 1–4). Oslo: Oslo School of Architecture and Design.

Davidová, M. (2013). Ray 2 The Material Performance of a Solid Wood Based Screen. In E. Thompson (Ed.), Fusion – Proceedings of the 32nd eCAADe Conference – Volume 2 (Vol. 2, pp. 153–158). Newcastle upon Tyne: Faculty of Engineering and Environment, Newcastle upon Tyne.

Davidová, M. (2014a). Environmental Material Performance of Solid Wood: pareSITE: The Environmental Summer Pavilion. In R. Cielatkowska & D. Jankowska (Eds.), Wooden architecture, tradition, heritage, present, future – Proceedings1 (pp. 87 – 92). Gdansk: Wydział Architektury Politechniki Gdańskiej za zgodą Dziekana.

Davidová, M. (2014c). Wood's Material Performance: Ray 2. In R. Cielatkowska & D. Jankowska (Eds.), In Wooden architecture, tradition, heritage, present, future – Proceedings1 (pp. 93–99). Gdansk: Wydział Architektury Politechniki Gdańskiej za zgodą Dziekana.

These were not included as full papers in the thesis for the reason of not complying with the logic of the structure: a) **background and position of the research** (see chapters 4 and 5); b) **methodology and its development** (see chapter 6); c) **material in relation to environment** (see chapter 7); d) **prototypes** (see chapter 8); e) **application discussion** (see chapter 9); f) **summary, discussion and conclusions** of the thesis (see chapter 10); g) **my bio and references** (see 11 and 12).

4 Placement of My Research in Reference to Performance Oriented Design and Systems Oriented Design

This research is a case study in a broad area of **Performance Oriented Architecture** (Hensel, 2010b, 2011a, 2012f, 2013), as a subfield of **Performance Oriented Design** (Hensel, 2015c) ratified and commenced in 2008 (Hensel & Sunguroğlu Hensel, 2013), focusing mainly on material-climatic-biotic performance and its sustainable application in architectural and urban design practice in the researched location. Though the history has a larger background (Hensel, 2013), the shift to performance in architecture in the context discussed in this thesis explicitly appeared in 2001, when Stan Allen reformulated the question of what is architecture to what architecture can actually do (S. Allen, 2011). This work is approached as a ***'figuration of fields of relationships'*** (Hensel & Menges, 2009). Therefore Systems Oriented Design, a ***'designerly way to work with systems'*** (Sevaldson, 2013b) and ***'Research by Design through full-scale prototyping'*** (Davidová & Sevaldson, 2016a; Hensel, 2013; Sheil, 2008) and **prototypes observations** appeared to be the most suitable methodologies for such. To reach these processes that are generating research through collaborative transdisciplinary projective practice, the project had to glue Academy, Practice and NGO in cooperation with industry through Research by Design (Davidová & Sevaldson, 2016b). The research also covered hard data measurements of micro-climatic conditions in relation to moisture content of the wood and its placement, but this data is not elaborated in detail within the thesis because it is not its focus. It only served as a generative input for the design development. The thesis is focused on practise and therefore covers a **wide and rich spectre of issues** while aiming towards **durable application and sustainability in many interpretations**. This mission is theoretically supported i.e. by paper: Sustainability from a Performance-Oriented Architecture Perspective – Alternative Approaches to Questions regarding the Sustainability of the Built Environment[24], proposing **holistic systems approach** (Hensel, 2012f).

The notion of **performance in architecture** was reformulated by Hensel as a ***'reconsolidation of form and function into synergy of dynamics of natural, cultural and social environments'*** (Hensel, 2010b). In 2013, the topic of Computation and Performance was assigned to the eCAADe conference, naming '*functional facilitation of its occupants' activities, aesthetics, economy, provision of thermal, light and acoustics comfort, sustainability with respect to material, energy and other resources, and so forth as a focus'* (Stouffs & Sariyildiz, 2013). Generally, performance is often related to computation, which could be seen by the fact that it became a topic of the conference related to computer-aided architectural design, but also it is clearly stated in the editors introduction in the Performalism publication (Grobman & Neuman, 2012). Though the research often touched on this field, it was not really its focus area. Unfortunately, we often encountered its limitations, especially when it came to simulations of single or interrelated complexity such as fluid dynamics, structural capacities or generally transdisciplinary relations, without even mentioning the relations of tacit knowledge. More than this, samples and full scale prototypes and architectures in relation to environmental observations and GIGA-mapping were

[24] 'This article introduces and discusses a series of alternative and interrelated concepts and approaches regarding questions of the sustainability of the built environment and architectural design. The need for this discussion arises from the realization that the majority of current approaches to questions of sustainability in architectural design tend to considerably stifle complexity in approach, problem analysis and definition. This development is characterized by isolated and partial aspects of environmental problems, instead of a more holistic systems approach, often present in the approaches of other disciplines or interdisciplinary efforts. The shortage of alternative approaches in architectural design requires a critical rethinking of the question of sustainability of the built environment and its relation to other domains in and outside the anthroposphere. To address this problem is the goal of this article. In doing so, it introduces and discusses concepts and approaches that are rooted in a systems approach and aims for more complex problem definitions, while taking longer-term perspectives into consideration. This is done from a performance-oriented architecture perspective, which operates on the dynamic interactions between local ecosystems (including humans), environment and the spatial? material organization complex of architecture.' (Hensel, 2012g)

largely employed.

Commonly, the **architectural performance** is being referred to in many different meanings in relation to interaction with environment, but mainly as structural optimisation in relation to gravity, natural ventilation or **material performance** (Davidová, 2014f). Starting from the point of the last one named in the meaning of biological material *'active agency'* (Hensel, 2009, 2012e), the project soon employed phenomenological and social observations of the performance. Such interaction of material and human aspects is mentioned, i.e., in article Material Performance already in 2009 in relation to culture (Hensel, Sunguroğlu, & Menges, 2008). While largely focused on human interaction, the project is really not anthropocentric and is creating a suitable **co-living environment** for many species through its **biotic and abiotic interactions**. Its first focus is given to interaction of wood and micro-climate. Also, namely algae or birds were considered and in the same time the prototypes were inhabited by them at their own will (see Figure 2, Figure 12, Figure 46, Figure 49, Figure 50, Figure 57, Figure 65 and Figure 66). Also, the natural biodiversity of forests in the researched area for the material used and therefore the impact on forestry was elaborated (see subchapter Ecology of Forests and Trees in Central Bohemia in Relation to Material). In this sense, the thesis is fusing the key concepts of Performance Oriented Architecture, ***'non-discrete'*** architectures and ***'non-anthropocentric'*** architectures, defined by Hensel (Hensel, 2015c) and believed to represent its **integrated approach** (Hensel, 2013). Taking one more argument ahead, this design-research claims to be **eco-systemic** in all its meanings, the performance and methodology in the same time as fusion of these. This **fusion** I decided to name **Systemic Approach to Architectural Performance**.

Figure 2: Our Everyday Mate at the EnviroCity Festival Sitting on the Loop Pavilion Became a Symbol for the Festival's Events Announcements Graphics (photo and graphic design: Škuta 2014)

This project fused **full-scale prototyping** with the **Systems Oriented Design** introduced by Sevaldson in 2005 (Sevaldson & Ryan, 2014), both as a research tool to complexity that is involved in the project. A central tool to Systems Oriented Design is ***'GIGA-mapping'***, a super extensive visual mapping of transdisciplinary relations. The GIGA-mapping involves relations of soft and hard data (Sevaldson, 2015) and was generated in the context of performative physicality in transdisciplinary and trans-organisational

'Rich Design Research Space'[25] (Sevaldson, 2008, 2012c). As the methodology is mainly used in *'Service Design'*[26] field (Sevaldson, 2017), my project developed its own tools for GIGA-mapping (Bjørndal Skjelten, 2014; Davidová, 2014c; Hensel, 2013; Hensel & Sørensen, 2014; Romm, Paulsen, & Sevaldson, 2014; Sevaldson, 2011, 2012a, 2013c, 2015; Singh, 2013) related to the project's conditions and agenda. This involves use of a) images for employing parametric models, samples, prototypes, architectures and tacit knowledge through photography, b) its own libraries that also use degrees of curvature and gradient placements, c) matrixes and feedback loops. The GIGA-maps are thematic – one zooming into problem of the other, thus developing extended ***'ZIP-analyses'*** proposed by Sevaldson (Bjørndal Skjelten, 2014; Sevaldson, 2016e).

GIGA-mapping in this field of research requires much more exploration and naturally not even in this thesis were all discussed themes mapped. The fact that the methodology is fully relevant and enriching to the field of Performance Oriented Design was something I realized during work on my master's course and diploma thesis (Davidová, 2007, 2009) at the Oslo School of Architecture and Design supervised by Birger Sevaldson and Per Kartvedt in 2006 and 2007. Hensel and Sørensen also argue for the benefit of Systems Oriented Design in Performance Oriented Architecture (Hensel, 2012f, 2013; Hensel & Sørensen, 2014). It proved to be a data organizer and thus an evaluation and design generator, discussion board as well as a presentation tool during the overall process. This provides ***'rapid learning process'*** (Sevaldson, 2013a) over the board, that gained its special meaning when it came to communication within the transdisciplinary teams as referred to by Sevaldson as a tool for collaboration (Sevaldson, 2011). I explored this concept within the very tight schedule of public furniture for communities prototyping workshop called *'Mood for Wood'* (Polish Architectural Association in Poznan, 2015a, 2015b) lectured by me and Šimon Prokop as Czech representatives within Visegrad countries, which involved both social and fabrication perspectives (see Figure 100).

This research demonstrated that GIGA-maps can also serve as a presentation tool, which had been previously questioned. Our GIGA-maps developed in the course *'Environmental Summer Pavilion II'* (Davidová, 2014c; Sevaldson, 2016c; Slavíčková, 2014) were publicly exhibited at the students' competition and exhibition *'Ještěd F Kleci'* (x-fatul, 2016) and next to the pavilion at the *'EnviroCity'* Festival (Davidová & Kernová, 2016; Kernová, 2014) at the Cargo Railway Station Žižkov, showing the complexity of the design research process leading to a full scale prototype. Especially in relation to the physical pavilion prototype, the GIGA-map attracted an audience who became interested in the background of the project. Thanks to that, broader co-design within the project took place. This supports the need for the **connection of GIGA-mapping and prototyping within one *'Rich Design Research Space'*** (Sevaldson, 2008, 2012c, 2017b) **as a designed ever-evolving result of itself**, discussed in the concluding paper of the methodology chapter (see Systemic Approach to Architectural Performance: The Media Mix in Creative Design Process (6.4) subchapter).

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[25] 'The Rich Design Research Space is an inclusive methodological framework and scaffold for research-by-design. The Rich Design Research Space especially addresses the issue of richness in design processes and design-led research.' (Sevaldson, 2012c)

[26] 'Service design as a practice generally results in the design of systems and processes aimed at providing a holistic service to the user. This cross-disciplinary practice combines numerous skills in design, management and process engineering. Services have existed and have been organised in various forms since time immemorial. However, consciously designed services that incorporate new business models are empathetic to user needs and attempt to create new socio-economic value in society. Service design is essential in a knowledge driven economy.' (Copenhagen Institute of Interaction Design, 2008; Stickdorn & Schneider, 2011)

5 Placement of My Research into State of Art in Reference to Material, Types of Prototypes and Location

This chapter covers the **key concepts** within the state of art in the fields of this thesis, and positions my own research within the field. It also describes the selection of the material through **Life Cycle Assessment** (LCA)[27] **comparison** of solid wood and plywood applied on my prototype Ray 2 for the **location of Czechia**. The selection of discussed projects is covering prototypes that have substantive contributions in the **responsive wood** field in the context of material research or the type of prototype application in relation to the environment or both.

The contemporary research on **performative/responsive wood** is mainly spearheaded by Michael Hensel and Defne Sunguroglu Hensel at the Research Centre for Architecture and Tectonics (Hensel, 2012a; Hensel & Sørensen, 2016) Oslo School of Architecture and Design (Oslo School of Architecture and Design, 2016) and by Achim Menges, Steffen Reichert, Dylan Woods and others at ICD University of Stuttgart (Menges, 2013).

The field generally suffers from a lack of enough clear or deep information that has been published. While many examples can be found, explanation and/or significance towards the material research, dates and contributions of diverse people and institutions involved are published insufficiently. In some cases, the memory of the authors, audience or even personal observations had to be used.

[27] LCA is a complex evaluation of environmental impact of a product throughout its life cycle – from seeding a tree, through the pollution produced by its harvest, material processing, product application, its recycling and so on.

5.1 Key Designs – State of Art

The background of the research is in Nordic panelling based on solid wood warping. Though some spoken knowledge exists mainly through its users, there is neither sufficient literature, nor research in the field. After the alienation from the traditions, an architectural research appeared on similar performance on laminated veneers. This research, though crucial to the field of performance, was not possible to apply in architectural practice due to its fragility. Therefore, this research led to experiments on ply-wood that even offered possibilities in fibre orientation for generation of double curved samples. Recently, also a comeback to exploration of solid wood performance has been taking place.

5.1.1 Traditional Norwegian Panelling

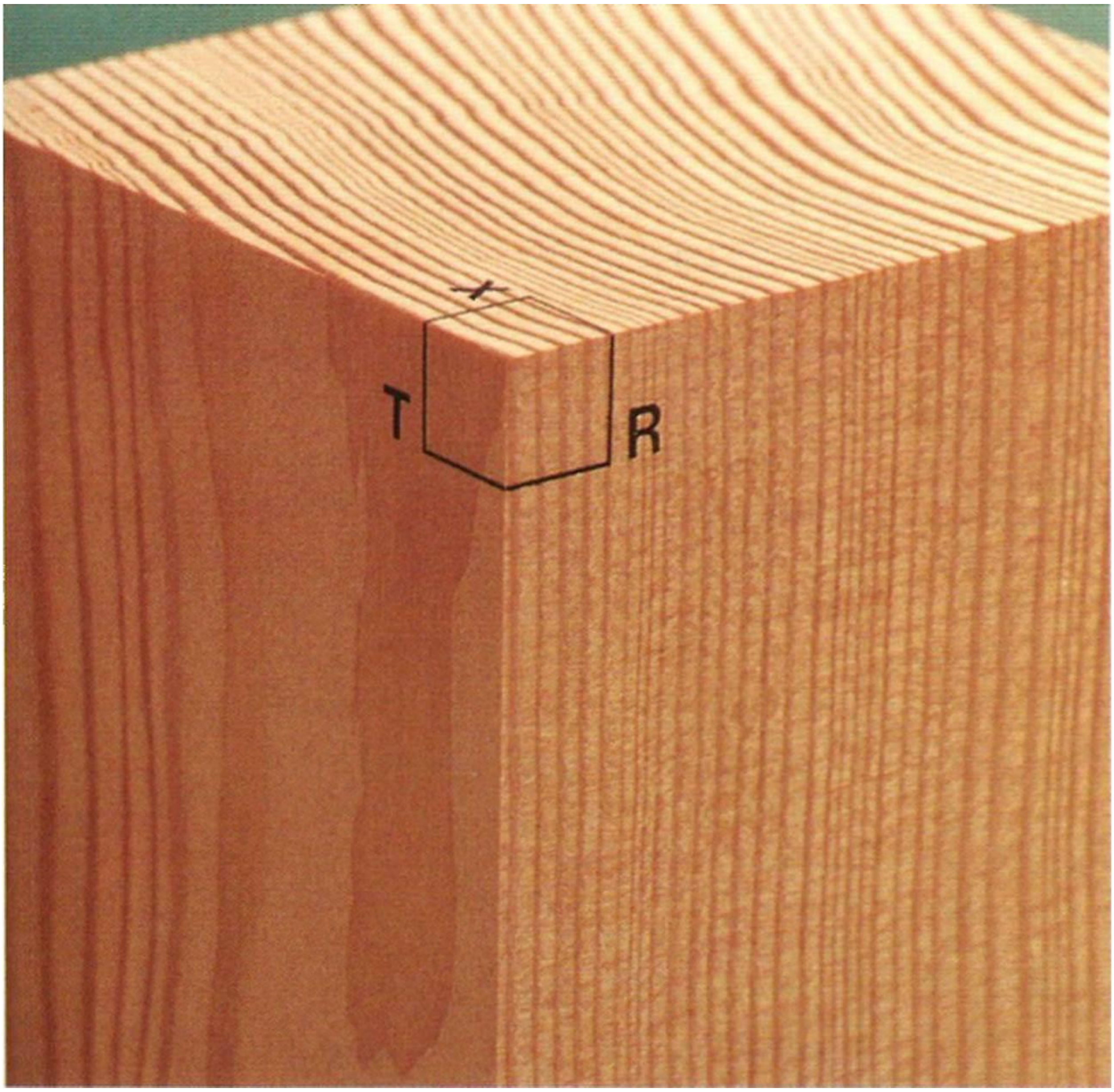

Figure 3: 'This block of Douglas-fir was cut to show three planes: the transverse or cross-sectional surface (X), the radial surface (R), and the tangential surface (T)' (photo by Randy O'Rourke from Hoadley, 1980 with the courtesy of Taunton Press)

A natural property of wood is warping. When the material is cut in tangential section (see Figure 3) it generates so-called 'cup' across the grain (Knight, 1961).

Humidity-responsive panelling systems based on the tangential section were used in traditional

Norwegian architecture with long boards nailed one on the top of another in one orientation and were compared to today's common solution by Larsen and Marstein in Figure 4:

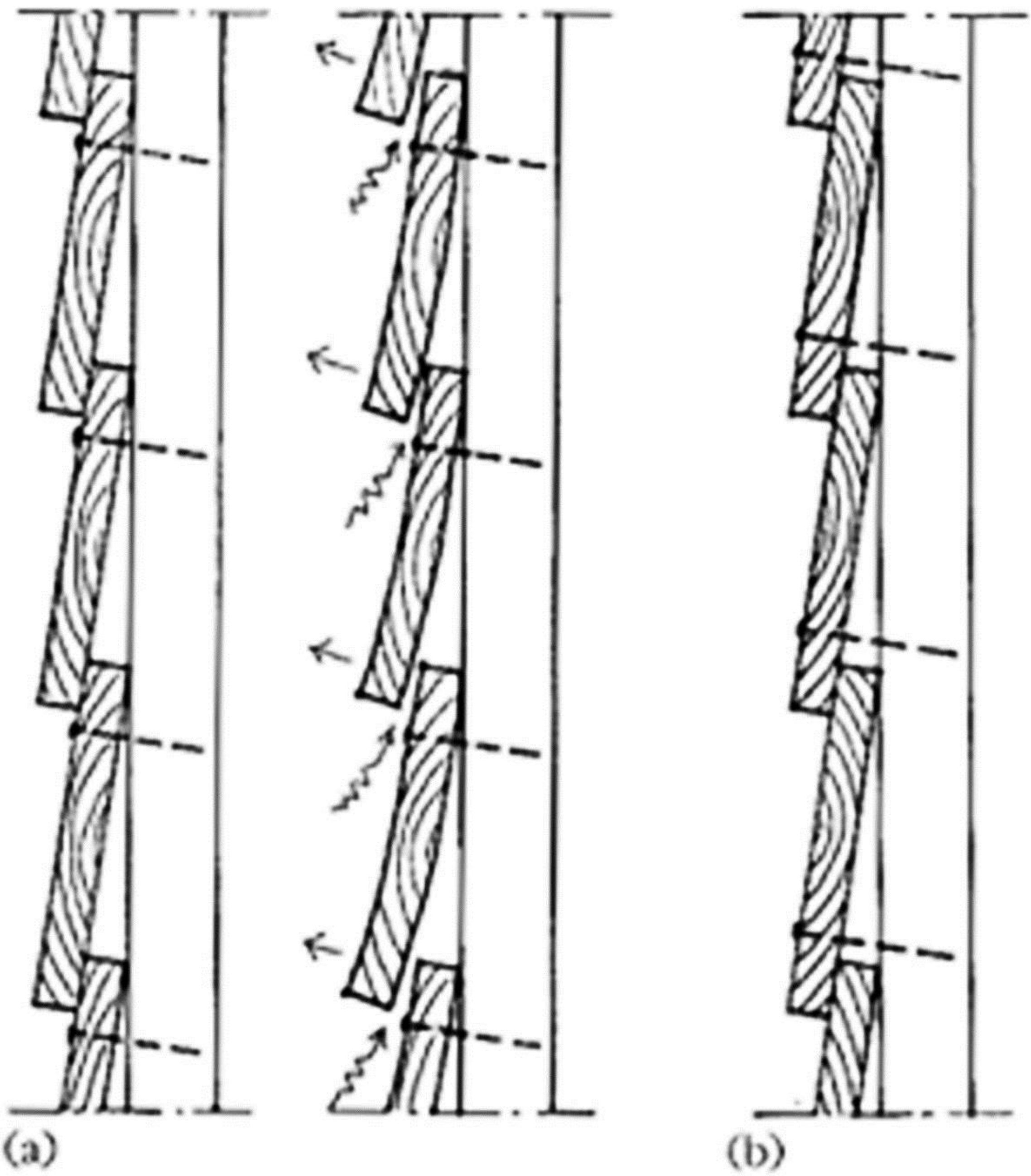

Figure 4: '(a) Traditional wooden panelling in boathouses, Nordmøre, Norway. The boards are nailed towards the upper edge, just below the joint where they overlap. In dry weather, the lower board ends bend outwards, allowing dry air into construction. In wet weather the boards close again. (b) Modern wooden panelling, Norway. The boards are nailed at the lower end. This ensures weather-tight panelling in all conditions.'
(from Larsen & Marstein, 2000 with the courtesy of Larsen)

Unfortunately, there is not any further literature or knowledge possessed by the staff of the outdoor museums in Norway on this topic to be found. From my observations, this panelling was also used in many variations on the cladding of the buildings with different use and as screens on its semi-interior spaces 'svalgangs', discussed in the conclusion of the thesis on the west coast of Norway that is known for an oceanic climate with high humidity and rain (see Figure 5). It is important to note that some of the panelling I saw was implemented in opposite performance. The traditional structures are making airing gaps in the terms of millimetres. From my observations, the triangular shape warps almost twice as much as the rectangular one. In long boards there is even more of a difference.

Figure 5: Panelling of Storehouse from Nes, Øvre Valdsaroy in the Open-Air Museum in Oslo
(photo: Davidová 2016)

5.1.2 Morpho-Ecologies Project at AA School of Architecture

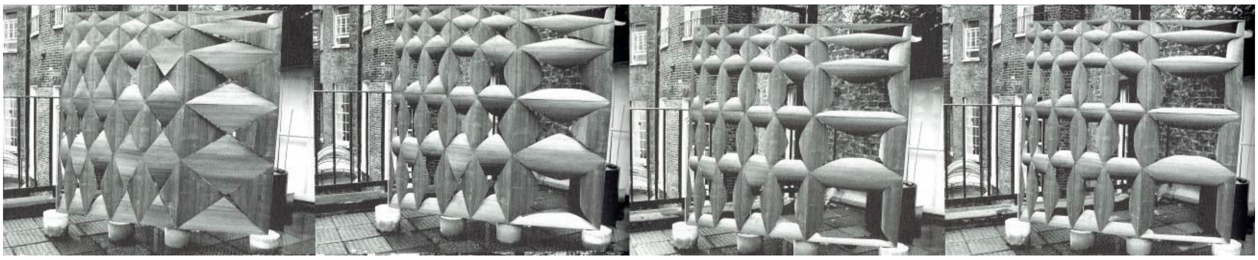

Figure 6: Study of Asif Amir Khan (from M Hensel & Menges, 2006; with the courtesy of Hensel)

The first current example illustrating pine wood-humidity interaction is the study from 2004-05 by Asif Amir Khan (see Figure 6) in the studio of Michael Hensel and Achim Menges at the AA School of Architecture that provides more extreme performance organisation system towards openness and closeness, while also showing a relation of scale/size in two directions (M Hensel & Menges, 2006).

This project is not only mapping the materialbut also the design in the means of size of the sheets/cells in relation to performance. According to the confirmation of the audience's observations when exposed in public space at Bedford Square, this prototype was based on laminated veneer, which showed great performance but seemed to be very fragile for any application. However, it possesses great significance as a first basic research prototype in this field.

Within this studio other responsive wood projects had also been conducted, such as Aleksandra Jaeschke's Continuous Laminae project (2004-05), using hygroscopicity for creation of building elements, where a speculation on salt in relation to wood's conservation that has been developed in this project is mentioned (Jaeschke, 2006) and Joseph Kellner's and Dave Newton's project Metapatch (2004), related to plywood elements responsive screen through bending by force (Kellner & Newton, 2006). Though crucial and inspirational in the field, these projects are not elaborated in detail, for they don't directly relate to discussed performance.

5.1.3 Warped

Figure 7: Warped Project (from Khan, 2011 with the courtesy of Hume)

In 2008 Matthew Hume at the Centre for Architecture and Situated Technologies Department of Architecture, University at Buffalo in New York developed a humidity responsive screen based on plywood with a grain running in different directions, generating surface to curl (Khan, 2011) (see Figure 7). The overall research design process is presented in Hume's thesis, where he clearly states in the conclusion that the full programmability of the behaviour was not in focus(Hume, 2008). The screen was not designed for any specific use but to demonstrate the capacity of the composite material. To my knowledge, it is the first prototype using this type of performance of plywood. Thus, as the keystone basic research prototype, also in reference to durability, it is of high significance.

5.1.4 Responsive Wood Architectures Studio

Figure 8: Haugen's Double Curved Plywood (from Michael Hensel & Sørensen, 2016 with the courtesy of Hensel)

The Responsive Wood studio was held by Michael Hensel and Defne Sunguroğlu Hensel at the Oslo School of Architecture and Design in the year 2008. Within the course in 2009, the student Linn Tale Haugen experimented with odd numbers of layers to control the warping and directions of the fibre in the laminate to reach double curvature. (Hensel, 2010c, 2011a)

Haugen took her project into diploma thesis in 2010 and also explored the performative plywood production process. She used two layers of beech veneer in the tangential direction for shrinkage and one in the opposite direction either from oak, which has lower tangential shrinkage, or beech veneer treated from the bottom side. With this composition, she managed to operate the bending of the composite (Haugen, 2010) (see Figure 8).

The thesis seems to be very substantial when it comes to composite material research that, thus far, has not been elaborated so explicitly in any available material and the resulting material system seems to be very durable. But her proposed projects are limited to the application within the field of product design. The potential of applications when it comes to performance within the field of architecture is not explored as she points out in the thesis. The application of this on moulds suggested by Hensel seems to be an interesting topic to explore (Hensel, 2011a). It seems to me this would have to be performed in the first steps in climatic chambers and the relation of filling material interaction would have to be studied; in the second step it would be very interesting to see all three: a) the climatic conditions, b) the mould material, c) the filling material, in symbiosis.

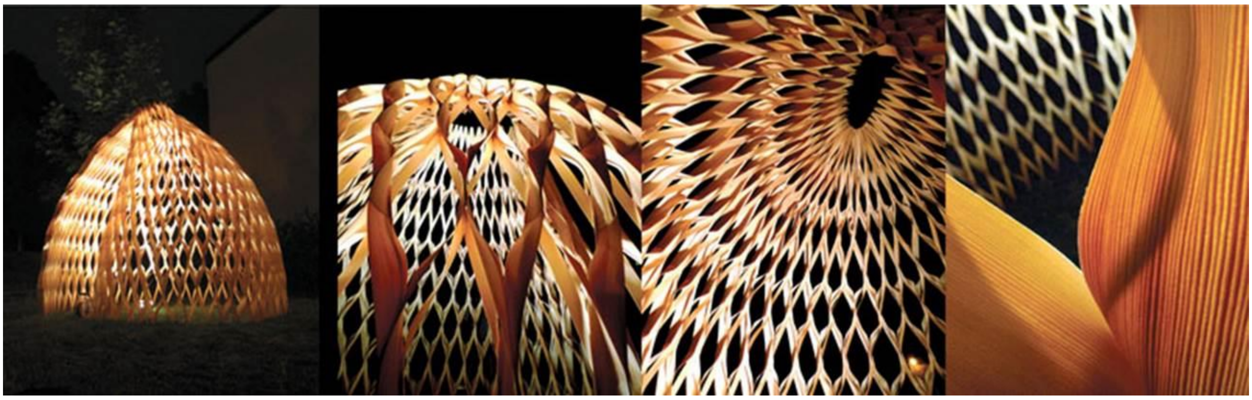

Figure 9: Wing Yi Hui and Lap Ming Wong: Completed Pavilion for the Oslo Architectural Triennial 2010 (from Michael Hensel, 2010b; with the courtesy of Hensel)

In 2010, structural capacities of moist wood were explored in the same studio. The outstanding example was Wing Yi Hui and Lap Ming Wong's full-scale construction of a small pavilion for the Oslo Architectural Triennial in 2010 (see Figure 9), which demonstrated exploration of the use of moisture content for structure made of bent 0.75 mm veneers. (Hensel, 2010c)

The pavilion exhibited basic research in structural capacity of moist wood and it is a crucial prototype amongst curved light weight structures in relation to moisture content. It seems to me from my personal experience, that the 0.75 mm thin pine veneer would be too fragile for long-lasting structural application, but this requires more exploration. Our pavilion pareSITE, discussed later, used similar performance for locking torqued solid wood planks in a triangular structure. At some places the stresses were too high and also the use of screws joinery is not ideal for use on green wood (Dinwoodie, 2000). We experienced problems in the most stressed cells after a year of exposure to climatic conditions, some of them caused already through the winter. Also the assembly of torgued planks into triangles required a great amount of human physical force. I believe this area requires separate research towards this performance application.

5.1.5 Responsive Surface Structure

In 2006 Steffen Reichert started to work on his Responsive Surface Structure project under the Department for Form Generation and Materialisation (Achim Menges), Hochschule für Gestaltung (HfG), Offenbach, Germany (Hensel et al., 2008). Since then he has been continuing his research under the leadership of Achim Menges at the Institute of Computational Design at the University of Stuttgart.

As published in 2012, he managed to program different behaviour of veneer composites in relation to humidity by lamination. (Menges & Reichert, 2012) In my observations, such behaviour can also be programmed by the wood moisture content when solid wood is cut. The Responsive Surface Structure is basic research which is not yet addressing rain resistance and industrial solutions for which, based on my observation, the suggested systems are far too fragile. But the programmability, which has not been fully explained, seems to be crucial in the field. The project is still being developed and has resulted in several installations such as the Hygroscope – Meteosenzitive Morphology pavilion (see Figure 10) discussed below, and Hygroskin Pavilion in 2013. The planned research on solid wood has not been published yet.

Figure 10: Achim Menges with Steffen Reichert: HygroScope – Meteorosensitive Morphology, Centre Pompidou, Paris, 2012 (from Menges, 2012; with the courtesy of Menges)

In 2012 Achim Menges and Steffen Reichert built the humidity-responsive 'Meteorosensitive Morphology' pavilion at Centre Pompidou, Paris (see Figure 10), which seems to be the first public humidity responsive pavilion employing wood warping in interaction with environment. However, it appears to be a basic research exhibiting pavilion, while not involving performance purpose or any human behavioural aspect, though it seems it had been inhabited anyway. It is also unclear if it worked as a prototype for its performance observations in relation to the environmental complexity of the location.

5.1.6 Microloop Panels

Mark Weston and Dan Greenberg developed composite plywood Microloop panels (see Figure 11) that serve as a passive lighting control where the movement of two sheets is causing the attachments to bend. (Weston & Greenberg, 2013)

The authors claim the performance variation (Weston & Greenberg, 2013), however it is not clear how the lighting control relates to relative humidity of the air. It could be that the relative humidity is high when it's cloudy, so the sun radiation does not require shading while the wood composite reacts to it. In the end the authors discuss the performance in all the situations arguing for allowance of fight penetration and diffused daylight while blocking direct sunlight. (Weston & Greenberg, 2013). It is therefore not clear how the material performance is used in another way than for aesthetic reasons. Furthermore, it is not clear in which circumstances the situation with the screen closure is at all wanted.

The authors state that the Microloop panels are produced in enough thickness for industrial production (Weston & Greenberg, 2013). This seems to be a step forward within the development for application.

Figure 11: Microloop Panel (from Weston & Greenberg, 2013 with the courtesy of Mark Weston)

5.1.7 Ray 2

Produced in summer 2013 according to my design, to my knowledge, Ray 2 (see Figure 12 and Figure 13) is the first responsive prototype made of solid wood. It is the first prototype of project Ray, whose first concept was not physically prototyped, just digitally simulated.

Ray 2 is an environmentally-responsive screen made of solid wood. Through its 0.8 cm thick pinewood panels cut in the tangential section's material properties, combining the left and right side of the panels, the screen is airing in dry and closing in humid weather (Davidová, 2014e). The system is generating airing gaps in terms up to 16 centimetres in distance in 10%RH and 21°C. The use of solid wood is one step more durable and/or sustainable in comparison to other prototypes in the field (see LCA Analysis Comparing Solid Wood and Laminates subchapter that is reasoning it). Though in the case of sudden rain, it does not immediately react to the increased humidity level, it immediately resists direct rain thanks to overlapping of its panels.

The system was first simulated in Grasshopper for Rhino 5 based on the data from measured samples. Afterwards, a 163 x 163 cm prototype was produced from 16 rectangular pieces.

The prototype performed in a similar way as the initial simulation. The upper triangles warp outwards and the lower triangles inwards thus generating large gaps within the system. In wet conditions the structure closes again. The prototype required further tuning as the system closes only in wet conditions and not in the case when the relative humidity is high. It is for that reason that the prototype was built from green wood.

For more information, go to the Ray 2: The Performative Screen section (8.2.1).

Figure 12: Ray 2 Prototype after Three Years of Being Exposed to Weather and Biotic Conditions
(photo: Yildirim 2016)

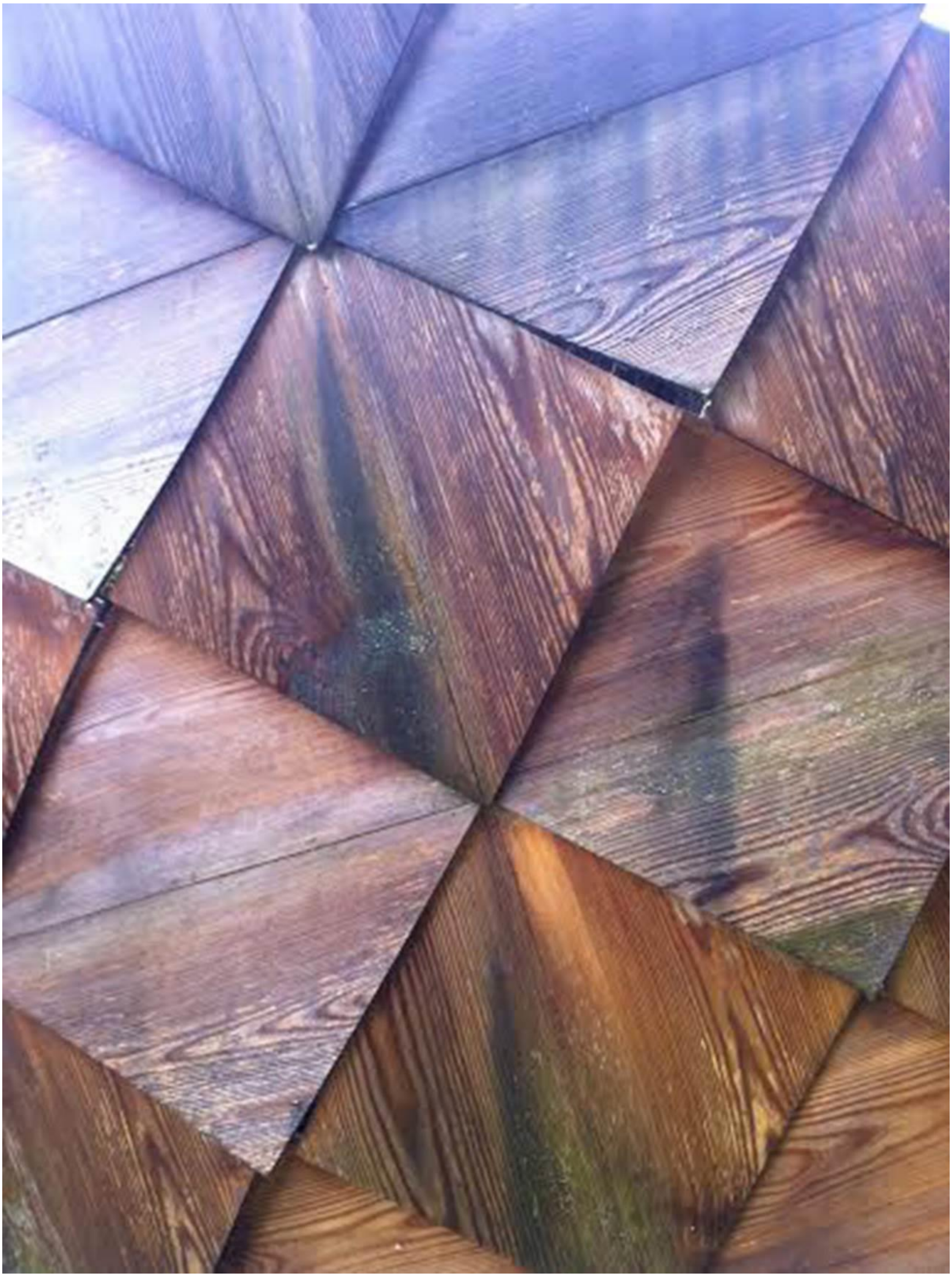

Figure 13: Closure after Artificial Wetting (photo: Yildirim 2016)

5.1.8 PareSITE, the Environmental Summer Pavilion I

This transdisciplinary project involved students from the Architectural Institute in Prague (ARCHIP, 2016) and the students of the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences Prague (FLD CZU – CZU, 2016), tutored by studio course leaders: Marie Davidová – wood, Martin Gsandtner – coding, and Martin Šichman – structure.

PareSITE – The Environmental Summer Pavilion (Nam, 2013) (see Figure 15) designed for the reSITE festival (Barry, 2016) is a möbius shaped structure built from torqued pine wood planks in triangular grid with half cm. thin pine wood triangular sheets that provide shadow and evaporate moisture in dry weather. The solid wood sheets, cut in a tangential section, interact with humidity by warping themselves, allowing air circulation for the evaporation in arid conditions.

Fabricating studios building wooden pavilions already became common when it comes to plywood, i.e., pavilions at Bedford Square by AA School of Architecture in London or at the University of Stuttgart by Institute for Computational Design (Fleischmann, Knippers, Lienhard, Menges, & Schleicher, 2012; Menges, 2012b; Menges & Reichert, 2015; Self & Walker, 2010). This prototyping studio was exploring the performances and structural capacities of the hygroscopicity of solid wood cut in a tangential section. PareSITE, as well as the later mentioned Loop pavilion, was built as a prototype for complex environmental interaction observations, including overall biotic (also social) and physical aspects, as well as a methodology generator.

By being freely inspired by the performance of both, the warping of wood in the tangential section in Norwegian traditional panelling and oriental screens called 'mashrabīyas' (Figure 14), this project aims towards generating a pleasant build up environment as an urban design through the concept of evaporating moisture and thus humidifying the air such as in orient. Today, European cities also suffer from arid conditions during the summer seasons. The principle of wooden 'mashrabīyas' operates on the hygroscopicity of the material and its environmental conditions. At night, when the relative humidity is high, the wood absorbs moisture which is evaporated during the day (Davidová, 2014a). This is also often supported by cans with evaporating water (Fathy, 1986). The performance of these systems were often discussed by Michael Hensel , pointing out their overall complexities such as light passage, airflow, temperature, humidity of air current and visual penetration regulation between interior and exterior (Hensel, 2013).

The project utilized the warping of 5 mm pine wood sheets in the tangential section for supporting circulation of humid air. The form of the pavilion did not allow subdivision into planar surfaces, but anisotropic properties of the material support torsion. The angles of cuts held the boards' torsion together in the joint. 20 x 150 mm planks of green wood were used for the structure. (Davidová, 2014a)

The pavilion generated a pleasant environment for its visitors during the hot days of the festival and resisted wear from public use. But as mentioned above, we experienced troubles in most stressed triangular cells joins after one year of weather exposure.

For more information, go to the pareSITE: The Environmental Summer Pavilion I section (8.1.1).

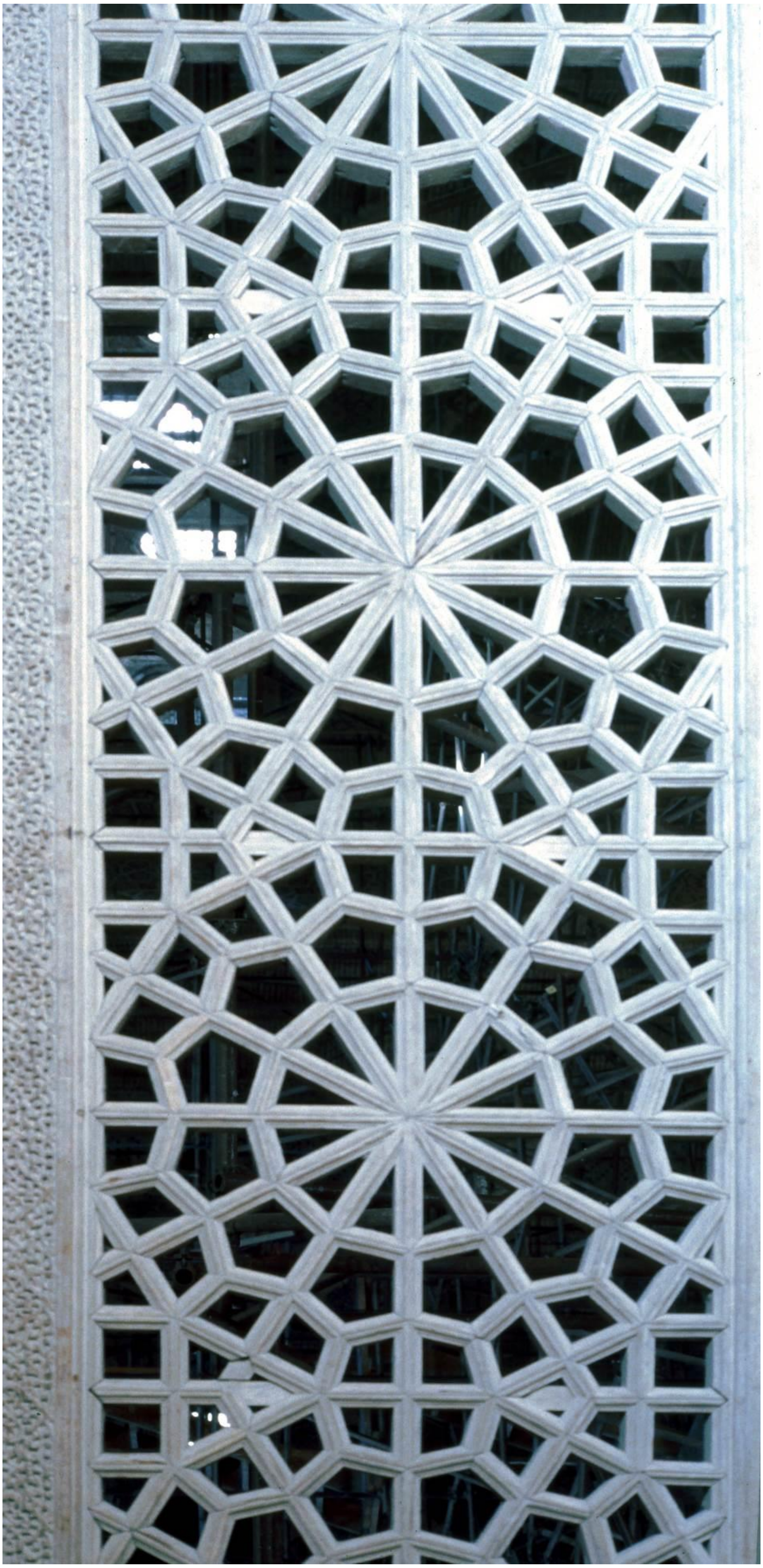

Figure 14: Wooden mashrabīyas at the Mausoleum of Sultan Oljeitu, Sultaniyeh in Iran
(source and with the courtesy of Wade, 2013)

Figure 15: pareSITE (photo: Zapletal 2013)

5.1.9 Loop, the Environmental Summer Pavilion II

Figure 16: Loop (photo: Davidová 2014)

This transdisciplinary project involved students from the Faculty of Art and Architecture at the Technical University of Liberec (FUA TUL, 2016) and the students of the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences Prague (FLD CZU – CZU, 2016). Studio course leaders were Marie Davidová – wood, Šimon Prokop – coding and Martin Kloda – structure.

The Loop pavilion (see Figure 16) follows the concept of the previous pareSITE project (Nam, 2013). This time the performance was increased by its spatial organisation, combination of the left and right side of the panelling and the overall form. The solar analysis affected the size of the sheets in relation to the wood's expansion due to humidity, as the panels were placed inside of the structure. The concept needs further research for extreme weather situations and structural capacities. The prototype became the focus of the EnviroCity Festival, becoming both a discussion generator as well as an observation tool for biotic-climatic environmental interaction.

For more information, go to the Loop: The Environmental Summer Pavilion II section (8.1.2).

5.1.10 Ray 3

Figure 17: Ray 3 Finalized in Carpenter Workshop, Defio, s.r.o. (photo: Kořínek 2016)

Ray 3 (see Figure 17) is my second prototype of project Ray, whereas the first concept was not prototyped. It has proposed answers to the questions of durability of the 0.8 cm thick panelling and joinery and added a thermo-reflexive surface for better comfort of the semi-interior space. Its programmed warping will be observed over time. By now, it seems to be the closest prototype when it comes to application in architecture however, longer observations are necessary.

For more information, go to the Ray 3: The Performative Envelope section (8.2.2).

5.2 LCA Analysis Comparing Solid Wood and Laminates

(Davidová & Kočí, 2016)

The use of solid wood instead of plywood or laminates was coming out of the speculation on better sustainability and a healthier environment. Laminates don't really seem durable for architectural application. At present, for wood warping in plywood, polyurethane glue is necessary. For that reason, the product is unrecyclable and may have a negative effect on the health of the environment. However, as more factors might be involved, I decided to evaluate the environmental impact through Life Cycle Assessment analysis comparison for both solutions on case study of Ray 2 conducted for the environmental conditions of Czechia. This study was elaborated in our paper co-authored with Vladimír Kočí published in the proceedings of Architecture In-Play2016 conference: 'Choosing the Material for Environment Responsive Screen: The LCA Comparison'. It is important to note that the study is site specific, using data for the Czech Republic or European Union when it is generally applicable for the year 2015. This kind of analysis doesn't consider speculations of future development, so the events expected to be applied in the far future are evaluated through present data. Therefore, the comparison serves as an argument for the current state in its location for a specific product, while different directions might be equal or even preferred in the future.

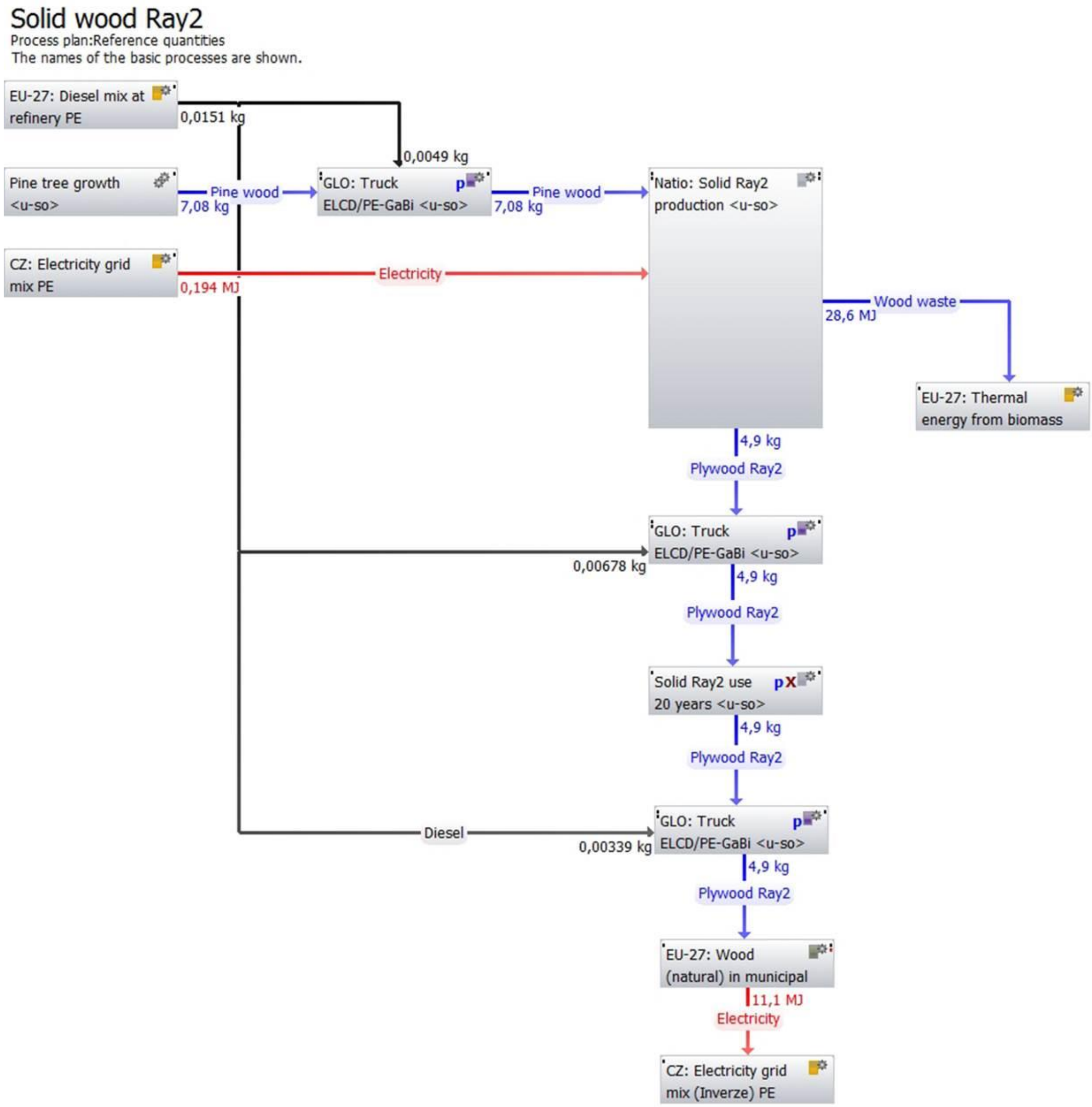

Figure 18: LCA Model for Solid Wood Based Ray 2 Screen Produced in Czech Republic (Kočí 2015)

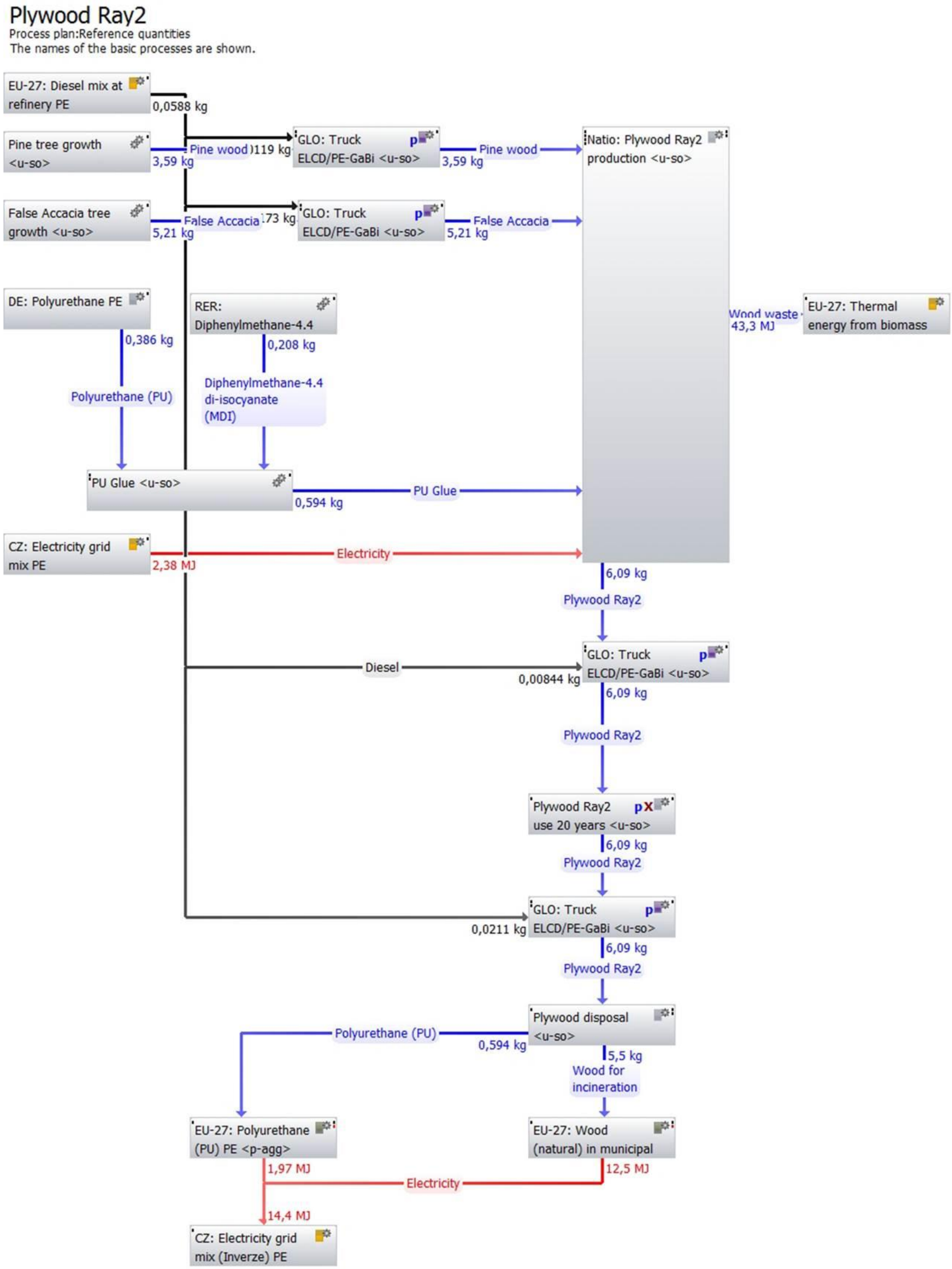

Figure 19: LCA Model for Plywood Based Ray 2 Screen Produced in Czech Republic (Kočí 2015)

5.2.1 Abstract

Wood performs based on its material properties by shrinking, expanding or warping due to the changes in relative humidity and temperature. This property intends to be utilized in architecture for purposes such as ventilation or thermal comfort. This concept was developed in the design of Ray 2, a screen that airs in dry and is resistant in humid weather. Two material options are available. Following contemporary research, plywood could be used in demonstrating the 'bi-metal' principle of different shrinkage of different wood species. In reference to the past, the tangential section applied in traditional Norwegian panelling, where different fibre density on opposite sides of the plate cause warping, was proposed for the prototype. The plywood research shows better programmability. However, our paper claims that the use of solid wood, at least in the Czech context for the particular product of Ray 2, is more sustainable and therefore it is in our best interest to explore past knowledge in the field. The data from the local manufacturers, as well as from the related universities, were utilized to compare both of the cases in LCA analysis (see Figure 18 and Figure 19) among all showing the energy savings and lower carbon emissions for solid wood.

Keywords: performance-oriented architecture; responsive wood; life cycle computer modelling; simulation of production complexity; solid wood versus plywood; sustainability

5.2.2 Introduction

Wood is the main renewable and recyclable building material that has been tested over generations, though administratively rejected due to the fire issues in many countries. Our study compares two ways of its use for design of performative screen Ray 2 that reacts to relative humidity and temperature of the environment. It is worth noting that no analysis is able to predict the future and account for all the circumstances. However, we decided to compare solid wood and plywood material in LCA analysis for this particular design. The screen is designed to be used on buildings and therefore is not a conventional product. This difference for Life Cycle Assessment is explained by Bribián et al., stating that LCA was mainly targeted at other low environmental impact products than buildings. Reasoning the difference in long life span, frequent changes, multiplicity of functions, inclusion of many different components, local production, uniqueness, causing of local impact, integration with infrastructure, unclear system boundaries, etc. (Zabalza Bribián, Aranda Usón, & Scarpellini, 2009). All these facts have to be taken in consideration when discussing our results and utilized data. Our focus was on the comparison of two materials for one product in a certain location over an established period of time. The following summary explains the application for both of them.

5.2.3 State of Art

While the current research in the field has been conducted on laminates or plywood, the traditional architecture was applying solid wood, cut in tangential section, for the performance. Therefore, the paper's research question is which approach is more sustainable for the particular first author's design in certain location.

… [This part is shortened as it is elaborated in depth in Key Designs – State of Art subchapter (5.1)]

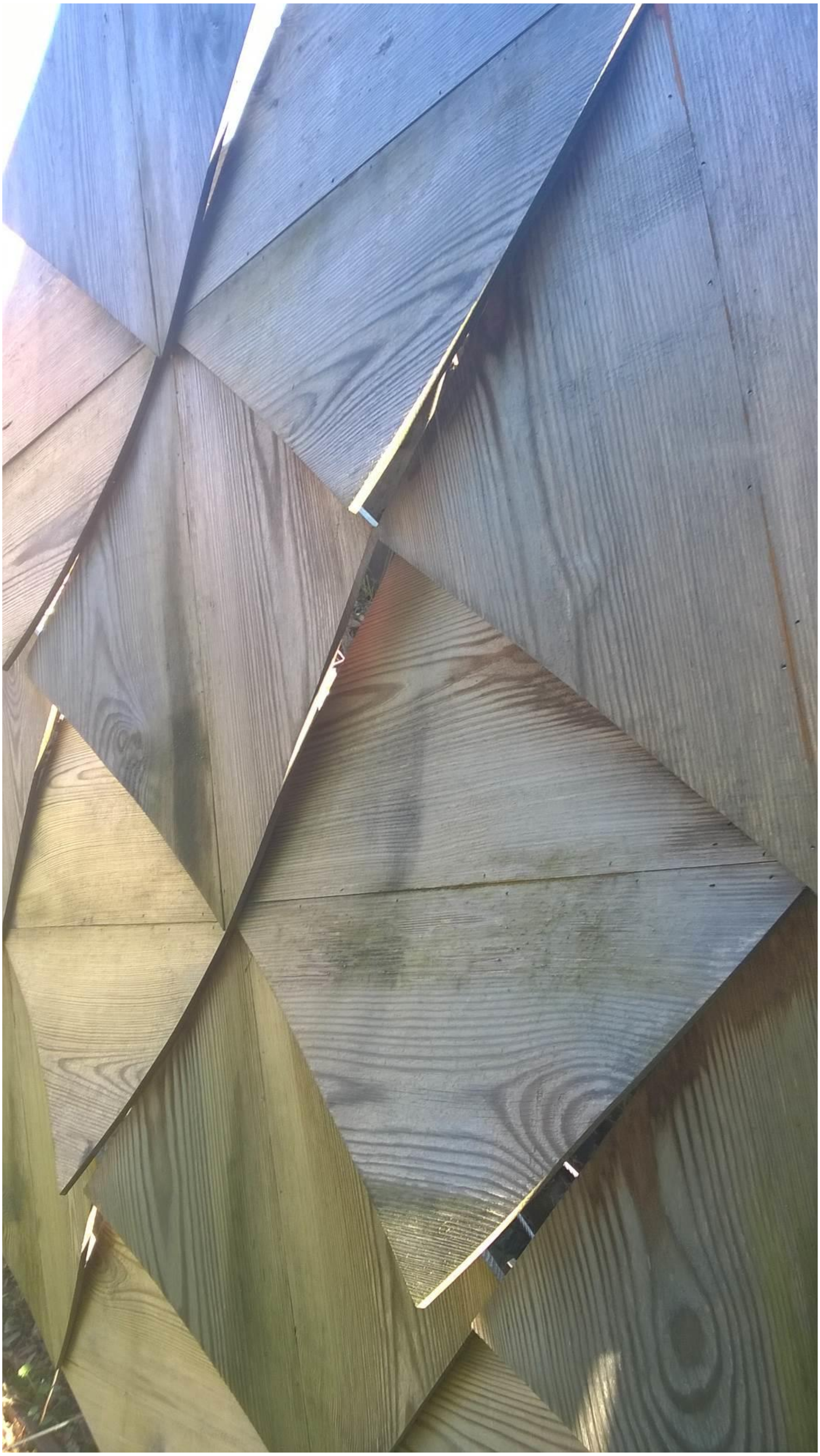

Figure 20: Ray 2 – Prototype after Three Years of Being Exposed to Weather (Davidová 2016)

…This refers to Berger et al. (Berger, Guernouti, Woloszyn, & Buhe, 2015), stating that moisture has an impact on the indoor air quality and the hygrothermal comfort of the building's occupants. From their observations on laminates, Holstov et al. (Holstov, Morris, Farmer, & Bridgens, 2015) conclude and suggest that the thickness of the active layer (means wood) is also the main factor affecting the response speed. Composites with comparatively thick active layers can be applied where the response to longer term changes in the surrounding conditions is required (i.e., daily, monthly or even seasonal changes), whilst thinner composites can react rapidly to hourly changes of ambient humidity or sudden rain. The thickness of the panels was selected at 0.8 cm as a compromise between amount of warping and reaction speed contra durability of the panel.

Samples observations prior to the decision were made hourly within 24 hours with the changes ranging from 10% to 90% RH on plates with the thickness of 0.3; 0.5, 0.8 and 1 cm when 1 cm was considered to perform too little and too slow and 0.5 cm was considered too fragile during the summer storms.

5.2.4 Conclusion for Material Selection Chosen for Comparison

This resume shows that current research at the other institutions has been done on laminates and plywood. Compared to the laminates, the plywood seems to be much more durable when it comes to vandalism, as it can combine the directions of the fibre. The laminates are very thin veneers with textile laminates that break very easily. Therefore, the plywood option was used for comparison with solid wood in Life Cycle Assessment analysis on the case study of the Ray 2 concept.

From the forest analysis of Central Bohemia, where the research is located, it became reasonable to use the combination of pine wood and false acacia. The solid wood model comes from pine wood. Pine wood is native to Central Bohemian forests (or Czech forests in general, as it grows there in all the places with low nutrients), therefore it is good to support its growth and harvest. At the same time, it has very high performance when it comes to warping in the tangential section. On the contrary, false acacia is a dangerous, invasive species with no local enemies. False acacia should be harvested and its roots excavated. When it reproduces, it poisons the soil, thus disabling natural biodiversity. Pine wood and false acacia have reasonably different tangential shrinkage, therefore its veneers would perform well on the concept of so called ‘bi-metal’. As a result, the species for both of the Ray 2 concept products were chosen, on one hand for its suitable material properties, on the other hand for its positive impact on local eco-systems with low carbon footprint during its transportation.

The speculation of the advantages of solid wood considered the energy and carbon emissions, but also the evaporation of poisonous chemicals. As Wójcik & Strumiłło puts it:

> ‘*Today, remanufacture of timber, i.e., the production of timber derived sheet components and glulam beams, is a way to meet the needs of modern economy. That is not without an impact on the environment. Processing a material means energy expenditure and may have an impact on health risks posed by this material, and also on its recycling.*’ (Wójcik & Strumillo, 2014)

5.2.5 Method – LCA

The methodology of life cycle assessment used in this project was based on ISO 14040 (ISO 14040:2006(en), Environmental management — Life cycle assessment — Principles and framework, 2006) and ISO 14044 (ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines, 2006) with detailed specification according to EN15084 (EN 15804:2014 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products, 2014), that can be used as product category rules for construction products. For detailed evaluation of environmental impacts, not only were impact categories required in

EN 15804 calculated, but additional impact categories based on USETox (Henderson et al., 2011) and ReCiPe (Goedkoop & and coll, 2009) were calculated as well.

The aim of the Life Cycle Assessment based comparison of the panelling compared to the Ray 2 design concept was to evaluate environmental burdens and/or benefits of having the panelling made of solid wood and or plywood. The functional unit chosen was one square meter of panelling possessing its fully-functioning ability for a reference lifetime of 20 years. In this study, the Life Cycle Assessment was principally performed on the production of panelling, its application including repair, and finally on waste management and energy utilisation of used wooden parts. Used system boundaries include wood production and atmospheric CO_2 utilisation and incorporation into wood biomass, panelling production, transportation, production of the ancillary materials and energy carriers, consumption of fuel and water, as well as atmospheric, aquatic, and soil pollution produced. The end-of-life phase of the panelling Ray 2 concept was modelled as in solid wood and/or plywood-contained energy recovery and its use for avoiding emission related to the production of the same amount of thermal energy.

LCA methodology was used to calculate the possible environmental interventions (inventory profile) and characterisation profiles (results of impact category indicators) (Koci & Trecakova, 2011). The pollution from diesel consumption and electric production, as well as the relevant processes dealing with polyurethane glue, were derived from use of the GaBi 6 Professional database (thinkstep).

5.2.6 Results and Discussion

Outputs of inventory analysis are summarized for following modules of life cycle: upstream module; transport; core module; energy recovery and end of life (EoL) module. Within upstream module all processes dealing with production of materials and energy carriers are included. Transport module covers production of during transport consumed fuels and emissions dealing with transport within all life cycle. In the core module, in site manual output was production of Ray 2 panels and its estimated repair during 20 years of use. EoL summarizes inputs and outputs within waste management and Energy recovery demonstrate potential benefits of use of wooden parts as biotic fuel during end of life of panels.

Solid wood Ray 2 needs a lower amount of all consumed resources and, in the case of the energy-carrying resources and water, avoids consumption of a higher amount of resources (expressed as numbers below zero). The main resource consumption is due upstream module and end of life module. Although during the core module there is principal consuming of Pine and/or False Acacia wood as a biotic resource.

The assessment of possible environmental impacts was conducted using CML IA. USETox characterization was used for evaluating toxic and ecotoxic impacts of both scenarios. The ReCiPe characterization method was used for sensitivity analysis.

Similarly, as in the evaluation of resource consumption results in impact categories due to the energy recovery of end-of-life wood and plywood express negative values, meaning the positive effect on the environment – so called avoided emissions/impacts. As the values decrease, the amount of avoided emissions rises. It seems that both of the products would be truly sustainable as the environmental impact of wood and wood products in general seems to be lower than other materials used in the building industry. This has been also concluded by a literary study comparing the results for cca. twenty years in Europe, Northern America and Australia by Werner and Richter (Werner & Richter, 2007). The LCA results argue for the use of solid wood with negative values in most of the categories. Therefore, it seems that solid wood is more suitable for Ray 2 product for Czech Republic.

5.2.7 Conclusions

The experience of vernacular carpenters, accumulated throughout generations, has been overlooked during modern times and must be revisited through 'Research by Design' in transdisciplinary teams by samples observations and the construction of prototypes in 1:1 scale. The Life Cycle Assessment of wood and plywood panelling clearly demonstrated that solid wood-based panelling of Ray 2 exhibits substantially lower environmental impacts than plywood, having lower results in almost all the values for the Czech Republic. This statement is valid for all applied impact categories and is not sensitive to the selection of impact assessment methodology. Therefore, research on performative wood should also consider the direction of solid wood.

From the designer's perspective, it is an important fact that Life Cycle Assessment is utilizing the most up-to-date data even for the calculations of the future and not the speculations of its possibilities. In this way, the system avoids failures of predictions in development, but on the other hand, it is unable to be precise in predicting its life cycle nor accurate in the evaluation.

5.2.8 Apendix: Tables

5.2.8.1 Inventory analysis results

In following table, the results of the inventory analysis are presented. All data is referred to as a chosen functional unit, i.e. twenty years of use of one square meter of panelling. The wood as a resource of thermal energy during the end-of-life phase was used.

*Table 1: Selected parameters of inventory analysis. All the data per F.U. (1m2*20 years of use)*

kg/1m2*20 years of use	Plywood Ray2	Solid wood Ray2
Biotic resources		
Resources		
False Accacia	5,21	0
Pine wood	3,59	7,08
Crude oil (resource)		
Crude oil (in kg)	0,138	0,000
Crude oil (in MJ)	0,434	0,003
Oil sand (10% bitumen) (in MJ)	2,67E-03	2,21E-05
Oil sand (100% bitumen) (in MJ)	2,33E-04	1,93E-06
Hard coal (resource)		
Hard coal (in kg)	0,070	0,000
Hard coal (in MJ)	-0,058	-0,171
Lignite (resource)	-1,298	-1,424
Lignite (in kg)	0,010	0,000

Lignite (in MJ)	-1,308	-1,424
Natural gas (resource)		
Coalbed methane (in MJ)	2,47E-05	-2,58E-06
Natural gas (in kg)	0,205	0,000
Natural gas (in MJ)	0,477	-0,023
Pit Methane (in MJ)	-0,003	-0,003
Shale gas (in MJ)	5,54E-05	-5,10E-06
Tight gas (in MJ)	6,83E-05	-7,12E-06
Uranium natural (in MJ)	-1,69E-05	-2,08E-05
Water	-400	-2047

5.2.8.2 Results of impact assessment

The assessment of possible environmental impacts was conducted using CML IA, USETox and ReCiPe methods. In the following tables the results of the characterisation are presented.

Table 2: CML IA impact category results of comparison of solid wood and ply-wood panelling. Results are expressed per F.U., i.e. per twenty years use of one square meter.

CML2001 - Apr. 2013 Impact category	Plywood Ray2	Solid wood Ray2
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	7,56E-06	-2,61E-07
Abiotic Depletion (ADP fossil) [MJ]	39,10819	-22,4971
Acidification Potential (AP) [kg SO2-Equiv.]	-0,01626	-0,02064
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	-0,0009	-0,00154
Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	2,820605	-7,69424
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	7,31E-07	1,64E-11
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	-0,0007	-0,00156

Table 3: USETox model results of comparison of wood and plywood panelling. Results are expressed per F.U., i.e. per 20 years use of 1 square meter.

USETox model	Plywood Ray2	Solid wood Ray2
USEtox, Ecotoxicity (recommended) [CTUe]	0,619997	-0,1573
USEtox, Human toxicity, cancer (recommended) [CTUh]	3,81E-09	-1,67E-09
USEtox, Human toxicity, non-canc. (recommended) [CTUh]	3,51E-07	-2,49E-07

Table 4: ReCiPe impact category results of comparison of wood and plywood panelling. Results are expressed per F.U., i.e. per 20 years use of 1 square meter.

ReCiPe (E) Impact category	Plywood Ray2	Solid wood Ray2
Endpoint level		
Agricultural land occupation [species.yr]	-7,50E-09	-5,34E-09
Climate change Ecosystems, default, excl biogenic carbon [species.yr]	-2,08E-07	-3,06E-07
Climate change Ecosystems, incl biogenic carbon [species.yr]	-2,31E-08	-1,42E-07
Climate change Human Health, default, excl biogenic carbon [DALY]	-3,89E-05	-5,75E-05
Climate change Human Health, incl biogenic carbon [DALY]	-4,34E-06	-2,67E-05
Fossil depletion [$]	0,153667	-0,08838
Freshwater ecotoxicity [species.yr]	1,13E-12	-5,25E-13
Freshwater eutrophication [species.yr]	-1,42E-12	-1,39E-12
Human toxicity [DALY]	4,85E-07	-1,42E-06
Ionising radiation [DALY]	-2,85E-09	-3,87E-09
Marine ecotoxicity [species.yr]	2,26E-11	-1,30E-10
Metal depletion [$]	0,015671	-0,00062
Ozone depletion [DALY]	1,29E-09	1,66E-14
Particulate matter formation [DALY]	-7,21E-07	-1,27E-06
Photochemical oxidant formation [DALY]	-1,08E-10	-3,58E-10
Terrestrial acidification [species.yr]	-1,71E-10	-2,53E-10
Terrestrial ecotoxicity [species.yr]	1,09E-10	-7,29E-11

Midpoint level		
Agricultural land occupation [m2a]	-0,38124	-0,27141
Climate change, default, excl biogenic carbon [kg CO2-Equiv.]	-11,0994	-16,3838
Climate change, incl biogenic carbon [kg CO2-Equiv.]	-1,23884	-7,61042
Fossil depletion [kg oil eq]	0,931315	-0,53565
Freshwater ecotoxicity [kg 1,4-DB eq]	0,001305	-0,00062
Freshwater eutrophication [kg P eq]	-3,19E-05	-3,13E-05
Human toxicity [kg 1,4-DB eq]	0,662751	-2,05899
Ionising radiation [kg U235 eq]	-0,17392	-0,23614
Marine ecotoxicity [kg 1,4-DB eq]	0,131911	-0,72944
Marine eutrophication [kg N-Equiv.]	-0,00131	-0,00125
Metal depletion [kg Fe eq]	0,219098	-0,00869
Ozone depletion [kg CFC-11 eq]	7,31E-07	1,64E-11
Particulate matter formation [kg PM10 eq]	-0,00277	-0,0049
Photochemical oxidant formation [kg NMVOC]	-0,00277	-0,00918
Terrestrial acidification [kg SO2 eq]	-0,01203	-0,01781
Terrestrial ecotoxicity [kg 1,4-DB eq]	0,000741	-0,00049
Water depletion [m3]	-0,4129	-2,04715

6 Methodology: Systems Oriented Design and Research by Design while 1:1 Prototyping

In this chapter, the methodology of the research that was also **explored within itself** is explained. It covers **transdisciplinary co-working**, full **scale prototyping** and **employment of different organisational structures** within **Research by Design**, all utilised in **Systems Oriented Design**.

Systems Oriented Design was introduced by Birger Sevaldson in 2005 (Sevaldson & Ryan, 2014), is being developed by Birger Sevaldson, Michael Hensel and Defne Sunguroğlu Hensel (Sevaldson, 2013b) and others and is applied in Research by Design. It has its origin in design practice, design thinking and the complexity theory and systems thinking. Sevaldson argues that the changes in our globalized world and the need for sustainability demands an increase of the complexity of the design process (Sevaldson, 2013b). A base of Research by Design in Systems Oriented Design is the concept of Rich Design Research Space. It covers physical, social and digital space in which different actors play their role. Sevaldson shows that the design investigations are combined with cycles of observation, registration, and reflection within the research-design process. (Sevaldson, 2008)

In my case, the **'Social Design Research Space'** is represented by trans- and inter-disciplinary networking of i.e., architects, coders, wood scientists, carpenters, the building industry, environment designers, structural engineers, ecologists, dendrologists, algologists, climatologists, artists and art and architectural theoreticians, culturologists, stage designers, dancers, musicians and actors-some individual, some related to different organisations and general public. The network was and still is growing based on the needs of the project and opportunities. The design is informed by transdisciplinary knowledge and skills, my personal measures of the samples, the prototypes and the biotic and abiotic environmental relations to it, simulations combined with the measured data, all discussed through personal experiences. The process is based on visualisations of such complex transdisciplinary relations via GIGA-mapping (see Figure 21). **GIGA mapping** is an extended visual diagramming of related knowledge that covers the design process. Sevaldson describes it as follows:

> *'GIGA-mapping is super extensive mapping across multiple layers and scales, investigating relations between seemingly separated categories and so implementing boundary critique to the conception and framing of systems... GIGA-mapping is creating an 'information cloud' from which the designer can derive innovative solutions. While mapping in general is a way of ordering and simplifying issues, so to say 'tame' the problems, GIGA-mapping intends not to tame any problems. GIGA-maps try to grasp, embrace and mirror the complexity and wickedness of real life problems. Hence they are not resolved logically nor is the designerly urge for order and resolved logic allowed to take over too much and hence bias the interpretation of reality.'* (Sevaldson, 2011)

From my observation, it is good to start with creating a GIGA-map straight during the literature study and updating it within the process. A GIGA-map certainly helps in leading the design phase in developing a complex product next to the simulation techniques, which in my case were mostly generated in Grasshopper for Rhino 5 based on the registration of the behaviour of the samples. Following a Systems Oriented Design process through GIGA-mapping led directly to different complexity full scale prototypes, research conclusions, questions, discussions and speculations on further development.

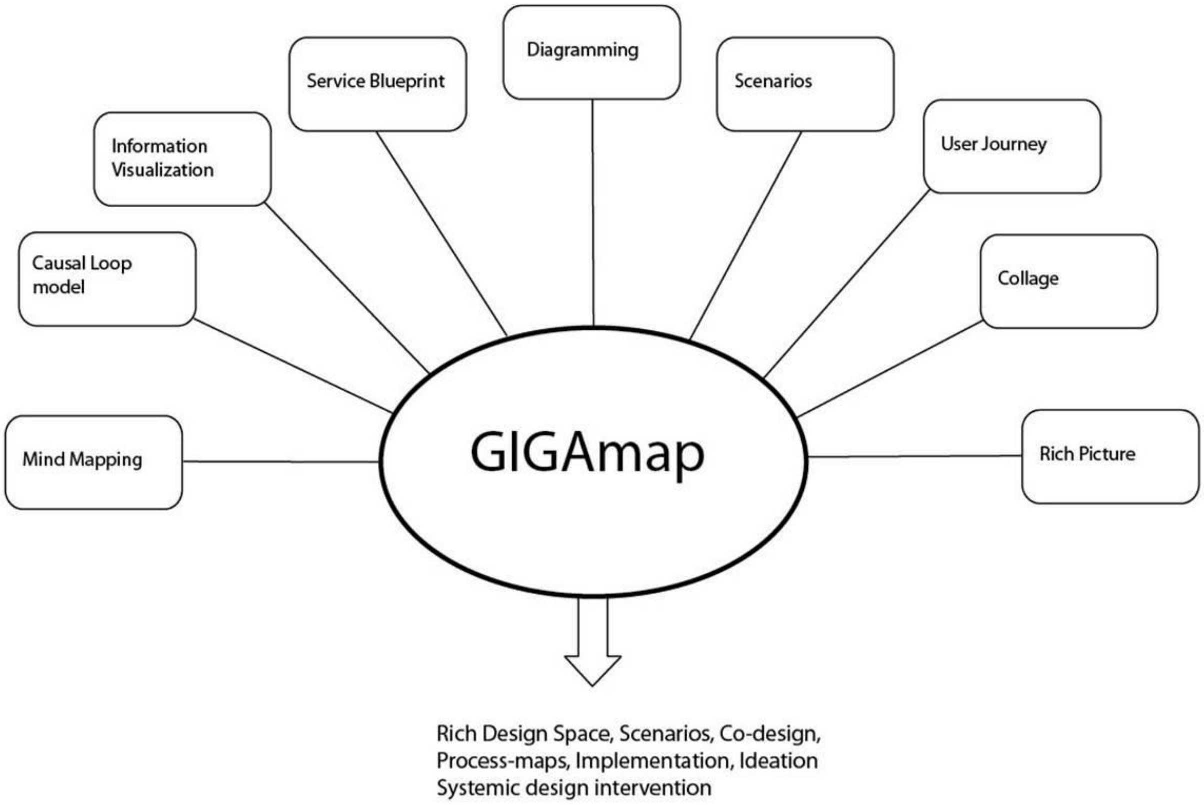

Figure 21: GIGA-map Map (Sevaldson 2014 – with the courtesy of Sevaldson)

My working paper 'Generating the Design Process with GIGA-map: The Development of the Loop Pavilion' explains how GIGA-mapping and online tools can be used in teamwork while designing and prototyping the Loop Pavilion and cooperating on the project in different locations. The paper introduces **MINI-maps** for fast concept sketching and physical GIGA-maps that can be reorganized during the overall process by using printed images, pins and threads.

The paper '1:1, A Transdisciplinary Prototyping Studio' co-authored with Birger Sevaldson explores the **necessity of full-scale prototyping** in comparison with the results obtained through samples observations and simulations and how the transdisciplinarity can be involved in such.

The discussion in the paper 'NGO, Practice and University Driven Research By Design on Performative Wood' co-authored with Birger Sevaldson opens the question, if the, by now only refered to, connection of research with practice in **Research by Design** is enough for experimental architecture. It is showing the example, how **NGO**'s, practices and universities were joint within this project, arguing for better flexibility and potentials of such. It is also opening the discussion of observations of material performance through interactions of performers' performance and opportunistic use inhabitation, that was clearly possible through NGO's involvement. Such settings enabled **time-based co-design** within the research.

The recently resubmitted paper ***'Systemic Approach to Architectural Performance: The Media Mix in Creative Design Process'*** is concluding the use of tools and actors involved within the design-research processes, arguing for the present necessity of development of project specific methods and proposing speculations for their further development. Instead of today mixing media, all interrelated in one **Physical Performative Environment GIGA-map** within **Rich Design Research Space**, being prototype and ever evolving result in the same time, is envisioned for the future.

6.1 Generating the Design Process with GIGA-map: The Development of the Loop Pavilion

(Davidová, 2014c)

This paper was formerly published in: Relating Systems Thinking to Design 3 Proceedings 2014. It explores the potentials of **GIGA-mapping within teamwork**, where the GIGA-map becomes a **discussion board with registered deadlines** that can be **reorganised** several times according to the current design stage while still **keeping the schedule on track**. Through the hands on discussion on different data and proposals it becomes a **generator and organiser of the design and its process** within the Rich Design Research Space. It also introduces **MINI-maps** in combination with **conceptual sketching** as **kick offs** for the project.

6.1.1 Abstract

This transdisciplinary project[28] involved the teamwork of the students from the Faculty of Art and Architecture at the TUL in Liberec and the Faculty of Forestry and Wood Sciences at the CZU in Prague[29] under the leadership of myself, Šimon Prokop and Martin Kloda. Various disciplines, such as mathematicians, software developer, structural engineer, mechanical engineers, urban planners and arts managers were included within the design process. The goal of the one semester lasting studio course was to build a wooden, environment responsive, pavilion that hosted cultural events in June 2014 of EnviroCity festival. The pavilion absorbed the humidity at night, while evaporated it the arid sunny afternoons. Its panelling generated the circulation of humid air.

The research method was Systems Oriented Design, Physical Modelling, Parametric Design, File to Fabrication and 1:1 Prototyping, where GIGA-mapping became the all covering working tool of the design process. Besides the literature, the students used my own GIGA-map of performative wood research as a study material for the starting point. The overall knowledge was mapped on the paper board on the table. To use the table instead of wall is recommended by Birger Sevaldson for the reason of better interaction of the participants. (Sevaldson, 2012b)

After the discussion we decided to map and predict our design process. The timeline with proposed time schedule of the course and different roles and responsibilities of the participants were drafted. All the results and expectations were put on the board and discussed in the team. In that sense, the design process of the overall team was generated and controlled by the GIGA-map.

6.1.2 The First Step

Before the course started, the students were invited to online folder on Copy, used for file sharing (see Figure 22). Copy allows more data space than Drop Box, but we were struggling with real time. Students could find there related literature and time schedule of the course. The first day started with all day lectures on the topic area and information on the first task. We established a Facebook group for the online discussion as the students were located in different cities (see Figure 23). Whenever somebody

[28] This project would never happen without a kind support of the Faculty of Forestry and Wood Sciences and the Czech University of Life Sciences in Prague, the Faculty of Art and Architecture at the Technical University of Liberec, Stora Enso, Rothoblaas, Nářadí Bartoš, Eurodach, Lesy ČR, Natura Decor, Easy Moving, Nadace Proměny and Collaborative Collective.

[29] List of Participating Students: Alena Novotná, Anna Hrušová, Antonín Hůla, Barbora Slavíčková, Jakub Kopecký, Jiří Fáber, Jiří Pokorný, Petr Tůma, Tereza Jílková, Radim Sýkora, Eliška Antonyová, Tereza Lišková, Filip Janata, Tomáš Kytka, Marie Kortanová, Vojtěch Holeček, Martin Vaníček, Jakub Hlaváček and Petr Havelka.

uploaded something to Copy folder, started also a discussion on FB. Copy folder had very organized structure.

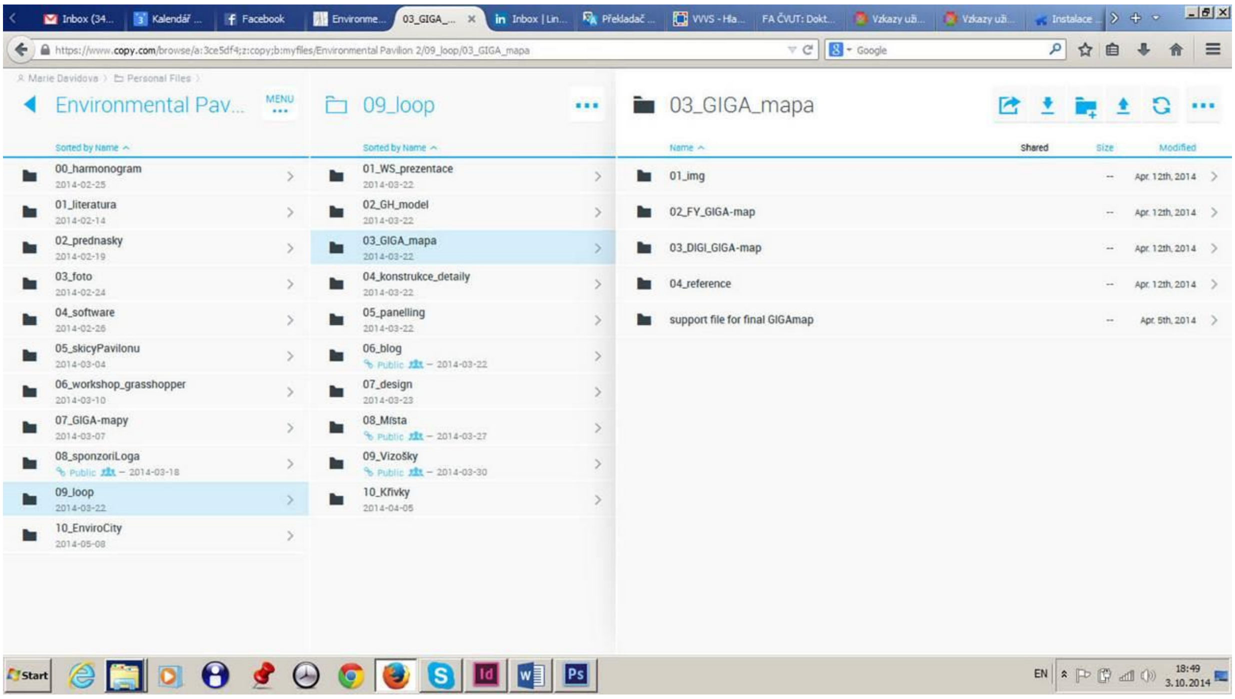

Figure 22: Copy file sharing (Davidová 2014)

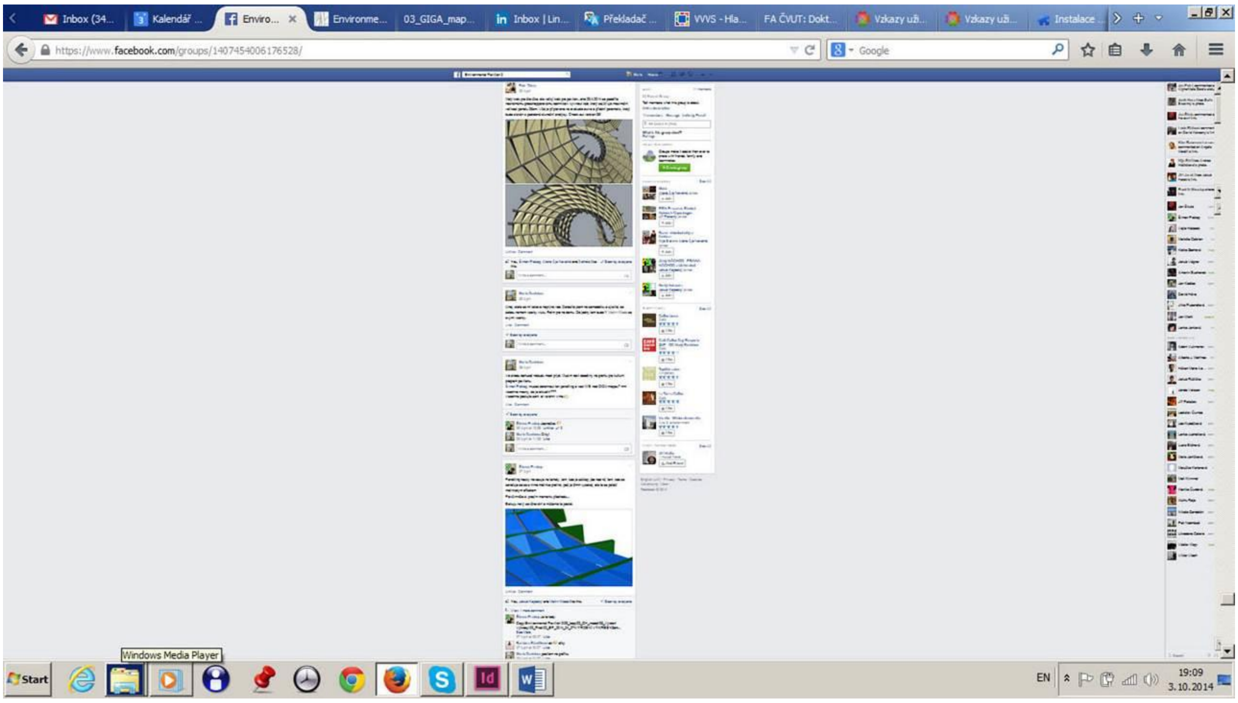

Figure 23: Discussions on Facebook group (Davidová 2014)

The students got two weeks for designing the concept of environment responsive pavilion from solid wood and creating a MINI-map (see Figure 24, Figure 25, Figure 26 and Figure 27) of their research and design development. MINI-map, as opposed to GIGA-map doesn't cover about 300 items but else, it has the same mission.

> *'GIGA-mapping is super extensive mapping across multiple layers and scales, investigating relations between seemingly separated categories and so implementing boundary critique to the conception and framing of systems...'* (Sevaldson, 2011)

In the sense of Performance Oriented Architecture, which was the goal of this project Michael Hensel is adding:

> '*GIGA-maps can be also used when exploring different strategies and approaches to integrating the different traits of performance-oriented architecture and help maintain an overview over directly or indirectly affected conditions.*' (Hensel, 2013)

It was interesting to note, that not all the students were successful with MINI-mapping and created them ex-post. However, they were able to involve themselves, working in the team on big GIGA-map. The students tested several software for generating the map but at the end, the Illustrator was selected as the main tool, allowing enough complexity in the relations. The same fact was also mentioned by Sevaldson. (Sevaldson, 2013c)

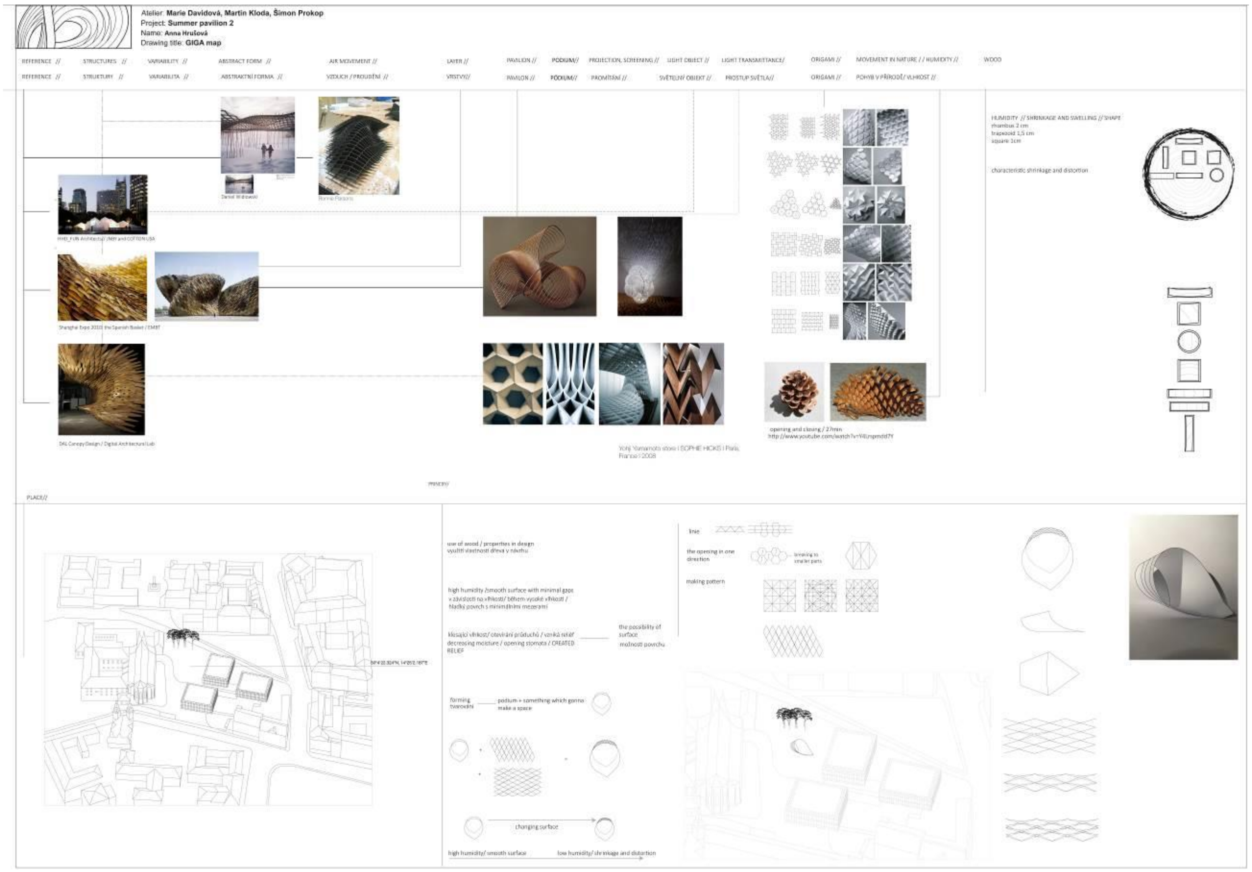

Figure 24: 1st stage MINI-map (Hrůšová 2014)

Anna Hrůšová's map was covering different inspirations stages with material and site analysis that lead directly to the design (see Figure 24).

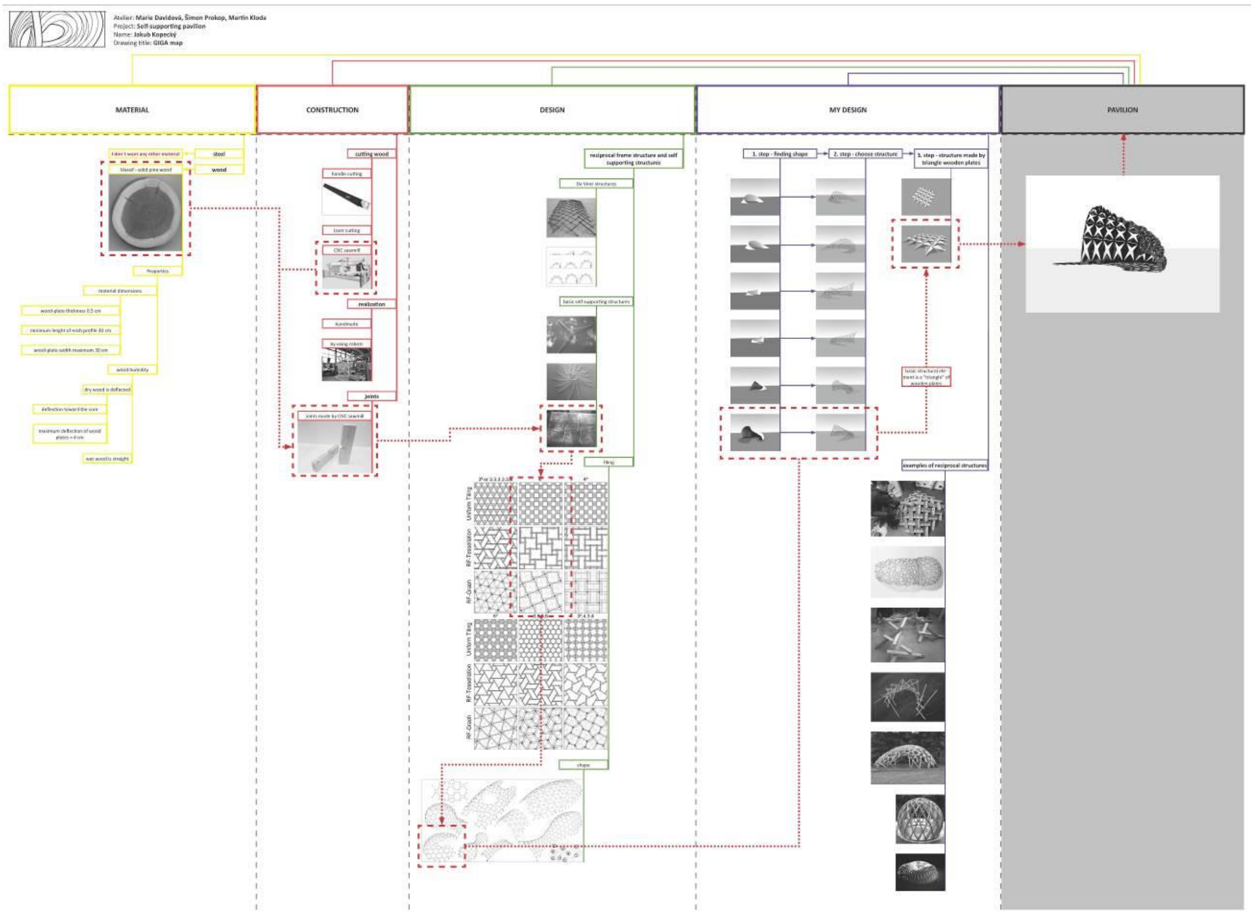

Figure 25: 1st stage MINI-map (Kopecký 2014)

Jakub Kopecký started with the knowledge of the material then he explored the possibilities of tools we could use, followed by self-supporting structures study that inspired his design (see Figure 25).

Barbora Slavíčková and Petr Tůma had a different approach from the others. Their process started with putting the stickers on the board. This method very well enabled them to collect data, on the other hand they struggled with connecting the relations. But in the end, when they were forced to make an order in their data and create the map in PC, they succeeded. Their map was showing all their design from the start to the finish of the task, covering the collected knowledge (see Figure 26).

Sevaldson does not recommend the sticker method for the exactly same reason – struggling with relations (Sevaldson, 2012b) but the result by the translation into PC was successful. Barbora and Petr were the only students who worked in group. It might mean, that the stickers can well work as a starting point for fast communication in the team.

However, we decided to follow the recommendation and use thumbtacks further on for a big GIGA-map that was covering the teamwork on selected project that was to be built (see Figure 30 and Figure 31).

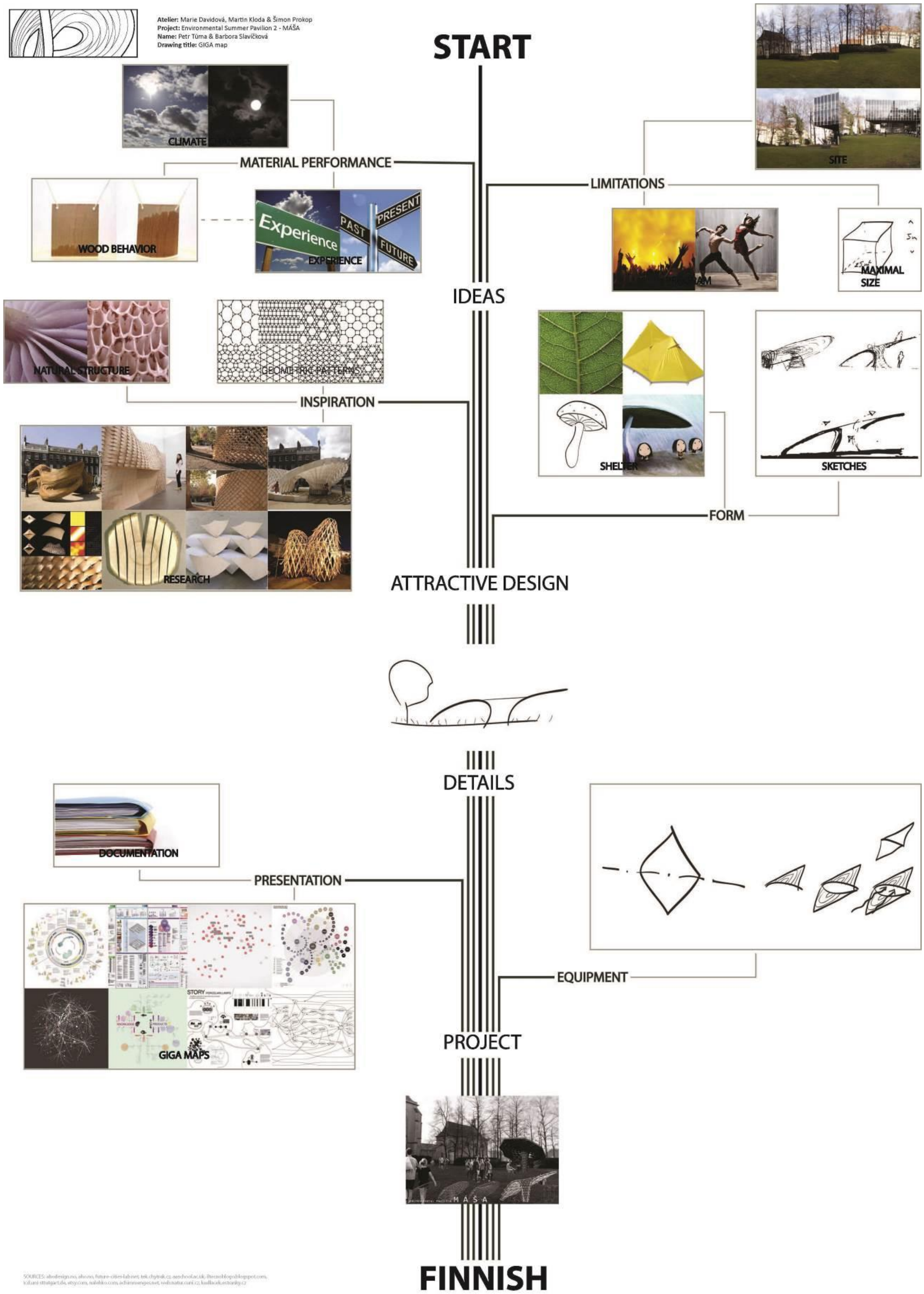

Figure 26: 1st stage MINI-map (Slavíčková & Tůma 2014)

6.1.3 Work on the Winning Design

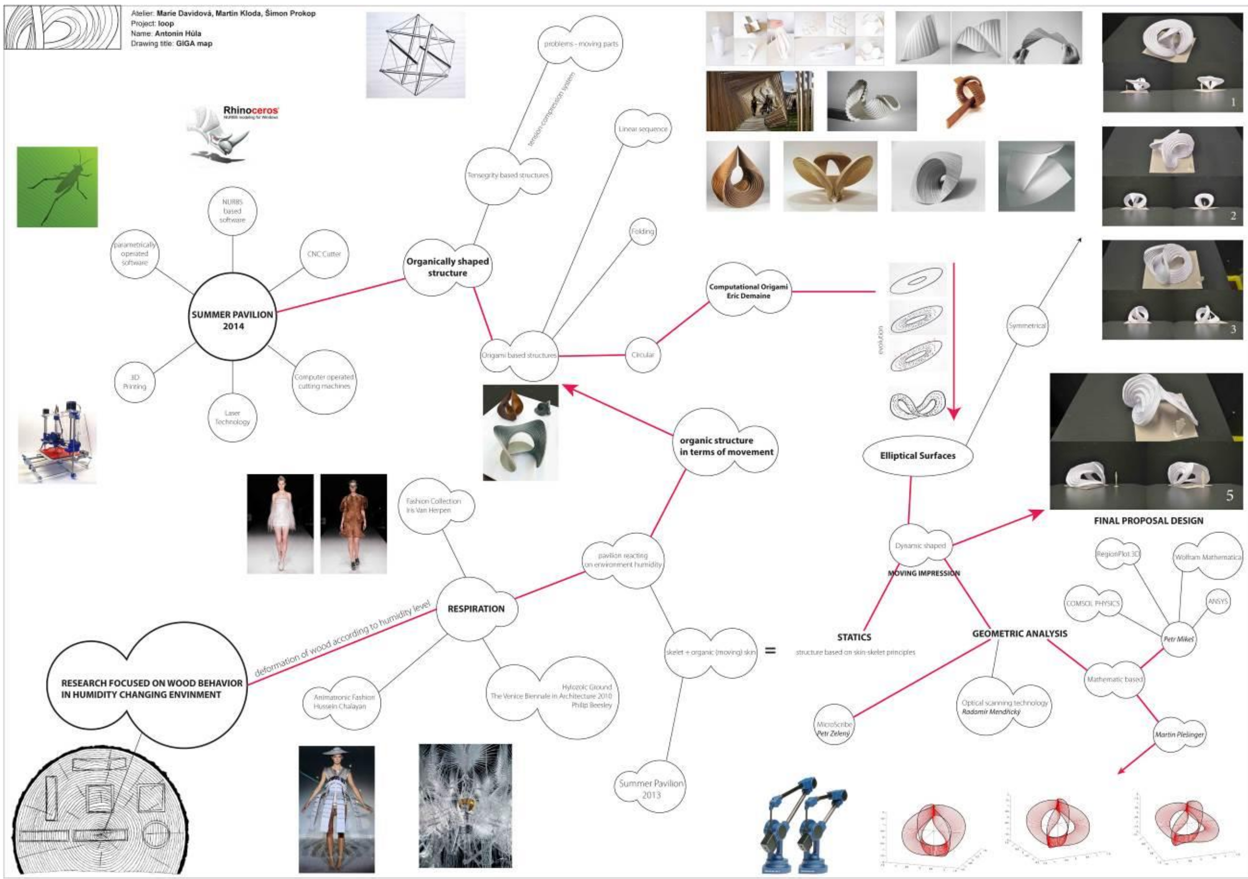

Figure 27: The winning design MINI-map (Hůla 2014)

Antonín Hůla's selected design was origami based, folded ellipse (see Figure 27 and Figure 28). It immediately asked for different professions who got involved in one big paper based GIGA-map (see Figure 30 and Figure 31). In the same time, the design of PC based GIGA-map was drafted and had an effect on the paper based one (see Figure 29).

We decided to create time based board which was covering my own GIGA-map in wood research, all the findings from the MINI-maps from each student and started adding other professions involved. The board was set by the time line from the preliminary course schedule. This way, all the participants had an overview, in which design stage they were positioned and were aware about the deadlines. The time based mapping for the groups is explained by Sevaldson:

> '*Mapping in groups has an effect on dialogue. It fosters dialogues and collaboration. Especially the short workshop types developed for strategic meetings in leader groups has a very strong impact on the dialogue. These most often are time based maps that follow a timeline. The time line is used as a sorting device that is immediately understood by everybody. This sorting device allows the group to skip the agenda, as long as one has a theme to investigate. The conversation is allowed to jump back and forth. Jumping in the discussion is done easily because everybody is brought along in the jump by pointing to the time line. The conversation stays focused on the topic but remains open ended and holistic.*' (Sevaldson, 2013c)

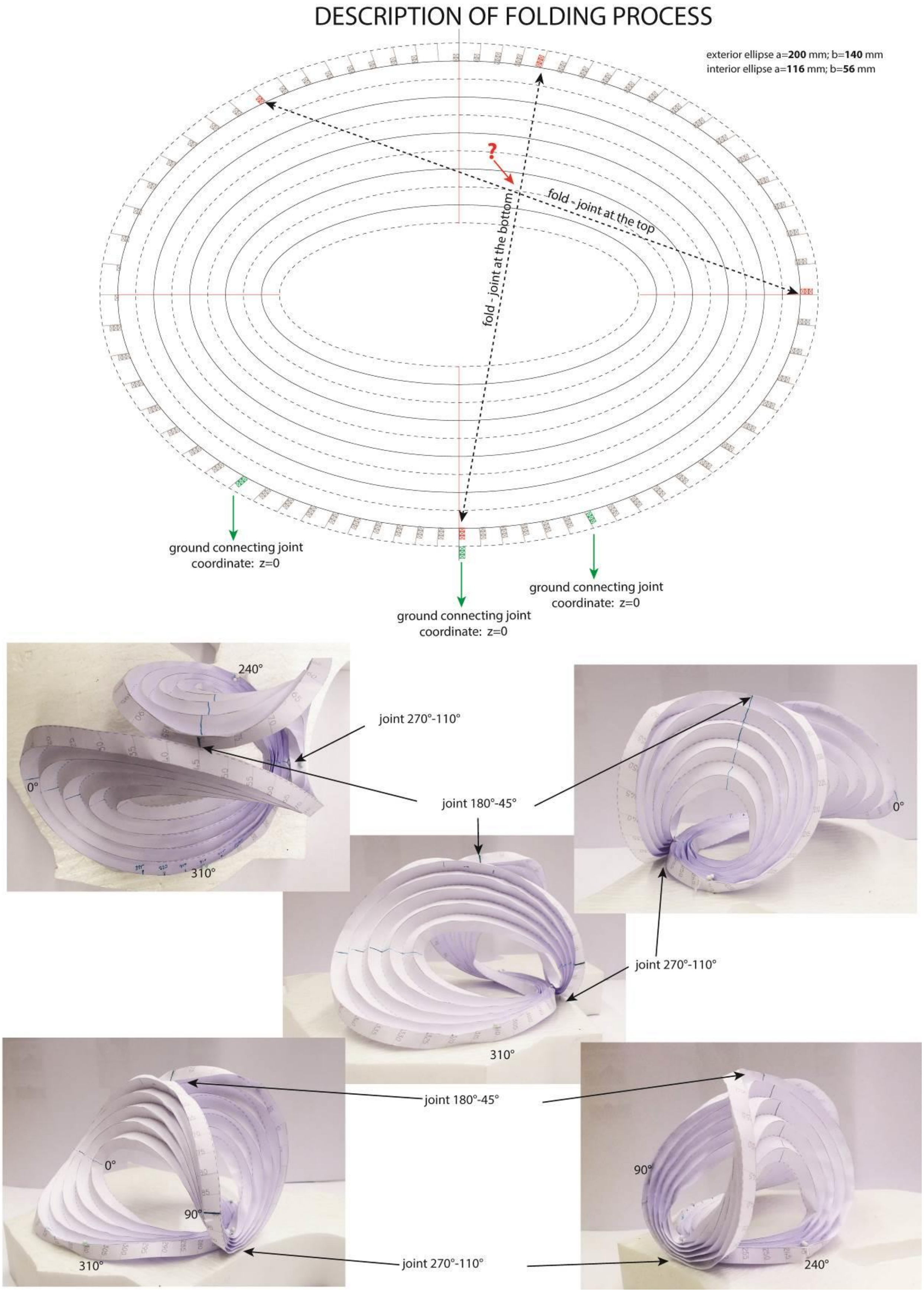

Figure 28: Loop Pavilion – the winning design (Hůla 2014)

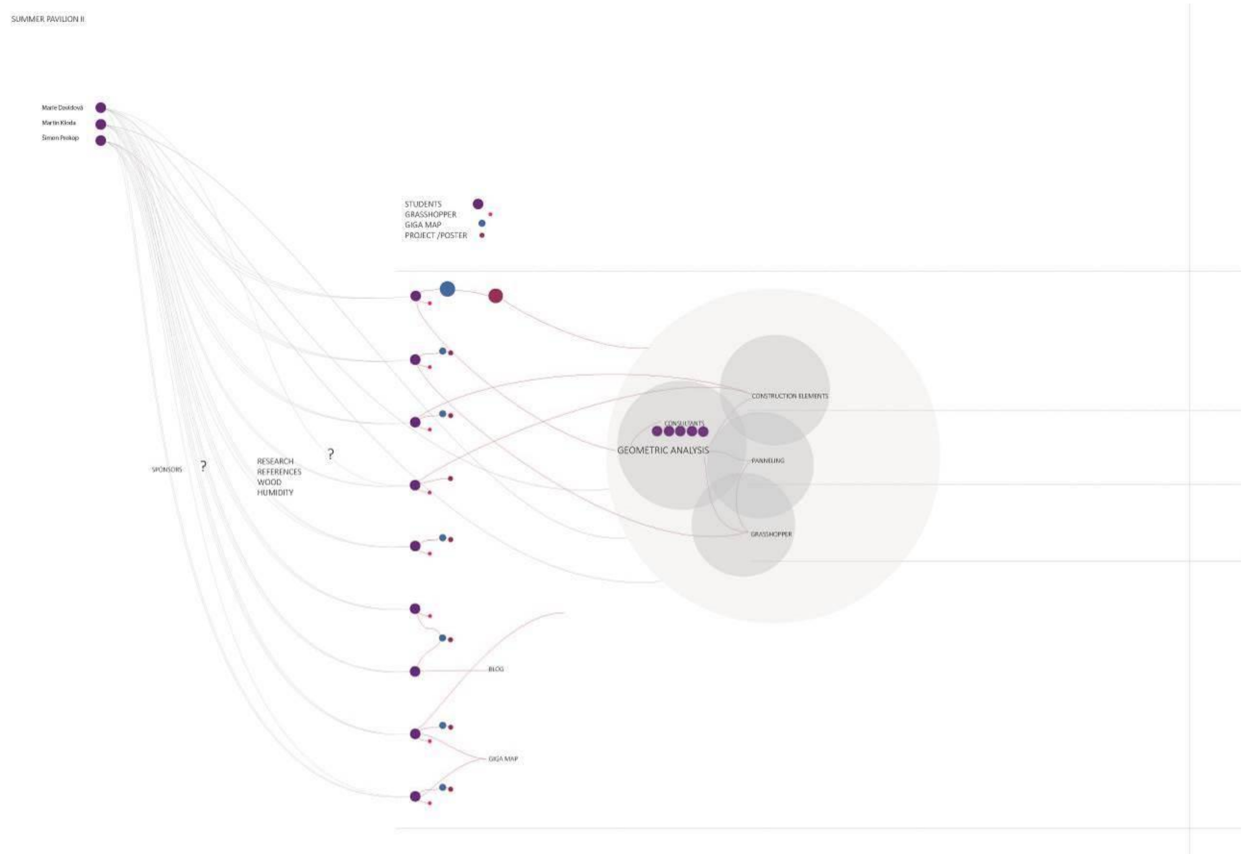

Figure 29: Draft concept of the final GIGA-map design (Hrůšová 2014)

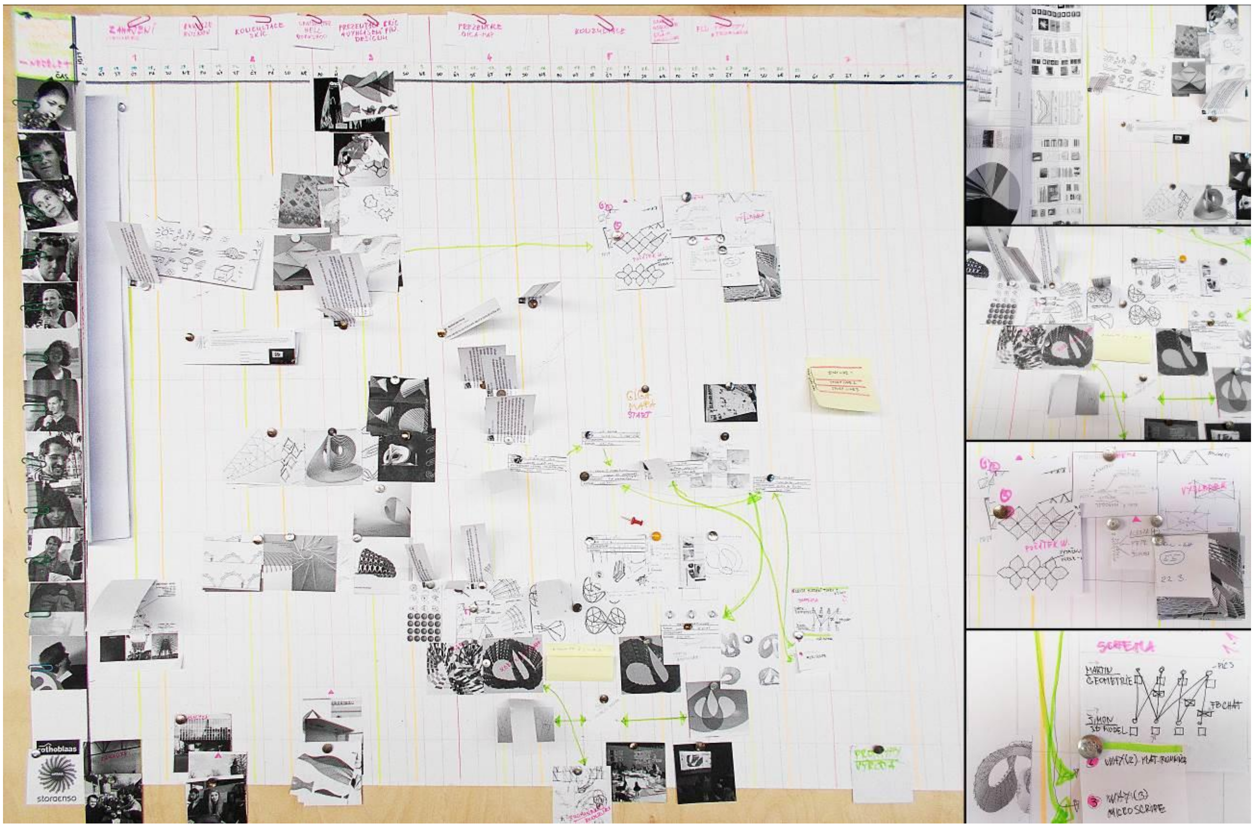

Figure 30: WIP board based GIGA-map (photo: Pokorný 2014)

The students were divided into six different, interrelated groups with special responsibilities and communicated among each other, as well, as with different professions through GIGA-map, where every group had its own line that was corresponding to the others (see Figure 30). Further on, in the process of mapping, the groups were replaced by topics of research, where the roles were mixed (see Figure 31).

Figure 31: WIP board based GIGA-map (photo: Pokorný 2014) – please, zoom in at Systems Oriented Design web site (Sevaldson, 2016a) or RSD5 proceedings (Davidová, 2016d)

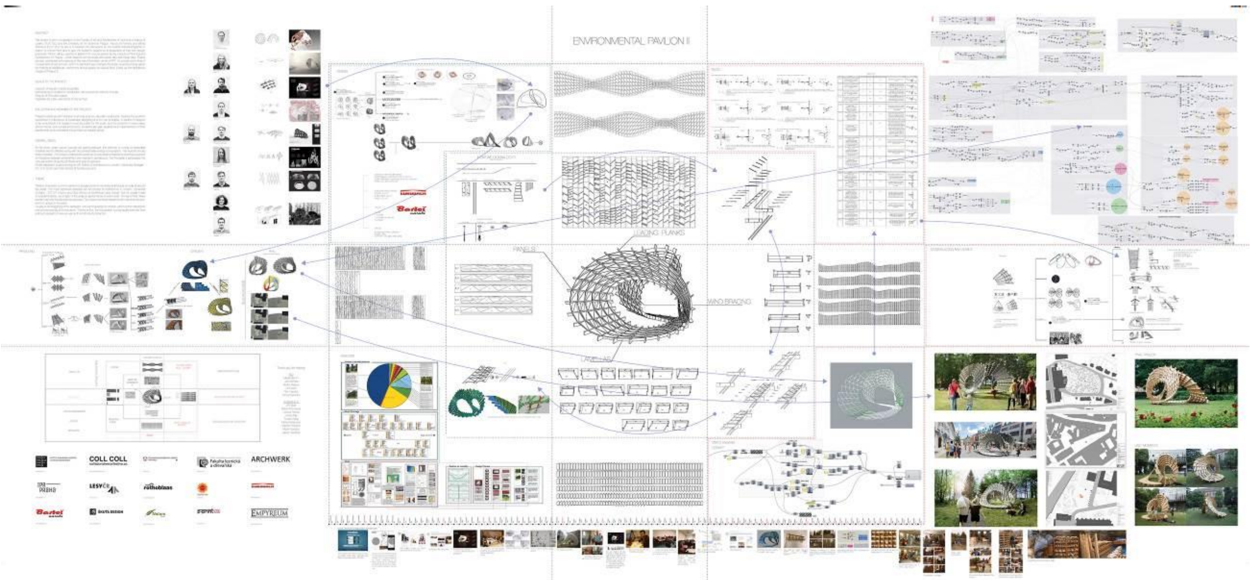

Figure 32: Final GIGA-map (FUA TUL & FLD CZU 2014) – please, zoom in at Systems Oriented Design web site (Sevaldson, 2016b) or RSD5 proceedings (Davidová, 2016h)

We used pins and strings for the physical GIGA-map, so, it could be easily reorganized all the time during the discussion. All the files were printed and moved all over.

The final GIGA-map didn't respect the timeline but the research topics took the main place at the end (see Figure 32).

6.1.4 Conclusions

Figure 33: Loop Pavilion (photo: Novotná 2014)

The GIGA-map was ricing new questions in the design process and therefore generating it.

Its time basis created an overview and control about the design stage and deadlines.

It was a great tool for the other professions to get overview of the project and to involve themselves more, than to be just asked questions.

It was a good tool to draft the design concept of the paper based GIGA-map in the PC first.

Creating a MINI-maps for each individual student/group was a good starting point that lead the students into the study.

The use of my own research GIGA-map gave a good study material for the students, who, thanks to the time schedule, couldn’t go so deep into the wood research themselves.

The time-line GIGA-map was a good tool for the process but might not be working for the final representation.

The sticker method might work, but only in the very first stage of the GIGA-mapping.

The method with pins and string was very helpful for the discussion and development.

The complex overview helped us to develop the concept of performative wood!

6.2 1:1, A Transdisciplinary Prototyping Studio

(Davidová & Sevaldson, 2016a)

The topic **Research by Design while 1:1 Scale Prototyping** was explained in the article co-authored with Birger Sevaldson for ASK.the.Conference 2016: '1:1, A Transdisciplinary Prototyping Studio.'[30] It elaborates on the **necessity of full-scale prototyping** within **Research by Design** and introducing how the **transdisciplinarity** was involved in the project through **practice**.

Figure 34: Loop Pavilion Building (photo: Davidová 2014)

6.2.1 Abstract

The main author is using transdisciplinary studio courses as a research tool in the field of performative wood. Through sharing the knowledge between architectural, environmental design, and wood science researchers and students, we managed to develop complex 1:1 scale prototypes (see Figure 34). The course process is a learning arena for students, teachers and researchers and the skills, competences and insights are being developed through experimental practice. The second prototype of the Environmental Summer Pavilion II course was created from reflection upon the first one while both serve as complex material-environment interaction studies for the development of responsive envelopes.

[30] This paper is a result of Systemic Approach to Architectural Performance project (Davidová, 2016e) that was kindly supported by EEA and Norway Grants (EEA and Norway Grants, 2016).

6.2.2 Introduction

The theme of this paper is to present and discuss the experiences of working in a transdisciplinary prototyping studio[31] forming a learning framework for a collaboration between two different university level institutions, working with full scale prototypes. The research guest studios have been led parallel at architectural schools, the Architectural Institute in Prague (ARCHIP, 2016)and the Faculty of Art and Architecture at the Czech Technical University in Liberec (FUA TUL, 2016)in 2013 and 2014, respectively and at the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences in Prague (Czech University of Life Sciences Prague, 2016). In both of the cases, there were three guest tutors, the first author, being the project leader and being responsible for the material and architectural performance of wood, Martin Gsandtner/Šimon Prokop, responsible for coding and Martin Šichman/Martin Kloda, responsible for structure, detailing and realisation. In addition, different specialists from both of the faculties were available for the consultations and prototypes testing.

The work conducted in the presented collaboration is based on material research by design on the dynamic features of wood. Following the work of Hensel (Hensel, 2010b) and others in using the performative material features of wood, for example shrinking and warping, as a dynamic material feature from which one could benefit, the research ought to further develop this approach.

The methodology for the research is based on Research by Design (Research through Design) as described by Frayling (Frayling, 1993) and others and developed in more detail by, e.g., Sevaldson (Sevaldson, 2000, 2010).

Research by Design is in the process of being established as a solid approach and a more effective version of the practice of Research in Design, (Morrison & Sevaldson, 2010) where uniqueness, reflexivity, discourse and generalization are addressed.

All modes of modelling in physical materials and digital models are applied during the experimental design work. Full-scale prototyping is central to this method. The models and prototypes work as a dialogic platform for trans- and inter-disciplinary inquiry. This way of design research had been common during the Renaissance times, for example in the work of Leonardo da Vinci. Highlighted by the most advanced structural experiments by the end of 19th and the duration of the 20th century, prototyping became a key method for material research and is used by the academy as well as by the industry.

Michael Hensel explains it as follows:

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[31] **List of Participating Students:**

pareSITE: Yuliya Pozynich, Jason Nam, Alena Repina, Daria Chertkova, Yana Vaselinko, Mikkel Wennesland, Dan Merta, Daniela Kleiman, Liv Storla, David Lukas, Christopher Hansen, William Glass, Jiří Šmejkal, Milan Podlena, Josef Svoboda, Tomáš Pavelka, Miroslav Runštuk, Ladislav Rubáš, Radim Sýkora, Anna Srpová, Ivana Kubicová, Gabriela Smolíková, Karel Ptáček, Jan Matiáš, Tomáš Mišoň, Lukáš Růžička, Jan Hyk, Marian Loubal, Jan Dostál, František Juhász and Jakub Vykoukal

Loop: Alena Novotná, Anna Hrušová, Antonín Hůla, Barbora Slavíčková, Jakub Kopecký, Jiří Fáber, Jiří Pokorný, Petr Tůma, Tereza Jílková, Radim Sýkora, Eliška Antonyová, Tereza Lišková, Filip Janata, Tomáš Kytka, Marie Kortanová, Vojtěch Holeček, Martin Vaníček, Jakub Hlaváček and Petr Havelka

Contribution:

pareSITE: The project was accomplished with the kind support of Skanska, Eurodach, Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences Prague, Lesy České republiky, reSITE, ARCHIP, Collaborative Collective and Oximoron.

Loop: This project would never happen without a kind support of the Faculty of Forestry and Wood Sciences and the Czech University of Life Sciences in Prague, the Faculty of Art and Architecture at the Technical University of Liberec, Stora Enso, Rothoblaas, Nářadí Bartoš, Eurodach, Lesy České republiky, Natura Decor, Easy Moving, and Collaborative Collective.

‘*…The findings of the material experiments are the basis for computational modelling and analysis, which serves to further elaborate the design as it gains in complexity. In most cases, the design experiments culminate in full-scale constructions that can be further examined in order to empirically derive reliable data for the further development of the specific material system, working methods and approach to design.*’ (Hensel, 2012b)

From the philosophical point of view, the method is argued for by Wallner:

‘*We understand what we have constructed. We cannot understand anything else.*’ (Wallner, 1994)

We could add that only when our experiments are finalized can we fully understand what we have constructed and what its implications will be.

Schön is describing the design process as reflection in action, explaining the reflective conversation within the situation, while gaining the skills by experience (Schön, 1983). Reflection in action has been central to the research process, beginning with sample observations and concluding with the built prototypes. The success or failure of design actions has been central in building a body of methodological and technological knowledge. Numerous failures were unavoidable due to the lack of particularly developed methods suitable for the case. Samples, prototypes, and measuring had to be repeated because of the utilization of methods that in hindsight proved to be inappropriate. As Sevaldson stated in reference to designing with digital tools: ‘clear models and methodologies do not yet exist – these are being developed through practice’ (Sevaldson, 2005). The same can be applied to material research by design, using digital tools and prototyping in 1:1 scale. The design problems we are discussing here are of a nature that confronts the designer with wicked problems (Rittel & Webber, 1973). There is no right or wrong answer, each problem is to a certain degree unique and it is only possible to base a resolution on prior experience to a limited degree. Therefore, the researcher needs to base her or his learning on practice, reflecting the failures that also bring the new findings. This process develops in iterations, which makes every new prototype more complex.

6.2.3 The Project: Wood as a Primary Medium to Architectural Performance

… [This part is shortened because it is elaborated in detail in Prototyping Design-Research Projects chapter]

…Both of the prototypes (pareSITE and Ray2) were observed and analysed and reflected upon and the findings were used as a starting point for the next pavilion course, led by Davidová, Prokop and Kloda. This time, a full semester was provided for the course so the schedule was not as tight. The resulting Loop pavilion utilised and developed further the gained knowledge to its fullest potential and increased the performance by design. The panelling was laid not only in combination of the left and right side of the tangential section, but also in spatial organisation into the structure. In this case, as it was observed on the prototype, the circulation of humid air was better. The team work was organized in a much more efficient way by arranging regular meetings with GIGA-mapping (Sevaldson, 2012a) for team work, an online file-sharing offered by Copy cloud service and a private Face Book group. This was especially useful because the two participating faculties were located in different cities (Davidová, 2014c). The GIGA-mapping method proved to be a perfect tool for trans- and inter-disciplinary communication both, within the team as well as with the invited specialists. The performed sampling, as well as parametric analyses of joints, wood extension or FEM simulation, was more promising in the end then the final full-scale prototype. This speaks to the fact that full scale prototyping is necessary within architectural research.

In both cases, the pavilions were designed by the entire team – the students as well as by the tutors, after the initial concept sketch was selected through a competition. In the second case, the responsibilities within the design tasks were more clearly outlined after being discussed by the entire team over a GIGA-map. In both cases, the students followed up observations of the prototype originally made by the first author. The students with backgrounds from different disciplines were initially not assigned to particular tasks but all were coping with design, engineering or environmental issues. Later in the process, the responsibilities were assigned according to particular interests relating to the profession that they were studying. In addition, the researchers from both of the faculties were engaged to assist with particular design questions.

6.2.4 The Transdisciplinary Prototyping

The cooperation between the disciplines proved to be smooth while each of the professions followed their particular missions. The cooperation between the Architectural Institute in Prague (ARCHIP) and the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences in Prague (FLD CZU) worked well as continual prototyping and designing were interchanging. Students from both institutions cooperated well during the overall process, exchanging their skills and using their institution's facilities and studios and competences, e.g., structural engineer of ARCHIP and wood workshops and wood technologists of FLD CZU. The mature and experienced students of FLD CZU, many of them with architectural background, organized the prototyping and fabrication as well as helped with digital data.

The Faculty of Art and Architecture at the Technical University of Liberec (FUA TUL) was well-suited for concept design and this part of the project was performed there, including regular meetings over one common GIGA-map that also served for the organisation of the team work. The Faculty of Forestry and Wood Science at the Czech University of Life Sciences is well-equipped with wood workshops and testing machines. Therefore, the prototyping, as well as the final fabrication, took place here. This time, we had few students from FLD CZU following the overall process but we had also a student with building engineering background in the architectural team, who could be involved full time.

The skills of the students perfectly complimented the equipment of the school. The wood engineering students had much better practical experiences with machines as well as with the materials and the architectural and environmental design students were learning such skills from them. On the other side, the architectural and environmental design students were better in following the complexity of the overall project while still maintaining responsibility for certain tasks.

Due to the different missions of the faculties, architectural and environmental students possessed a time advantage in having the studio as the main subject. This changed when it came to the building phase, when wood engineering students were given the task as their full time exercise in professional practice.

Though we believe it would be ideal if both teams could have participated equally, the division of the work intensity according to the different professions worked well. The wood engineering students focused on material and prototyping consultancy or small tasks within the concept design phase, which was mainly executed by architectural and environmental design students. The architectural students had a perfect overview of the design and fabrication data and could organise the building process when the wood engineering students were engaged in the workshop.

6.2.5 Conclusions

The 1:1 scale prototyping is necessary for Research by Design development when it comes to material-design experimentations. Though the sample observations and digital simulations are helpful, they are not fully representative for the overall situation. So, despite that constant learning was achieved through action and analysis throughout the whole design process, the main learning input was obtained from the full scale prototype. And thus the Loop pavilion gained the most from the previous prototypes and studio experiences while it brought forth new questions for further consideration. New experiences, successes as well as errors were recognized.

The transdisciplinarity of the project played a crucial role within the process. While the wood engineering students proved to have the best experience with physical prototyping, the architectural students were better equipped for design tasks, using digital tools and handling fabrication data. At the same time, the environmental design students had the best understanding of implementing the local conditions. One of the students had a graphic design background, which was of great assistance, when deciding the organisation of the GIGA-map, as well as its finalization for print. GIGA-mapping turned out to be an ideal tool to bridge differences between the groups and for coordinating the work.

The full scale prototype generates a distinct and clear transdisciplinary understanding because all team members focus on one common product while implementing their professional background and observing and analysing the common result at the end.

6.3 NGO, Practice and University Driven Research By Design on Performative Wood

(Davidová & Sevaldson, 2016b)

This paper published in the DCA 2016 conference proceedings discusses **more options for relating different partners and actors** within **Research by Design** than just academy and practice[32] and how their roles can be mixed and interlinked based on the suitability to project's needs and opportunities at certain moment. Hardly any of the steps within this work would be accomplished without creativity and flexibility within ***'Design Management'***[33] that become crucial to its methodology.

The necessity of active role of **NGO**s next to the academic research in **sustainable participatory design** in brother overview has been discussed by Nerkis Kural at the same conference (Kural, 2016). This paper covers a **case study** of presented research related to **prototyping and its performance observations**. Thanks to involving NGO's into play, the tool box is also introducing research through what von Uexkül defined as ***'individual Umwelt'***[34] in 1936 (von Uexüll, 2009) within interaction of ***'enacted'***[35] and/or ***'embodied'***[36] (Merleau-Ponty, 2002) field by different professions, institutional status members, gender and age agents that are engaged in social aspects. It is opening the notion of performance also to ***'stage design-body experience'*** perspective discussed by Böhme (Böhme, 2006). I.e. the performers on stage, the audience or locals thus become a **research tool as well as 'co-designers'** (Szebeko & Tan, 2010) of next stages within the **time based design-research process** (Sevaldson, 2017b), sharing and developing **tacit knowledge**.

Hemmersam and Morrison ask: 'what the local enactment of the transect[37] walk does in terms of shifting the non-representational perspective of 'reading' and 'writing' urban space, to one in which ascription to the place is important – that is: writing space before reading it, thus shaping the

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[32] The project would never happen without a kind support of Collaborative Collective, Faculty of Forestry and Wood Sciences at Czech University of Life Sciences, ARCHIP, Faculty of Art and Architecture at Technical University of Liberec, Faculty of Architecture at Czech Technical University in Prague, Academy of Art, Architecture and Design in Prague, Prague Institute of Planning and Development, Landscape festival Praha 2014, Nákladové nádraží Žižkov, SKANSKA, Stora Enso, Rothoblaas, Eurodach, Natura Dekor, Nářadí Bartoš, Lesy ČR, P-Print, Škuta Design, Empyreum Information Technologies, Meloun Production, Easy Moving, Nadace Život umělce, Nadace Proměny, Paperlinx, Vinařství Sonberg, Městská část Praha 3, Nová síť, o. s., Nadace Proměny, Auto*Mat, Lunchmeat, TANEC PRAHA, Uličník, Rekola, I Need Coffee, Architekti ve škole.

[33] Design Management: 'strategy that speaks to the ideals of stewardship and ethical behavior, pathways that prod us to reevaluate and rebalance our consumer culture' (Walton, 2010)

Skills Required from Design Manager: '• Purpose: is the direction and leadership that design managers provide to both individual colleagues and the organization as a whole.• People: provide the talent and the interdisciplinary collaboration design managers orchestrate as they respond to immediate and long-term business challenges.• Presence: is the understanding of organizational goals, values, and norms with which design managers nurture their decision making and that they express in all they create.• Process: is the term for the broad-based idea development and problem- solving techniques design managers make use of in dealing with their assignments.• Project: is the team approach and discipline design managers must establish in order to address problems creatively while meeting deadlines and other technical parameters.• Practice: is the management of the financial, planning, technical, and human resources essential to leveraging design assets in an enterprise.' (Walton, 2010)

[34] Umwelt 'is constituted by the subjective experience of the surrounding world by the individual organism through its specific senses.' (von Uexüll, 2009)

[35] Enactment: 'An instance of acting something out; in psychiatry: The controlled expression and acceptance of repressed emotions or impulses in behaviour during therapy.' (Oxford University Press, 2017b)

[36] Embodiment: 'A tangible or visible form of an idea, quality, or feeling; The representation or expression of something in a tangible or visible form' (Oxford University Press, 2017a)

[37] 'The transect is a well-known concept in landscape architecture, often referring to sections of bioregions or ecosystems, local topographies or urban landscapes.' (Hemmersam & Morrison, 2016)

understanding of space via the transect walk as a tool' (Hemmersam & Morrison, 2016). This and the next paper try to elaborate on this discussion but they are not discussing ***'space'*** but **ambient eco-systems**. To the **mix of collaborators and interactors** applies a similar fashion as to the **mix of tools**, both discussed in closing sub-chapter of this chapter, bringing more complex agenda into play.

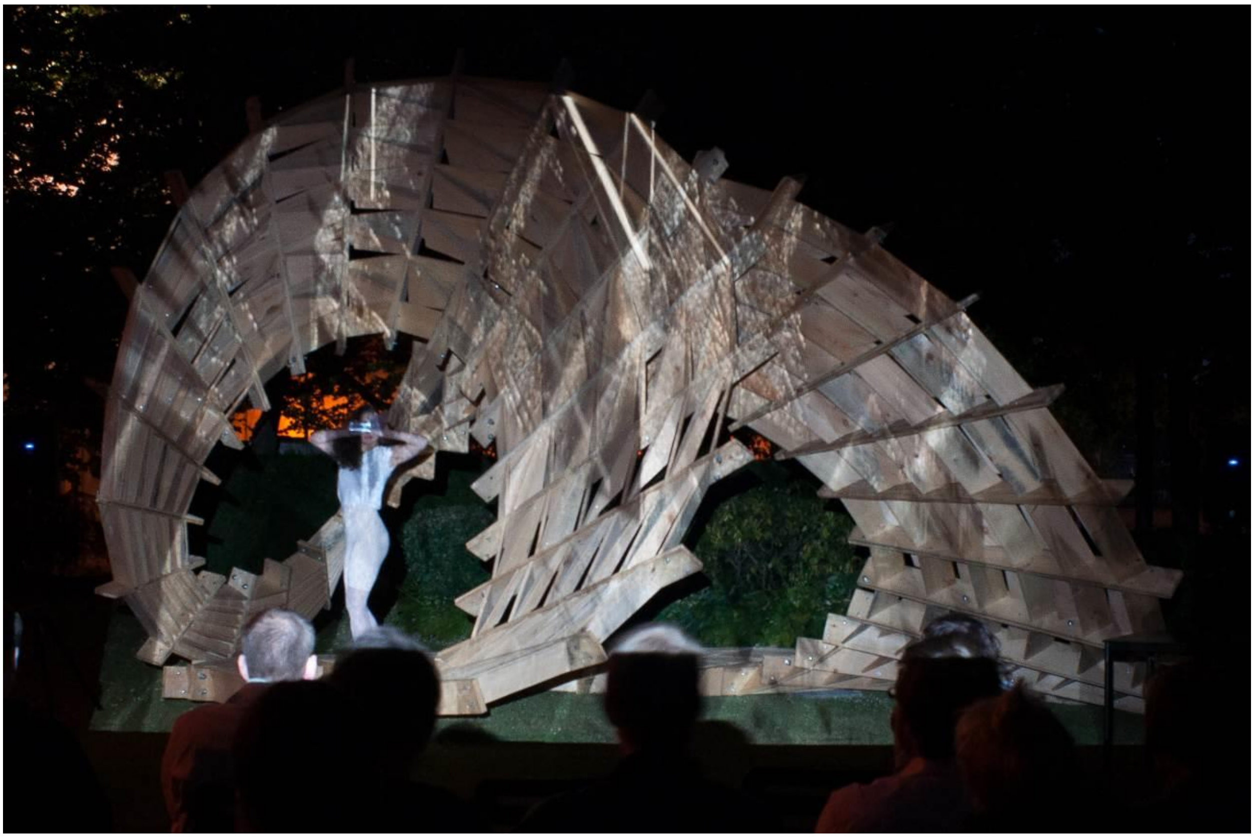

Figure 35: Loop pavilion; Light Performance: Lunchmeat; Dance Performance: Jana Vrána (photo: Dvořák 2014)

6.3.1 Abstract

The present paper discusses the possibilities of a relationship between academy, NGOs and practice in Research by Design on the case study of the first author's PhD research in performative wood and chairing of NGO Collaborative Collective, o.s. (Collaborative Collective, 2012). The more common link to commercial practice in this case might not reach the goal due to the long lasting sampling and prototyping compare to the timeframe of commercial projects. On the other side, academy is often not as flexible as small NGOs in its organisation and goals. While, in this case, the academic research is focused on responsive wood material, design and environmental science, the NGO can link this with society, culture, education and popularisation of science. By doing so, the project is reaching higher complexity, connecting art, science and public life. Within this project, two Environmental Summer Pavilions, pareSITE (Nam, 2013) and LOOP (Slavíčková, 2014), have been built in the city centre of Prague and hosted multi-genres festivals, reSITE (Barry, 2016) (see Figure 37 and Figure 38) and EnviroCity (Davidová & Kernová, 2016; Kernová, 2014) (see Figure 35, Figure 36 and Figure 39), related to public space during summer 2013 and 2014, respectively. The pavilions themselves relate to hot and dry summer city environments by absorbing moisture at night, when the relative humidity is high and evaporating it during arid summer noon of the Prague city centre, thus pleasing the stay of festivals' visitors.

6.3.2 Introduction

Lately, it is getting more common to establish NGO next to the academic research, to create a stage for experimental practice as an alternative to practise based research conducted in, e.g., a design company. This model was pioneered amongst others by Ocean, starting as a network in 1994 and registered as Ocean Design Research Association in 2008 (Hensel, 2015b). In 2010, a special issue of FORMakademisk was released, discussing research related to design or otherwise. In this issue Sevaldson maps out a long range of definitions, concepts and approaches in practice research in design with emphasis on the relations between design practice and research (Sevaldson, 2010).

Most of these perspectives are more or less meant to be linked to professional practice. This has been discussed by Dunin-Woyseth and Nilsson:

> '*Grillner and Stahl also presented a sketch to map the different sites where practice-based research in architecture may be related both to more conventional 'professional' practices as well as to alternative, 'academic' practices, meaning experimental practices based in academia and pursued through teaching, exhibitions and publications.*' (Dunin-Woyseth & Nilsson, 2012)

The potentials in linking practice research to NGOs is not discussed. However, this discussion takes already into consideration not only the education and academic results, but also the popularisation of science, in the case of exhibitions. Different modes of research have been discussed by Koskinen et. al. and conceptualized as the lab, the field and the gallery (Koskinen, Binder, & Redström, 2008). The special setup with research by design involving NGOs in the cultural field might be ideal for combining the three modes of research mentioned.

The first author is taking this idea forward, by examining how research by design can benefit from a relation to a NGO. By exposing her collaboratively built prototypes, to a living public space, as a central stage of multi-genres festivals on and in public space, organized by the NGOs. The audience is attracted by the cultural events while, in the same time the prototypes are tested by the performers.

6.3.3 The Method of Cooperation between Academy, Practice and NGO

The first author originally planned to link her research with her own practise, but she didn't reach that goal. Though the work is based on one to one scale prototyping that should be applied in the building industry, the time frame and targeted resources did not fit. Due to that fact, she founded an NGO, Collaborative Collective, o.s. (Collaborative Collective, 2012) with the colleagues from her practise (Collaborative Collective, 2012). There is a close link between the member's practices and the collective especially as an arena for speculation of future applications. The Collaborative Collective and the architectural practises are presented in public as one unit and they use the same facilities. Thus the practise and the NGO get attention from different target groups, which leads them to more financial recourses and popularisation of the work. At the same time, the research has been conducted as PhD research at different institutions. During the realisation of two of the Environmental Summer Pavilion prototypes, the cooperation between the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences (Czech University of Life Sciences Prague, 2016), Architectural Institute Prague (ARCHIP, 2016) and the Faculty of Art and Architecture at the Technical University in Liberec (FUA TUL, 2016) was established as a research based design studio course lead by the author and her collaborators. Parallel to this, the private sponsorships for the materials and outsource CNC, etc. were arranged through NGOs as well as all of the festivals' events and organisation. The sponsorship is easier due to the fact that the academy has more complex administrative responsibilities, therefore a small NGO is more flexible, at least when it comes to the laws in the Czech Republic.

The festivals were public, not targeted to science or academic education in the first place. Various performance artists, musicians, VJs and DJs, anthropologists, urban planners and designers, architects and landscape architects, theoreticians and city gamers were invited to perform an event of their wish that preferably relates to both, the pavilion, as well as to the surrounding public space. By perceiving the expressions coming from different disciplines, the authors of the prototypes got the opportunity to see their work in different perspectives. The first author's research, as well as the development of the pavilions with all the participants was in both of the cases presented and introduced at the opening of the pavilions as a first festival event before the light, music and dance performances to the public (see Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39).

The first pavilion, pareSITE (Nam, 2013), was built for a bigger event named the reSITE festival (Barry, 2016) and conference (see Figure 37 and Figure 38), ran by the NGO with the same name where Collaborative Collective (Collaborative Collective, 2012) cooperated as a small part of the big event's sister arrangement in public space, while a big un-public conference was held as a main interest of reSITE NGO. It was concluded by both sides that such a constellation was not suited for both of the partners, as their aims and audiences differ. Therefore the festival EnviroCity (Davidová & Kernová, 2016; Kernová, 2014) for the LOOP pavilion (Slavíčková, 2014) was fully ran by Collaborative Collective and managed by Michaela Kernová and the first author with technical and financing support of the Prague Institute of Planning and Development (Prague Institute of Planning and Development, 2016) and Landscape Festival Prague (Galerie Jaroslava Fragnera, 2014) as co-organisers (see Figure 35, Figure 36 and Figure 39).

Figure 36: Loop pavilion; Light Performance: Lunchmeat (photo: Dvořák 2014)

Figure 37: pareSITE pavilion; Dance Performance: Antonie Svobodová (photo: Vajdová 2013)

Figure 38: pareSITE pavilion; Dance Performance: Nami Maria Halingten (photo: Vajdová 2013) – additional thesis author's note: In the case of the situation on this picture, the audience and performer are exchanged. The audience covers the pavilion from outside – not inside which is proving its different use options in relation to human behaviour.

Figure 39: Various Performances, Lectures, Workshops and City Games at EnviroCity Festival at Both its Locations (photos: Novotná 2014)

6.3.4 Discussion

6.3.4.1 pareSITE pavilion on reSITE Festival, navigating complex networking problems

The pareSITE pavilion was part of the author's PhD studies at the Academy of Art, Architecture and Design in Prague (UMPRUM, 2015). As the structure of this institution did not enable her to lead a studio course there, she made an agreement with a private school, Architectural Institute Prague (ARCHIP), to hold a visiting studio at their institution. The cooperation with reSITE NGO helped with the negotiations, as both of the organisations are linked through the dean being the founding member of NGO at the same time. However, as ARCHIP had already confirmed its study plan, we were given only half a semester for the task. The original plan of the author was that the course will involve students from various schools, which was cancelled by the argument of ARCHIP that their students pay study fee as opposed to the students from state schools, therefore the course cannot be open to them. As the initial agenda had addressed also the other students, the students from the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences got very enthusiastic and discussed the options for joining the course with their school management. It is sympathetic fact, that the first author's long lasting cooperation with the faculty was initiated by their students, who arranged the first meeting. The school offered their specialists and workshop equipment, both necessary for the project, as the transdisciplinarity of the proposal was very attractive to them. All materials were covered by ARCHIP's major sponsor, SKANSKA and the design part was conducted in ARCHIP's studio spaces. The schools signed the contract on their transdisciplinary cooperation for the project. The salaries of the tutors were covered by reSITE and the first author received a stipend through Collaborative Collective sponsorship application from Lesy České Republiky (Czech State Forests). ReSITE is a big transdisciplinary conference and has its festival as a small public event on the side of its main activities. This caused several failures. For them, our project was insignificant compared to their larger activities and responsibilities to their sponsors. The positive fact about the cooperation was that the organizers were very open to first author's ideas and she took large part in the festival concept. The unfortunate fact was that the cooperation was very difficult as the conference and festival were happening simultaneously and the first author and members of Collaborative Collective ended up volunteering for the festival's success without rights on decision making or any PR. Same difficult situation emerged with large sponsors, who supported the conference, but wanted to be exposed at the festival, as it addressed the public, with cheap, but larger attractions, overshadowing the pavilion, though it was the only stage of the festival.

Lessons were learned. It was definitely not enough to agree on only a half semester lasting studio course for such project, but that time, it was our only option. The cooperation with reSITE brought an insight into the festival organizing but we learned that it is not suitable to be a small add-on of a big event. The conclusion of reSITE not to split their energy into small events seems to support the theory. The organization could have been better through the establishment, for instance, of discussion groups for all participants with phone notifications as was done in the second case. Most likely, as all of the participants were new to such large partnership, the organization was very chaotic and stressful. Thanks to this cooperation we learned how to create such projects in the future. The festival itself was very successful. Happening at largest square in Prague, Karlovo Square, it hosted about 1600 visitors just during the weekend (Davidová, Šichman, & Gsandtner, 2013). The pavilion concept was not affected by the robust organization and the performance was experienced by many visitors due to the extent of the event. The sponsors were decently engraved into the pavilion's panels as it was explained to them that they would get the best PR from city sensitive Prague citizens.

6.3.4.2 LOOP Pavilion at the Festival EnviroCity

This project largely benefited from the learned lessons. The PhD studies moved to the Faculty of Architecture at the Czech Technical University in Prague (Faculty of Architecture at the Czech Technical University in Prague, 2015) and the author was offered to host a whole semester studio course at the Faculty of Art and Architecture at the Technical University in Liberec. The same cooperation contract was signed with the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences in Prague. The studio had to be better organized, as the students were living in different cities. In addition to regular meetings with physical GIGA-map for coordinating team work, an online file sharing offered by Copy and a private Facebook group was established (Davidová, 2014c). The author decided to organize the festival, as well as the material and research sponsorship through Collaborative Collective, o.s. due to the conclusions drawn from the previous experience that this can better serve the project's goals. As for the materials small local companies were intended as suppliers of the materials, at the end Stora Enso was sponsor for the wood, Rothoblaas for the joinery and EuroDach for CNC. It seems, that larger companies can better afford research/or PR. Smaller sponsorship was covered by smaller local companies such as tools landing by Nářadí Bartoš and moving of the materials and pavilion from site to site by Natura Décor and Easy Moving. The research stipend was again sponsored though Collaborative Collective from Lesy České Republiky (Czech State Forests).

The festival's concept was addressing the research questions of the first author, while adapting to later agreed co-organizers' who had to submit to the already created concept. The project management and coordination of the cultural program was conducted by Collaborative Collective's client Michaela

Kernová, who has been connected to their practice for a long time, through collaborations with the author. Graphic design was sponsored by Škuta Design with creating strong CI. A private Facebook group was arranged for the management of the organizers and volunteers. As the Collaborative Collective was founded as a civic association for research and innovation within the field of architecture (Collaborative Collective, 2012), the NGO could also apply for grants for the dancers and musicians, because they related to research in architecture by the performance. The site, technology, facilities and partly PR was covered by the co-organizers, the Prague Institute of Planning and Development (IPR) and the Landscape Festival Prague. The cooperation between the two differed. While IPR is a state institution run by the city municipality, the Landscape Festival is run by architectural gallery, Galerie Jaroslava Frágnera. While the gallery was more free and dynamic, the state institution had more possibilities, such as establishing an agreement with the appropriate person for certain situations, such as covering the commercials on city trams. Thanks to the previous experience, the project was organized in a less stressful, agile and light weight way while lasting much longer, though new lessons were learned by different settings. Thanks to the whole semester studio course, we could create more complex projects and increase the performance of previous pavilion (elaborated in separate paper for the conference). Involving a professional project manager and cultural program coordinator brought much stronger seriousness to the festival and secured its smooth process. The professional coordinator working for Collaborative Collective was also following and fulfilling the needs of the partial research goals, gained through observing and questioning an interaction with the pavilion and public space by performers from different disciplines, as well as by the visitors. Many were really targeting the connection and were getting attached to the object and its closest environment as close as possible by all their senses (see Figure 35, Figure 36 and Figure 39). The dancers were eager to explore its materiality and form in relation to the ground by lying under it or climbing it while expressively touching and smelling it or receiving its energy. The landscape architects were impressed by the humidity and fresh, wood smelling, air circulation inside of the prototype. Musicians were exploring its shape-material acoustics. The city gamers used its space for room division or board for notes, while the architectural historians used it as a meeting point for their city walks. Two different locations, one covered by greenery at IPR's gardens, the second rough at the suburbs at Freight Depot of Žižkov, brought different perspectives to the environmental conditions of the object both by different constellations, especially of the ground, as well as through different aesthetics. The employees in the location used it periodically for lunch breaks, commenting on its pleasant environment and expressing their worry it might be removed. It was of course loved by kids for their spatial games. It is the main author's experience from both of the cases that placing a beautiful object into a public space never leads to vandalism.

As it was its first year, we considered the EnviroCity festival as a great success. It attracted over 800 visitors during the summer of 2014. Over one hundred visitors came to the festival opening at IPR's gardens. By engraving the sponsors' logos on the panels we created an attractive offer that was a gift to the donors after pavilion's disassembly.

It seems the NGO can function as a bridge or glue between different interests because of its non-profit organization. The action diagram of Loop and EnviroCity management organisation shows clearly the NGO as the central point while all the institutions benefit from the cooperation. Through the process it seems to be proved that a small NGO with non- profit ambitions is more flexible and can be seen as a caring and kind spider in the net. On the other side, the larger, more powerful organisations operate with better resources and opportunities. However, it is strongly beneficial when most of the administration is left on the NGO (see Figure 40).

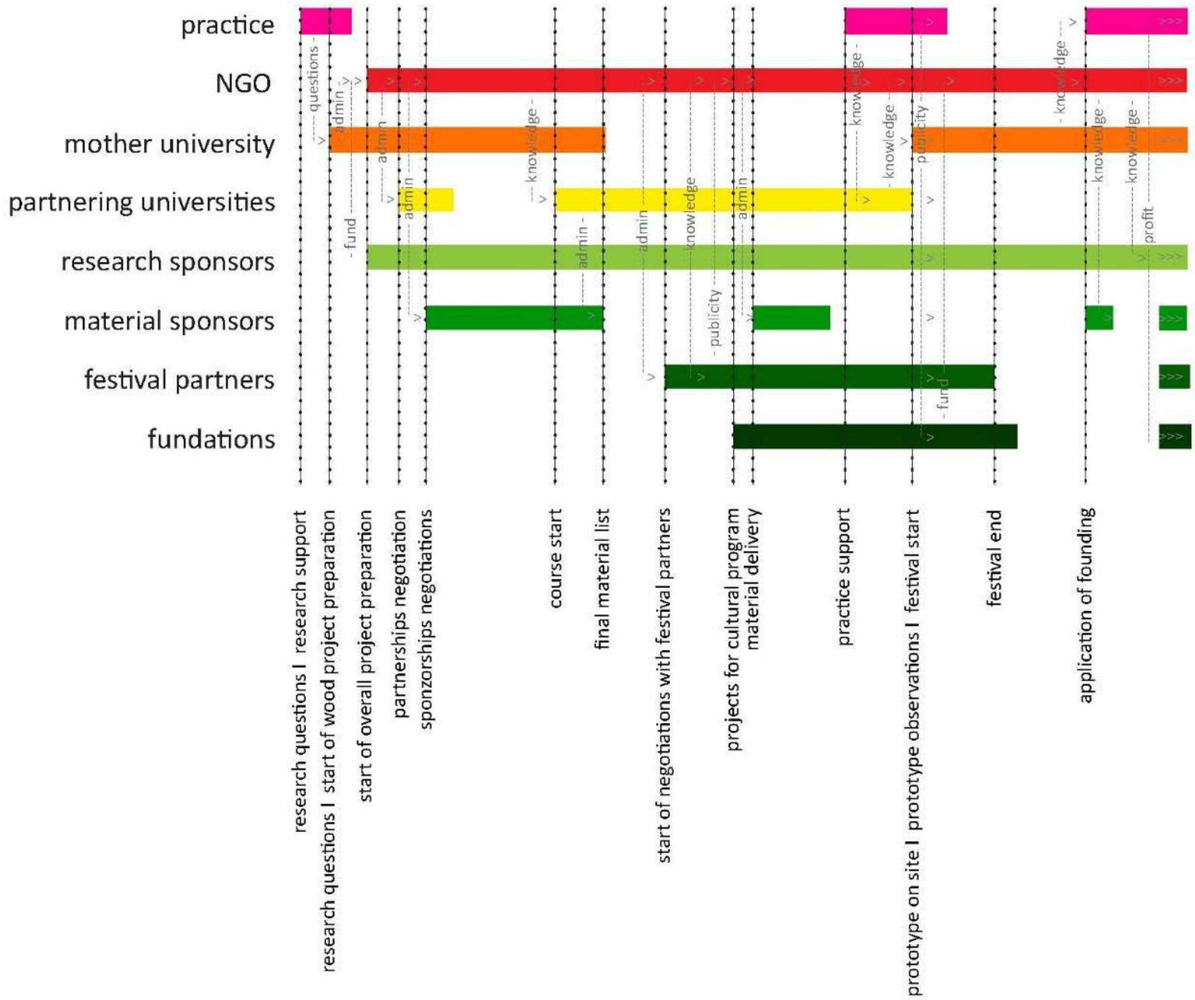

Figure 40: Action Diagram Mapping the Project Of LOOP Pavilion and EnviroCity Festival (Graphics: Davidová 2015)

6.3.5 Conclusions

The cooperation between a NGO and the universities worked perfectly, probably for the reason of one person sitting at both places. It has been proven that for some purposes organisations that are less and for some purposes organisations that are more complex are suitable. Without any of the type of them, even without the minor part of the practice, the project wouldn't have happened.

When cooperating with different types of organisations, it is possible to reach different goals, audiences, as well as financial resources. The parts that are almost impossible to solve for one organization are very easy for others.

The introduction of NGO's to Research by Design is necessary for reaching better disciplinary complexity of the projects and thus design-research results, perceived by the authors in all the fields. Especially the dance performers were very enthusiastic about receiving new inputs from the relation of dance, material – environmental – body interaction through architectural object, public space, music; and light performance, when applicable. Similar feelings were experienced by the authors of the pavilion when seeing the performers in action. The landscape architects were very sensitively commenting on the pleasant humid environment with the beautiful aroma of wood on hot summer days in the city centre of Prague. It is very difficult to explain the experience of observation as it happens in near or totally subliminal level. The interaction of materiality and environmental conditions, together with the enactment of the performers and visitors, made all experience the exploration of strong feelings.

The introduction of the research field of performative wood to the public, as well as to the performers and presenters, reached its audience even among people who wouldn't consider it as their focus of interest. The discussion with such people enriched the views of all of us.

It is more suitable to keep autonomy within organisation, not in the transdisciplinarity. While the first might lack the understanding for certain purposes, the second needs the equality for bringing benefits of particular field to the discussion.

6.4 Systemic Approach to Architectural Performance: The Media Mix in Creative Design Process

Davidová, 2017 - this paper is currently in reviewing process of FORMakademisk's *'Systemic Design'* [38]III special issue.

Following paper in review: *'Systemic Approach to Architectural Performance: The Media Mix in Creative Design Process'*, authored by me, is concluding on use of the **tools** in relation to **agents** involved in **experimental design research**. It argues for the necessity of **seeking specific methods** according to the **specific design's needs** in reference to the borders of the tools today and in the past and envisioning the future possibilities of Systems Oriented Design tools in architecture or design in general for ***'participatory design'*** and ***'co-design'*** with both **biotic** as well as **abiotic** agents, including humans. The division between these two *'participatory design'* and *'co-design'* is used here in the meaning as discussed by Sanders and Stappers (Sanders & Stappers, 2008) and as it is commonly used in Central Europe, where participation means that the related stakeholders are invited to the discussion board, while co-design means **'co-creation'** (Sanders & Stappers, 2008) where the **stakeholders** play a **creative active role** within the design process as **co-authors**. However, these notions often fuse, as mentioned in the paper. Therefore, it leads into ratification of a new design field: **Systemic Approach to Architectural Performance**. The discussion is lead from **Systems Oriented Design perspective**, suggesting integration into one **collaborative *'Rich Design Research Space'*** (Sevaldson, 2008, 2012c) which is in the same time **performative time-based never finished design result**.

6.4.1 Abstract

This article presents experiences from several design projects conducted by myself. What they share in common is that they are based on media richness and collaboration. It argues that such a complex design process is a socio technical system in its own right and is often deeply involved with natural systems.

My collaborative research in the field of Performance Oriented Design (Hensel, 2012c, 2015c) is mixing both digital as well as the physical conceptual sketches, simulations and prototyping. GIGA-mapping (Sevaldson, 2011, 2012a) is applied to organize the data within the design process. The design process accesses the most suitable tool for the task at a certain moment and the media is mixed according to the current needs. The paper discusses design methodologies of several projects and the development and trends in the tools for it. It argues that the digital tools tend to produce similar results through given pre-sets and that it often does not correspond to the real needs. This makes the need for prototyping in the creative design process more significant. Mixing of media and cooperation across the disciplines is unavoidable in the holistic approach to contemporary design. This means to bring diverse biotic as well as abiotic agents into play. I argue that for coping with this complexity physical, as well as digital GIGA-mapping, is a crucial tool. Furthermore, I propose integration of physical and digital outputs into one GIGA-map and the participation and co-design of biotic and abiotic agents into one 'Rich Design

[38] 'Systemic design is distinguished from service or experience design in terms of scale, social complexity and integration – it is concerned with higher order systems that that entail multiple subsystems. By integrating systems thinking and its methods, systemic design brings human-centred design to complex, multi-stakeholder service systems. It adapts from known design competencies – form and process reasoning, social and generative research methods, and sketching and visualization practices – to describe, map, propose and reconfigure complex services and systems.' (Jones, 2017) – I wouldn't agree on the *'human-centered'* perspective of this quotation and would extend this field to multiple biotic and abiotic actors/agents. However, as I state in the paper Socio-Environmental Relations of Non-Discrete Spaces and Architectures: Systemic Approach to Performative Wood (see subchapter 9.1) which I presented to this systemic design community, to design human-centered means to center the design to overall ecosystem.

Research Space' (Sevaldson, 2008, 2012c) resulting into an ever evolving research-design process-result 'Time Based Design' (Sevaldson, 2004, 2017b).

Keywords: Systems Oriented Design, Rich Design Research Space, GIGA-Mapping, Prototyping, Full Scale, Media Mix, Time Based Design, Co-Design, Biotic and Abiotic Agents

6.4.2 Introduction

The use of computing in architecture emerged as a big breakthrough in the nineties. Offices or collaborative networks such as Ocean (Hensel, 2015b), Nox (NOX, 2016), Asymptote (Asymptote Architecture, 2016), dECOi (dECOi architects, 2015), FOA and others, started submitting their experimental design-research proposals for competitions. These projects used computing in a highly artistic way, receiving unpredicted results from experimentations with different tools, such as animation. Sevaldson from Ocean expresses the atmosphere as such:

> *'The rudimentary traces of an experimental design practice developed further when I slowly became aware of the generative potential in the machine. The machine had the ability to surprise me.' (Sevaldson, 2005)*

Sevaldson states that the computer technology can help us to understand, visualise and design complex systems (Sevaldson, 1999), the partially developed digital tools specialized for different disciplines included a lot of bugs. All kinds of different specialist computer software were used in explorative design processes. Such tools included animation software made for the film industry, sound analysing software, biological systems simulations and others. The different disciplinary properties as well as the bugs were exploited for use in design and became a great arena for mixing such media within creative design processes of these offices. Today, design computation is most commonly discussed in regards to performance (Peters, 2013). Related to this, the term of 'media' is used here as *'an intervening agency, means, or instrument by which something is conveyed or accomplished'* (Dictionary, 2017). The first processes were sort of soft systems based compared to today's common use of parametric design, *'a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response'* (Jabi, 2013).

The rise of 3D printing techniques and technologies enabled prototyping of these design attempts and started an easier way to mix physical with digital media. The method of 3D print prototyping for innovation through trial and error in the field of product design is explained by Capjon in 2004 (Capjon, 2004). In 2005 Sevaldson discusses the *'hybrid design process'* in which many digital and traditional techniques and design strategies melt together. He discusses the mix of media in addition to the role of individuals in the team with different responsibilities (Sevaldson, 2005). Soon after, he introduced GIGA-mapping. GIGA-mapping is a type of visual diagramming which maps out complex transdisciplinary data and relations. Consequently, it appears to be currently the most suitable design tool for handling diverse data and responsibilities in teamwork of such transdisciplinary and transmedia actions.

In 2008 a special issue of Architectural Design edited by Bob Sheil called *'Protoarchitecture: Analogue and Digital Hybrids'* asked for hybrid modes of experimentation in the post-digital age with focus on prototyping in architecture (Sheil, 2008). In the same year Sevaldson published an article defining the Rich Design Research Space:

> *'The concept of the Rich [Design] Research Space includes the physical space of the design studio or research environment, the multiples of digital and analogue design media, the virtual information space, and the social, cultural and aesthetic spaces. The aim is to engage a holistic research approach and to nurture it as a skill rather than a method.'* (Sevaldson, 2008)

In 2011, Neri Oxman demonstrated an integrated approach to design and additive manufacturing technique (– adding the material – not subtracting it), by promoting a direct link between virtual performance-based design and its physical prototyping of the material systems according to the performative properties (Oxman, 2011).

Sevaldson concludes the contemporary state as follows:

> *'Design culture indicates that we are more on the soft, fuzzy and wicked side of that landscape but reality tells us that we more than often work with, e.g., technology. Technological systems at large are 'hard' and deterministic. Our lack of grips at the hard side we compensate with interdisciplinary collaborations with, e.g., systems engineers and other experts. This is not limited to the hard end of the scale but it also expands throughout the field involving in any experts and stakeholders.'* (Sevaldson, 2014)

In one aspect, today's digital design tools, such as parametric simulations and agent based simulations lack the complexity to simulate the performance of real world with its abiotic and biotic properties, including social behaviour i.e. At the same time, the tools have become overly specialized and framed with pre-sets that do not always fit practical needs.

The process is getting dominated by hard systemic approaches where soft approaches such as creative and/or complex design processes have become truncated because the two modes are not synchronised. Contemporary *'experimental'* designers are computing with an enormous amount of data, but when it comes to physical full-scale prototyping, they are experiencing failures within their output due to the fact that they are not dealing with the complexity of integrated environment.

Furthermore, experiencing materiality is important. The physicality of fabrication is often necessary for developing tacit knowledge and intuition on the individual level but especially for transdisciplinary work and co-design or participatory design, as well as in physical prototyping. In reference to prototyping and participatory design, Capjon defines his *'Negotiotypes'* as negotiated understandings of materiality within his *'Plant of Emerging Materiality (PoEM)'* participatory process model. He argues that *'physically experienced break downs inspire engaged minds to find new and innovative solutions.'* And that *'through establishment of shared atmospheres of play and wholeness experiences representing all actors' contributions, development scenarios can be achieved which resemble the above descriptions of a state of focused awareness which can unite subjective and objective representations'* (Capjon, 2005a). As a positive research tool and gain, he is mentioning *'language without words', 'basic understanding', 'behind the verbal discussions', 'shared understanding', 'catalyst for communication', 'simultaneous experimentation', 'iterations', 'radical solutions', 'playgrounds'* and *'sense feedback'* in participatory design process (Capjon, 2005b).

The concept of participatory or co-design is not new to architecture at least when it comes to necessary collaboration with the client. The difference between co-design and participatory design was explained by Sanders and Stappers, co-design as co-creation while participation as involvement of the stakeholders into discussion (Sanders & Stappers, 2008). However, there is a very penetrable boundary between the two and i.e. Szebeco and Tan are quite freely mixing the two within their co-design exemplification (Szebeko & Tan, 2010). To my understanding, this is the reason that design is no longer reduced to a physical object proposal. No matter if we discuss design for health care as the mentioned authors, or if we discuss architectural design as in my case, we are designing the performance. While these mentioned authors are exemplifying human-centred co-design, true design for complexity has to involve also all the other biotic and abiotic agents. To exemplify: a biological co-design was discussed by Carole Collet[39] on an example of grown fungus patterns on materials for interior design. However, Collet by now uses this creative co-design for generating visual effects which are stopped at a certain moment by baking it and

[39] Carole Collet's public lecture at Academy of Art, Architecture and Design in Prague 28.11. 2016

the application of such as a final product. The idea of biological time-based co-design is not new. There are historical examples, such as living root bridges in Cherrapunji from secondary roots of the Ficus elastica (rubber) tree (Watts, 2011), 'Natural architecture' movement's work mainly built from willows (Rocca, 2007) or even common living fences that have long lasting reference in traditional architecture i.e. in Central Europe. The case, when biologically grown material (wood) can *'participate'* through its *'active agency'* in interaction with abiotic agents (clime) in non-discrete design has been for long time studied in *'Responsive Wood'* project (Hensel, 2012c) I would call this participation co-design within *'Time-Based Design'*. This field in architecture has mainly been discussed by now as *'weathering'* (Kudless, 2009; Mostafavi & Leatherbarrow, 1993) that seem to slowly open the discussion towards non-anthropocentric (Hensel, 2013) perspective.

To Performance Oriented Design field, the mentioned types of co-design in relation to prototyping, unified into an ever evolving endless time based co-design discussed by Sevaldson in his Systems Oriented Design publication that is recently in press (Sevaldson, 2017b) is of particular interest.

As design has crucial effects on our living and non-living environment and vice versa, the time based co-design with overall biotic and abiotic agents as stakeholders needs to be addressed. Co-design is central to systemic design though it was not yet considered in Peter Jones' paper upgrading systemic design methods in 2014 (Jones, 2014a). But already this year (2016), this topic was widely discussed at Relating Systems Thinking to Design 5 conference in Toronto, organized by the same author. Within systemic design field, there is a tradition of participation for example through Pangaro's *'dialogues'* approached through the side of cybernetics, mixing digital media with human users (Pangaro, 2009). As such, in Prague, where one of the locations of my research is placed, participatory design is already practised and supported on public level with the released working version of Manual of Participation by Prague Institute of Planning and Development (Návrat, Brlík, Macáková, McGarrell Klimentová, & Pelčíková, 2016) as well as it is one of major requirements in most of the projects calls, funded by both public and private sector. Unfortunately, all the other than public community interests, such as non-anthropocentric environment or private business sectors are more or less excluded from the discussion. This lack of representation of diverse interests has been criticized by the author who has been invited to the working group for mentioned Manual preparation as a local NGO representative and will hopefully have an effect for the future.

Systemic Design, as a field of design for complexity, needs to adopt these tendencies to move towards more complex approaches in design, involving both biotic and abiotic inter-actors and parameters. These agents, spanning from the bacteria snow storms, involving various public and private stakeholders may address the complexity in its physicality and interaction. This cannot rely only on underdeveloped digital simulations, nor on not enough complex physical prototypes. In a similar way as it has been discussed by Koffka that the whole does not perform as a sum of its parts in Gestalt Psychology, this feature has been proved in more complex full scale prototyping in opposition to less complex digital and physical simulations by the author and her team (Davidová & Prokop, 2016; Davidová & Sevaldson, 2016a). The projects discussed below are definitely not resolving the situation but serve as my personal co-worked examples of some development in this direction.

6.4.3 Methodology

This methodology research is developed through practice of particular project's needs and agendas, and its further observations and evaluations approached by 'reflective practitioner' (Schön, 1983) within feedback looping processes. For this reason, this paper greatly refers to my design-research practice projects based publications. This *'praxiological'* perspective with *'designerly ways of knowing'* (Cross, 1999) is grounded in 'development of theory through practical investigations' (Sevaldson, 1999). Within this work, the methodology is also seen as a design 'result' within the meaning of its time-based evolution, because it employs co-design and co-designed unpredictable performance that is targeted by this work. None of the case studies discussed in this paper are considered as entirely complete but being in a continuous design-research process. Therefore, the notions of design and its methodology are not separated and both are discussed as one in following text on cases.

For each of the discussed projects, the media is often changed depending on the suitability of each task. My education started traditionally by mixing hand drawing with model making, through mixing physical and digital modelling and animations and physical computing prototypes. I eventually went on to using GIGA-mapping of complex, environment responsive systems that are sketched, physically modelled, digitally designed and simulated, sampled, full scale prototyped and afterwards observed. This is done in collaborative manner, where the actors have different roles from project to project (more in following text). The difference from mentioned traditional model making and prototyping is in its design process tooling meaning. While model is a tester of form, prototype is a tester of performance, involving diverse agents.

6.4.4 The Media-Mix in Praxis, Development Towards Co-Design

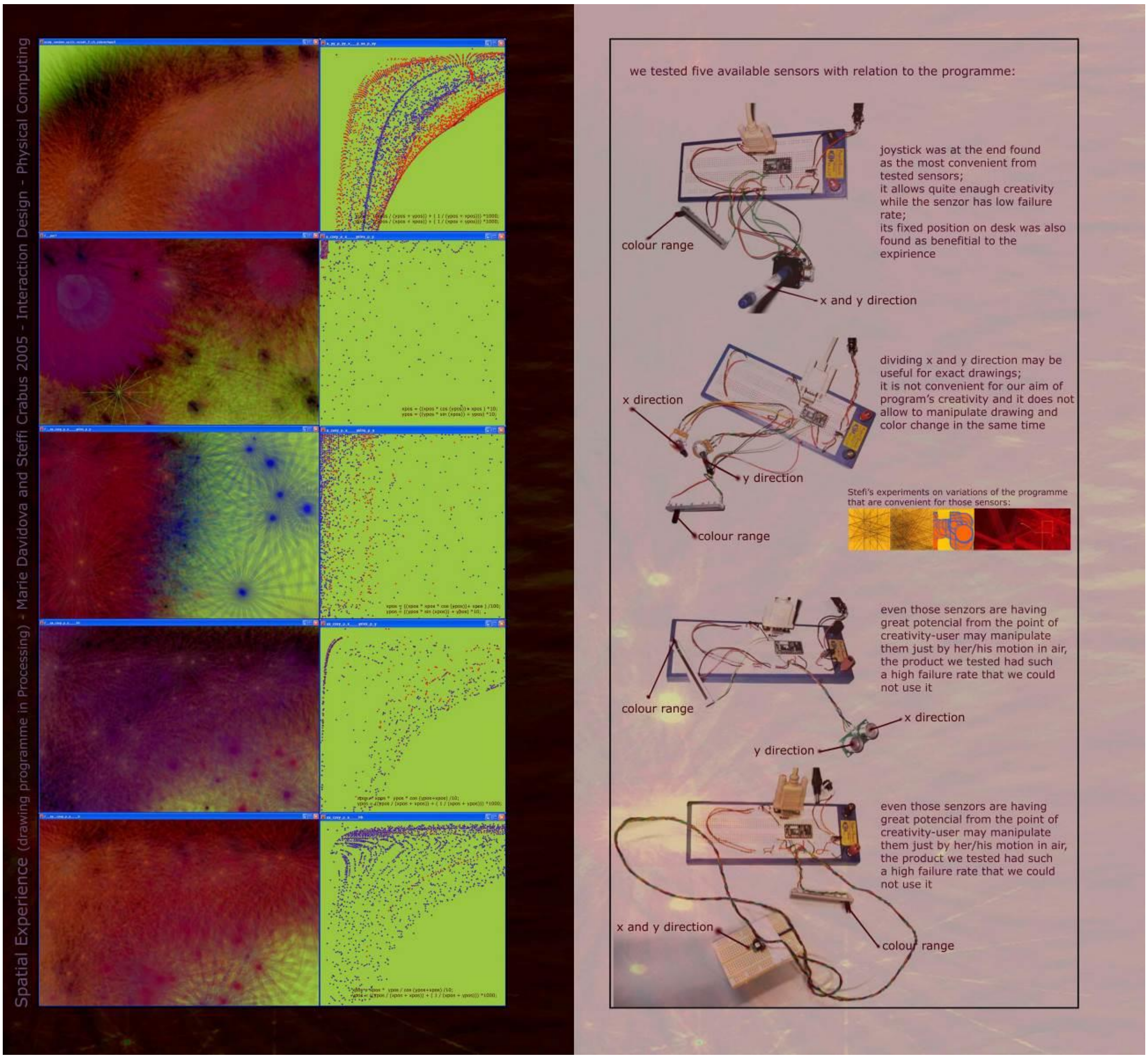

Figure 41: Davidová & Crabus: Spatial Experience, A Drawing Program for Architectural Spaces 2005

In this section I will report a series of examples based on my experience that form the basis of a media rich practice in design.

My first experience with prototyping method was in the field of physical computing (see Figure 41) – the use of computation within the physical objects or those in combinations with computer. This project was not generating the architectures viewed from today established design differentiation perspective of unchanging physical space, as such. It was a design for generating interactive architectural spaces through reading different digital sensors through script translating x and y direction into mathematics formulas with added randomising function. The tools for creating this prototype involved *Processing* software sketch book (Fry & Reas, 2016) connected through Basic programming (Lien, 1986) with *BasicX* chip (NetMedia, 2012), development computing board and various sensors that were tested for their interactive performance.

In 2006 I integrated GIGA-mapping next to the physical and digital prototyping discussed in above project. GIGA-mapping is an excellent tool to map and relate all of the mix-media and transdisciplinary data in a visual way that is necessary for designers that need to handle complexity. A sufficient and suitable software for this mapping doesn't really exist, so traditional graphics software was used for GIGA-mapping. The mapping involved is only individual work.

My first mapping that involved phenomenological *'conversations'* and its *'iterative process'* (Pangaro, 2008) was from an observation day in the city of Istanbul. The goal was to explore the complexity of this field with multiple historical development and cultural mixture. This mapping was inspired by situationists' *'derive'*, mapping cities' atmospheres (Debord, 1956) while this case involved equally both, biotic as well as abiotic factors. The phenomenological journey was composed of unintended pathways based on intuitive walking and stepping into random public traffic devices, moderated by interactions and conversations with locals. The GIGA-map mixed media format made up of photography, written reports from experiences of interacting with locals in different places, city soundscape and personal conversations recordings on MP3 players and physical objects/souvenirs – mainly music instruments – connected to the board by wires to interact. This map served as a tool for both analysing and memorizing, as well as an exhibition artefact, reporting this study trip.[40]. The multi-media and interactive character of the map involving physical performative objects helped to communicate and generate experience of the multi-layered phenomena of the city, rising curiosity followed by discussions – *'conversations'* of/with the exhibition audience – students and academic stuff of the school passing by.

The following example demonstrates a mix-media GIGA-map next to the prototypes with performative capacities, interacting with sound, light and radio waves operated through material-temperature interaction related properties generating movements of the designed installation through *'nano-wires'* - *'shape memory alloys'* (Kumar & Lagoudas, 2012). In the mapping in the project HOLOSLO: The Penetrating of Latent (Davidová, 2007, 2009)(see Figure 42), I used only computer generated graphic images and diagrams while physically adding the relations by different color-coding with fishermen's strings (see Figure 43) and attaching sound and radio scanned recordings on MP3 players. The map was constantly used in relation to the prototypes of this proposed environmental performative installations design spread over the city of Oslo and speculative animation of the performance. Within the design-research process, this was to relate computer generated models, processes analyses and recordings, mapping the paths of different data sources that were parameters for the proposed design sound, light and radio waves responsive city urban design operated by local micro-climate temperature. Some of the features of these environment - responsive installations (see Figure 44) over the city of Oslo, such as acoustic responsiveness of these geometrically complex moving objects, combined of flat and hyperbolic reflective surfaces, would be almost impossible or very difficult to handle in computer simulations, while easily physically prototyped.

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[40] study trip of the Birger Sevaldson's, Per Kartvedt's and Geir Øxseth's Complexity and Systems Thinking studio at the Oslo School of Architecture and Design

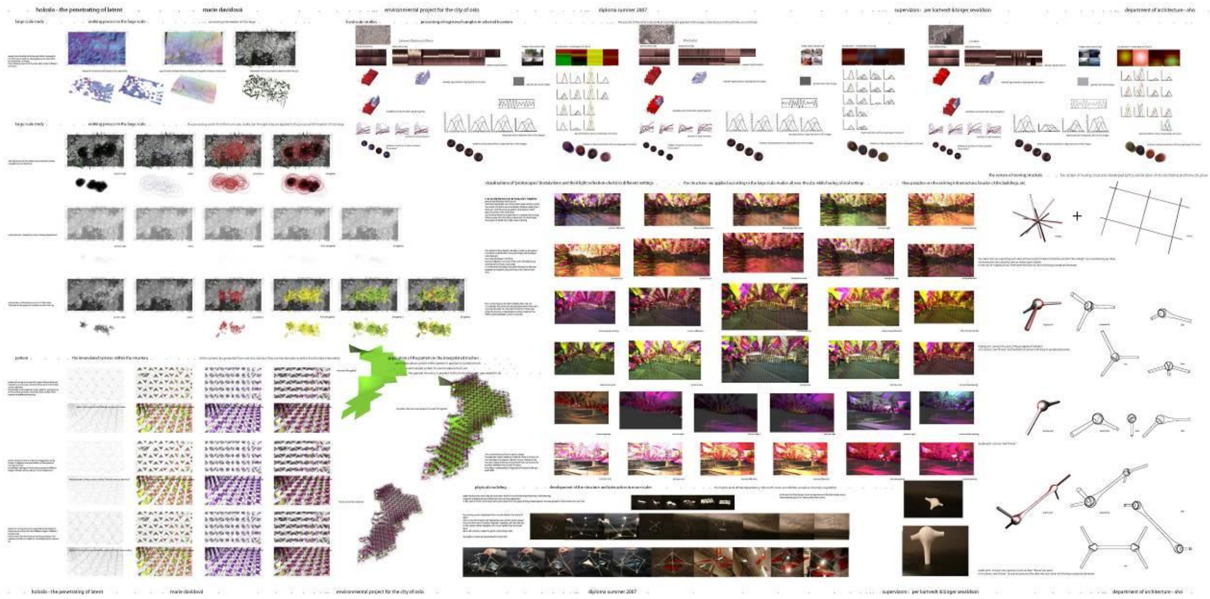

Figure 42: Davidová: HOLOSLO: The Penetrating of Latent, diploma thesis at the Oslo School of Architecture and Design, Supervisors: Sevaldson & Kartvedt 2007 – please, zoom in at Systems Oriented Design's Giga-Mapping Gallery (Sevaldson, 2017a)

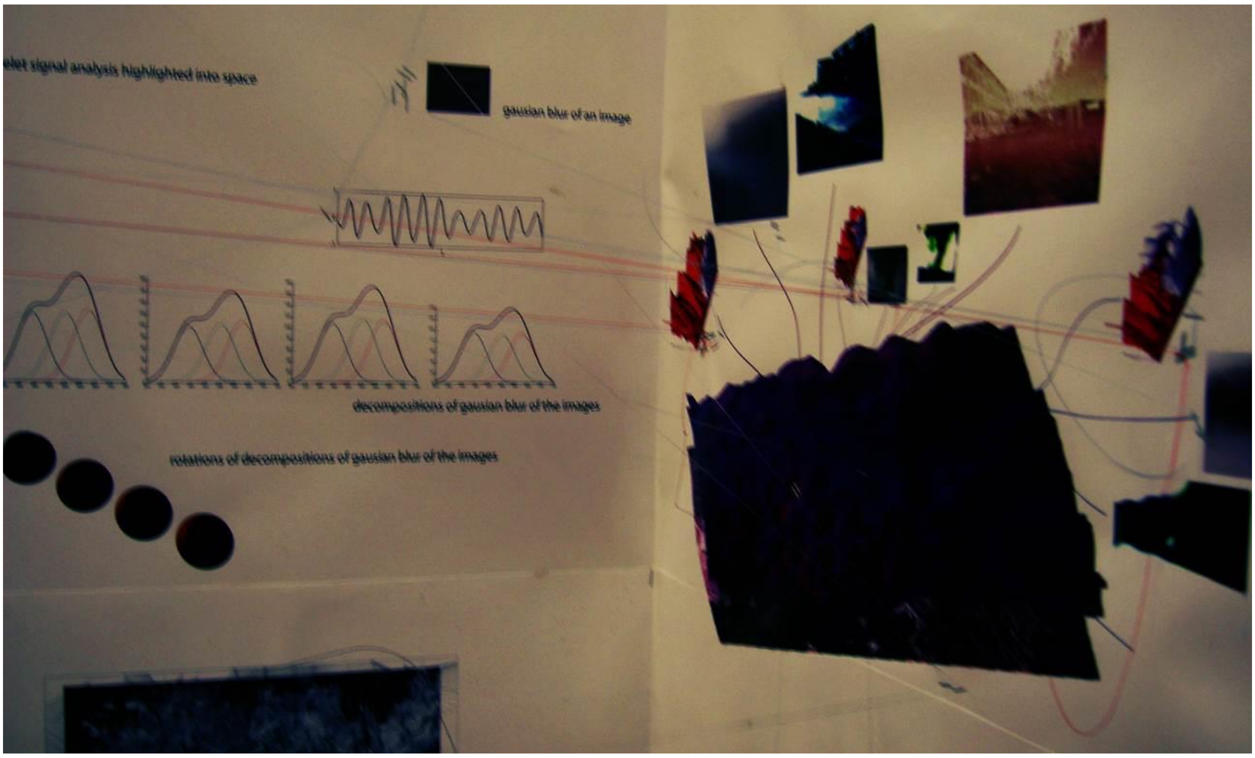

Figure 43: Figure 3: Davidová: Color-coding with fishermen strings in GIGA-map of HOLOSLO: The Penetrating of Latent, diploma thesis at the Oslo School of Architecture and Design, Supervisors: Sevaldson & Kartvedt 2006 (photo: Žilinek 2006) – please, see the poster at Systems Oriented Design's Giga-Mapping Gallery (Sevaldson, 2017a)

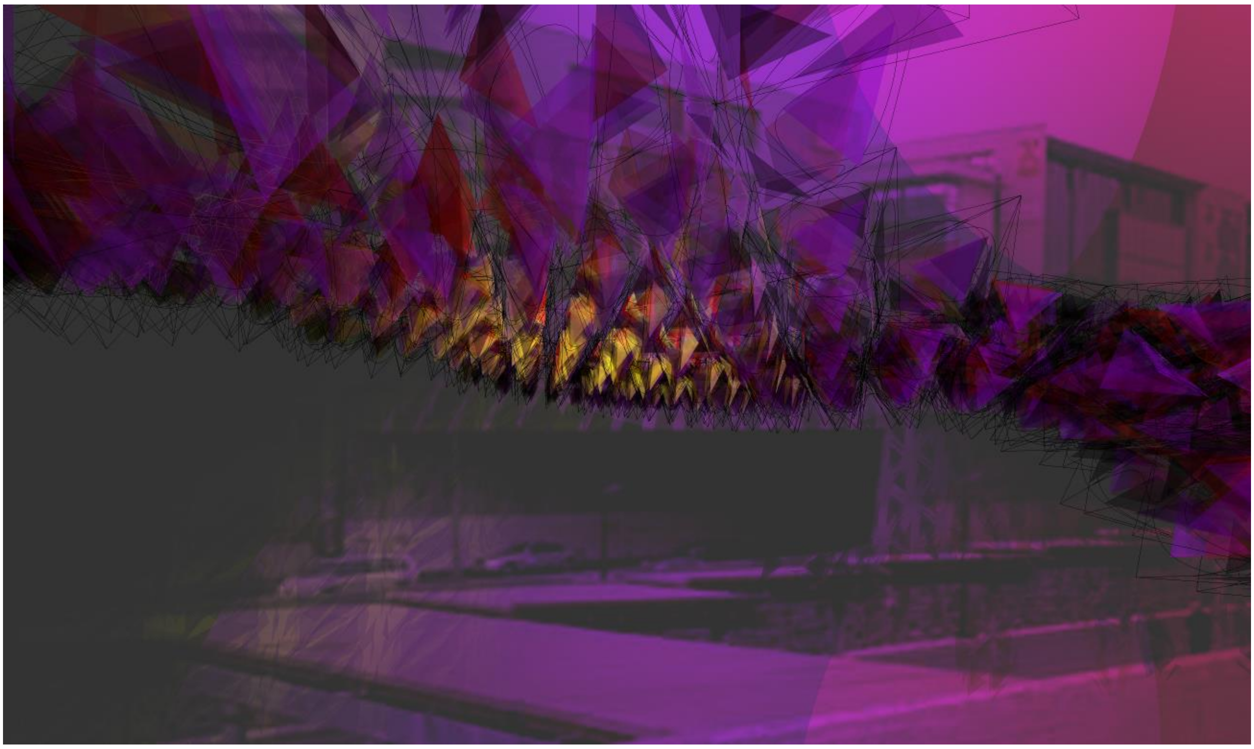

Figure 44: Davidová: HOLOSLO - The Penetrating of Latent Installation in Lysaker, Oslo 2007

The media included sound, radio waves and visual video recording and my synesthetic, a synchronised stimuli of diverse senses (Pallasmaa, 2005; Stower, 2006), visualising of recorded sounds. These samples were wavelet analysed (The MathWorks, 2016b) and colour decompositioned into basic colours components similar to the imColorSep command in *'MATLAB'*, a tool for analysing data, developing algorithms, or creating models, (The MathWorks, 2016a), with the difference that the data were represented in composition graph, all analysed in *'MATLAB'*. This was read from 2D colour coded vector field into 3D surfaces in *'Rhino 3D'* a 3D nurbs modelling software (Robert McNeel & Associates, 2016) originally developed for boat design. Similar way were processed several *'MATLAB'* wavelet analysis of Oslo city landscape and demographic data plans, interpreted through reading by a *'voronoi'* (Okabe, 2000) plug in for *'Rhino 3D'*. This served as a background for *'Rhino-'* scripted[41] model and physical prototyping/rapid prototyping development of the installation – from its material-systemic performance to the detailing of movable joints. The recorded local environmental data informed the physical properties of the installation in order to be responsive to it. GIGA-mapping, together with prototyping, in this project was engaged as the design process, synchronising media-mix database, analysis, speculation, all feedback looping within an evolving design-research process development and its registering. The meta-mapping of registering process within the process plays a crucial role especially because the data should be reduced as less as possible. This enables the previous less focused options to be more relevant in later stages of the process. This means that the mentioned feedback looping is composed of several layers and the time-base of the design is not linear but rather layered iterative.

6.4.5 Media-Mix within Time Based Co-Design

The project SpiralTreeHouse (Davidová, 2013c, 2014d, 2016j) (see Figure 45) was co-designed by its client, geologist Prokop Závada, our volunteering co-building friends and the surrounding local natural environment. This is a situation of when the computing tools in design are not sufficient enough to handle the complexity one faces when interacting with a biotic and abiotic environment. The house was

[41] *'RhinoScript is a scripting tool based on Microsoft's VBScript language. With RhinoScript, you can quickly add functionality to Rhino, or automate repetitive tasks.'* (McNeel, 2017)

built in public forests from the trunks harvested from a dying, unnatural, densely seeded pine forest, a monoculture from the communist period. The project was built under a personal verbal agreement with the forest keeper on the basis that the project would improve the conditions of the forest. Its helix self-standing dynamic structure is climbing based on its joint system geometry which doesn't rely on trees but synchronically joins it dancing in the winds. It serves as its spiral ramp access in the form of a climbing structure and as a frame for its removable fabric cocoon.

Figure 45: Davidová & Závada: SpiralTreeHouse – Project Start in 2010 (photos: Davidová 2010 and 2012)

Not a single drawing was made before we started to build it, only an abstract physical sticks mock-up of the structural system geometry was sketched. Through the process building, the thickness and the angle of the logs were tested in 1:1 scale. When the entire structure was built, it was measured on site to digitally model the fabric for the removable cocoon in Rhino3D. At that time, Rhino Nest plugin (TDM Solutions SLU, 2016) for nesting the surfaces from 3D model into 2D canvas was not yet advanced in organizing the orientation of the parts. Therefore, the sewing drawings had to be adjusted by physically on canvas in order to respect the rain protection of the folds in the environment.

Alternatively, if we were to model the project by a traditional method by solving all design issues before starting to build, we would have to make a 3D scan for each log because the thickness of the log defines the angle (see Figure 45). We would have also had to run a structural analysis which in that time the fibre direction of the wood wasn't taken into consideration. In addition, the cocoon's natural ventilation with the central fire place functions similarly as a Native American tepee. All of the properties were analysed physically through experimental building – co-designed with naturally grown biological material properties and its attached trees and surrounding physical environment. We used our experience and tacit knowledge instead of a simulation that would require much more work with less holistic and useful output.

The further 'Time Based Design' (Sevaldson, 2004, 2017b) process is already also co-designed with other species of the forest (see Figure 46). We gave the basis of moss on the platform and plan to gain support of the construction with local climbing ivy in the future. From Figure 45 one can observe how the structural organization of logs defines the moss' habitation. At the same time the moss co-creates the platform, giving it comfortable surface for human's overnighting among other properties. For this reason, the project's design develops over time in relation to its environment and will be taken over by nature where all of its material originates from. These biotic processes would be very hard to simulate as the empiric experience of such complex conditions is lacking. Therefore, the SpiralTreeHouse serves as a symbiotic prototype for observations of such environmental performance. Being built in public forests nearby Prague, the structure is accessible to be inhabited and therefore co-lived and co-designed by variety of species, including people.

Figure 46: Davidová & Závada: SpiralTreeHouse - Local Moss Inhabiting the Platform after One Year of Seeding. Notice the Habitation Based on the Structural Direction of the Logs (photo: Davidová 2012)

Further investigations on time based co-design where done in my PhD project supervised by Florián and Sevaldson. The project Wood as a Primary Medium to Architectural Performance that's main focus is clime-material interaction, covers prototypes of two pavilions (Davidová, 2013a, 2014a, 2014b; Davidová & Prokop, 2016; Davidová et al., 2013; Nam, 2013; Slavíčková, 2014) (see Figure 51), one responsive screen (Davidová, 2013b, 2014e) (see Figure 50) and one responsive envelope (Davidová, 2016g). Samples observations data were mixed with *'Grasshopper'*, a graphical algorithm editor integrated within *'Rhino 3D'* (Davidson, 2016) that is used in parametric design, code here. The results from the measuring of the climatic conditions with a digital weather station and its material response with slat with a hole through and calliper (see Figure 47) and electric moisture meter combined physical and empiric data with a simple geometry-based code in Grasshopper for performance design simulation and further concept development. As discussed with programmers specialised in complex environmental simulations, to write a code that would be considering complex environmental data with a material responsive systems such as mentioned prototypes that are defined by trunk's moisture content at the time the material is cut as well as by its spatial position in the log, would be very difficult. Different transdisciplinary data, including forestry, meteorology, wood science, craftsmanship and different types of wood fungi, my own samples observations of the material-environment performance of micro-climate and algae, as well as the design process, have been GIGA-mapped since the time of the literature survey until the realisation of the full scale prototype (see Figure 48 and Figure 49). The prototype Ray 2 is placed under a forest hillside nearby Prague. Therefore, rich biotic and abiotic environmental interaction takes place at the site. The performance is co-designed and co-created with blue stain fungi, algae and lichen that together with the micro-climate operate the moisture content of the material and thus provide warping. At the same time, the material moderates the micro-climatic environment when its change occurs, getting into its equilibrium state and the habitation of algae, organized according to its fibre direction (see Figure 50).

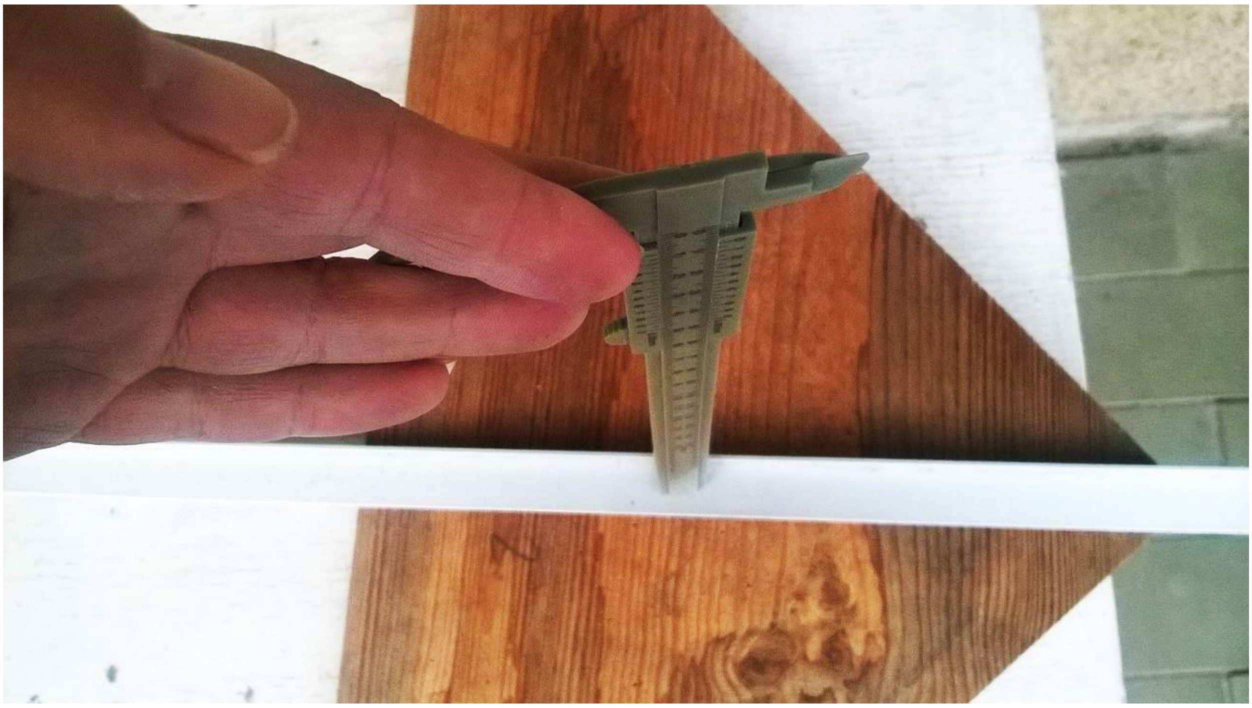

Figure 47: Samples Measuring with Slat with a Hole through and Caliper (photo: Davidová 2016)

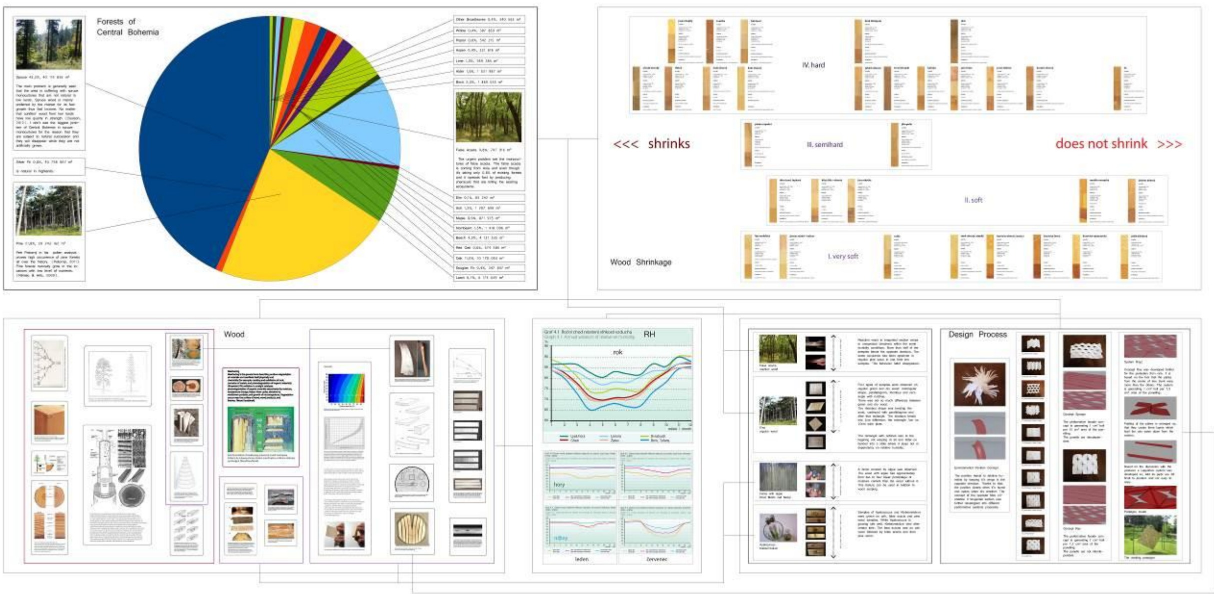

Figure 48: Davidová: Environment Responsive Screen GIGA-map, Showing Transdisciplinary Relations within the Project, Research by Design GIGA-Map (Davidová 2013 – images from Forest Products Laboratory, 2010; Hoadley, 1980; Menges, 2009; Němec, 2005; Tolasz & Coll., 2007 or photographed by the author, used with the courtesy of USDA Forest Products Laboratory, Taunton Pres, Achim Menges, Grada and Tolasz) – please, zoom in at Systems Oriented Design's Giga-Mapping Gallery (Sevaldson, 2017a)

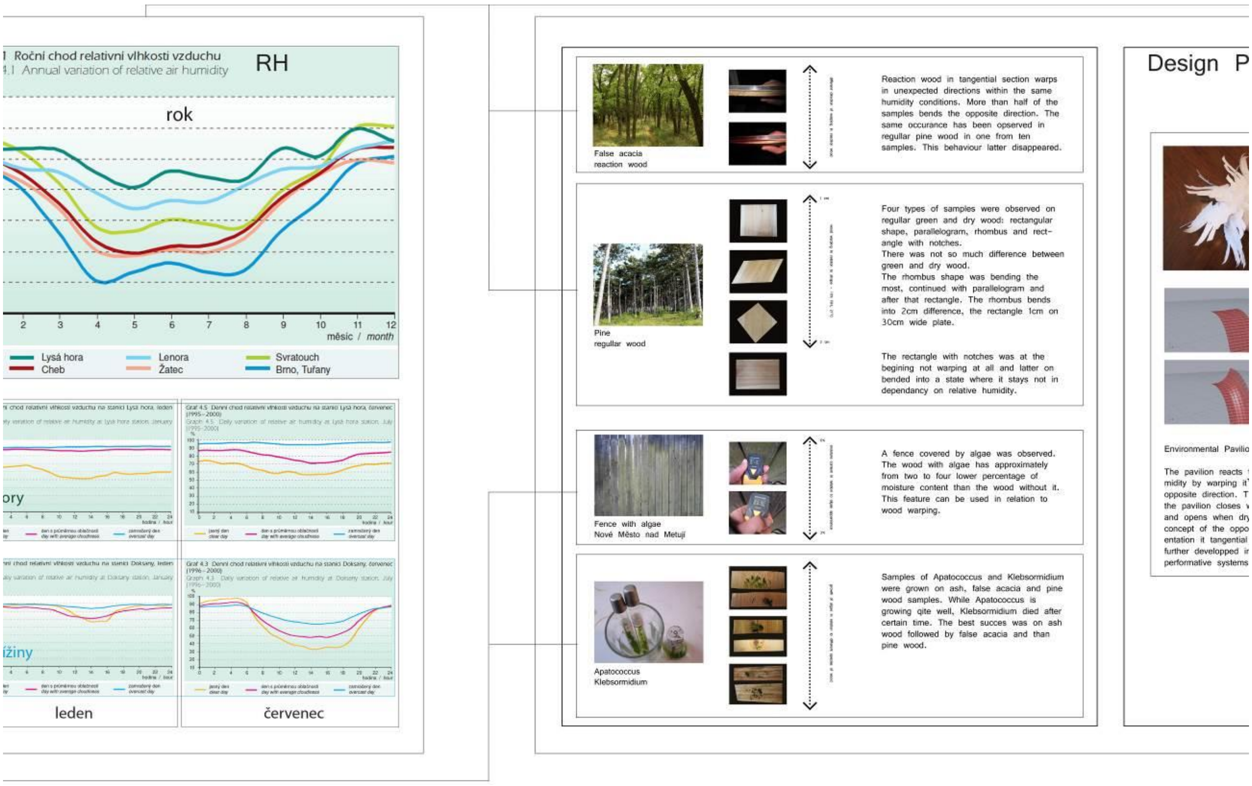

Figure 49: Davidová: Detail of Environment Responsive Screen GIGA-map Showing Climatic-Forest-Tree Specie – Wooden Material Relations and/or Summaries of Samples Observations Evaluations in Reference to Design (Davidová 2013, climatic diagrams from Tolasz & Coll., 2007, used with the cortesy of Tolasz) – please, zoom in at Systems Oriented Design's Giga-Mapping Gallery (Sevaldson, 2017a)

This interdependency shows that transdisciplinary relations are crucial in Performance Oriented Design for the reason, that the agents in game are trans-related regardless peoples' knowledge and skills disciplines specified by humans. This corresponds with the use of non-one issue focused images in my personal mappings or mappings organized by myself in co-design. The work is focused on mapping with images as opposed to vector graphics icons. The reason is twofold: it corresponds better to the media used in my research field and at the same time from my experience, the image provides more in-depth background information, even on a subliminal level, that might not be of much interest with mapping but may be of greater interest later in the design process. By referring to the commonly used slogan by architects, *'one image says all'*, I am able to avoid any loss of data even from an emotional perspective. Different impasses which remained on the board were unexpectedly used when concluding particular design issues. Because of this non-single orientation of mapped 'items', the GIGA-map has more layers and is way more complex. It maps the performances of the whole as well as relations inside the images and among them. This way, better tacit knowledge is generated in a similar way as it is used in here prototyping. Therefore, across the discussion board and prototypes, there are also said phenomena for which we do not have words due to the lack in language as well as lack of language skills across international teams.

While working in transdisciplinary teams in the material-clime-responsive wooden pavilions projects focused on moderating 'city heat islands' (Meteorology, 2009) (see Figure 51), handling the data became crucial (see Figure 52). Here GIGA-mapping proved its value in the generation of the design process that was discussed in a separate paper (Davidová, 2014c). The physical collage of printed computer generated data/images and site photographs, connected by threads with pins, covered the team's and external co-operators' holistic overview in relation to the design of the performance and its physical material prototyping. The GIGA-map was organised as a timeline according to the responsibilities in the team. My previous GIGA-map from the responsive screen project was used as a starting point as a scientific background for the complex project (see Figure 48).

Figure 50: Ray 2 Prototype Being in Time-Based Co-Design with its Micro-Climatic Conditions and Blue Stain Fungi, Algae and Lichen that Inhabit It, All Regulating the Moisture Content of Wood, Thus Causing Warping. Notice Also the Organisation of Algae Habitation Caused by Material's Fibre Direction and Thus Moisture Distribution (photo: Davidová 2016)

Figure 51: LOOP Pavilion (photo: Exner 2014, with the courtesy of City Council of Prague)

Figure 52: LOOP Pavilion Design-Research Process GIGA-map as a Result of Transdisciplinary Studio Course[42] (administrator of the map and photo: Pokorný 2014) – For high resolution image see Systems Oriented Design web site (Sevaldson, 2016b) or RSD5 proceedings (Davidová, 2016d)

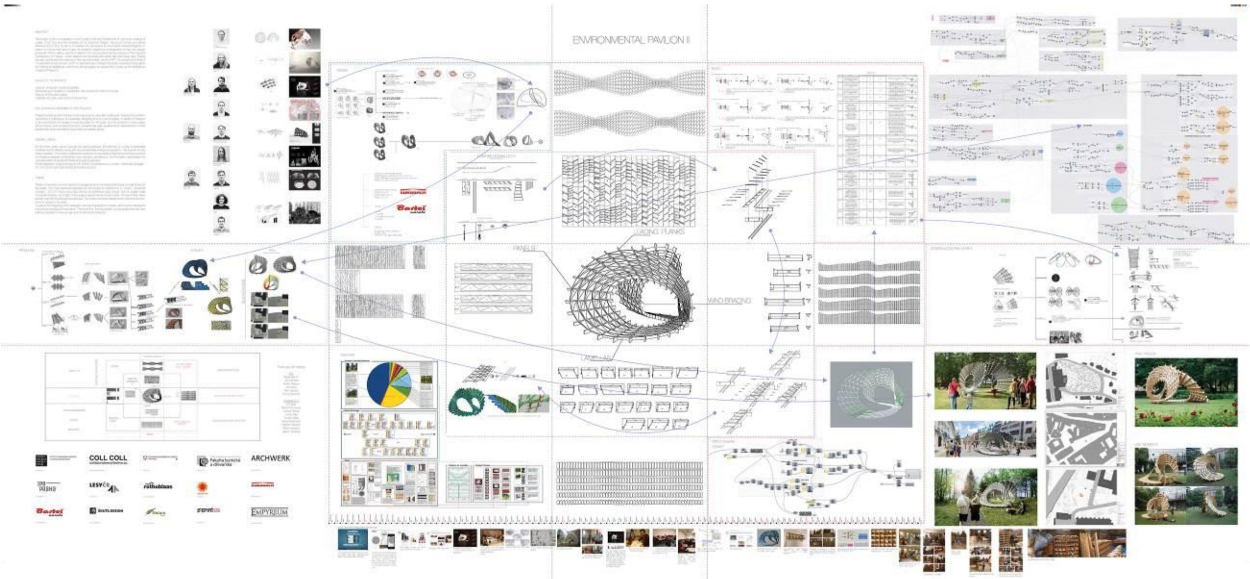

Figure 53: LOOP Pavilion GIGA-map as a Result of Transdisciplinary Studio Course (administrators of the map: Hrušová & Pokorný 2014) – For high resolution image see Systems Oriented Design web site (Sevaldson, 2016b) or RSD5 proceedings (Davidová, 2016h)

The media, such as digital 3d scanning, Rhino, Grasshopper for Rhino, its Lady Bug (Sadeghipour Roudsari, Pak, & Smith, 2013) and Donkey (Svoboda, Novák, Kurilla, & Zeman, 2014) plug-ins for environmental performance simulation, physical prototyping and testing of joints, CAD/CAM and digital fabrication, V-ray rendering plug-in (Visual Dynamics, 2016) and Photoshop image processing (Adobe, 2016) for visualising the public and public space relations and atmospheres were involved. Simultaneously, the Facebook group discussion and cloud file sharing at Copy (Barracuda Networks, 2016) was a crucial part of the team's organisation. The media richness was an important element of generating the social network of the project, the project's development and the pavilion itself. Several times reorganized, the collage GIGA-map (see Figure 52) was a generator of collective creativity by addressing the visual relations on discussed topics. Unfortunately, the digital analysis tools, as well as the physical joints tests, proved to be a failure when it came to whole 1:1 scale prototype. This clearly argues

[42] tutors: Marie Davidová, Šimon Prokop, Martin Kloda, students: Alena Novotná, Anna Hrušová, Antonín Hůla, Barbora Slavíčková, Jakub Kopecký, Jiří Fáber, Jiří Pokorný, Petr Tůma, Tereza Jílková, Radim Sýkora, Eliška Antonyová, Tereza Lišková, Filip Janata, Tomáš Kytka, Marie Kortanová, Vojtěch Holeček, Martin Vaníček, Jakub Hlaváček and Petr Havelka 2014

for integrated holistic mapping, prototyping and simulations. But today design tools are not developed for such ‘hybrid processes’(Sevaldson, 2005). As a discussion on today’s situation, Sevaldson suggests switching the media across the board:

> ‘Start with simple, low-threshold media like big paper rolls and markers but switch to other media later. Redraw the mapping on your computer and plot it out in large formats to continue working manually. Then repeat the process with new iterations.’ (Sevaldson, 2012b)

Figure 54: Opening of EnviroCity Festival with Public Lecture and Discussion on Design-Research (photo:Dvořák 2014)

In this case, such iterative process was done by reorganizing the existing mapping, thus finding and redrawing new relations and the overall map over time. Finally for presentation purposes, a digital GIGA-map was designed ex-post, exhibiting the complexity of the project at the multi-genre EnviroCity festival (Davidová & Kernová, 2016; Kernová, 2014) (see Figure 53 and Figure 54). The map was not organised as a timeline but according to different topic areas and their relations, thus saving a lot of white space on the board for print’s budget reduction. For the next time, it would be interesting to leave that white space as an interaction field for the festival’s visitors. A similar method for participation and co-design in public space has been in the location used for a long time i.e. by the activist group Uličník (Ulicnik, 2016) with board and yellow stickers, engaging the local neighbours to comment on local community and public space issues.

Figure 55: Landscape Architect Jolana Říhová Discussing the Design-Research from Her Discipline's Perspective (photo: Novotná 2014)

Figure 56: Pavilion's Embodiment by Dancer Kateřina Dietzová (photo: Novotná 2014)

Figure 57: Pavilion's Embodiment by Black Bird (photo: Škuta 2014)

In contrast to what Koskinen at.al. states in his discussion on 'Showroom' as a research arena that design provides a *'script'* that people are assumed to follow, and they usually do or *'making people think'* borrowed from art (Koskinen, Zimmerman, Binder, Redstrom, & Wensveen, 2011), this design-research is driven by opportunistic interaction. Such interactive participatory and co-designing exhibitions-events serve as a research tool in Time Based Co-Design-Research. In this case, this was supported by pavilions' performative objects-prototypes, *'enacted'* and *'embodied'* (Merleau-Ponty, 2002) by locals, audience (see Figure 55), festival events' multi-genre performers (see Figure 35, Figure 39, Figure 55 and Figure 56) or even by city birds (see Figure 57), not having other suitable place to rest on within the built up environment. We found the inter-active exhibition of the complexity of the design process for an audience next to the full scale prototype very successful. And though not fully interactive, the GIGA-map encouraged more engaged participation at a discussion level, especially when the lecture about the project was performed at the festival in the pavilion (see Figure 54) – the physical full scale performative prototype next to the GIGA-map. As such, it stood as a co-design tool, engaging the participants through festival's public events both the locals and the festival's audience as well as the performers within its environmental city perspective topic.

6.4.6 Discussion and Conclusions

From my observations, some of the creative artistic processes were lacking in new tools development while others have appeared through its increased collaborative, physical and real-time based character. A small amount of pre-sets and predefined codes are often repeated without any in-depth considerations and understanding regarding the current practice and education. The newly emerging technical digital tools often fail to predict the performance as well as engage the designer's cognition compared to full scale prototyping and physical GIGA-mapping practiced, enacted, embodied and observed within a time-based co-design process. The single field focused tests such as FEA or even partial physical prototypes in general lack the overall complexity of the design and its ambient local environmental data. Therefore, mixing the media and agents is a necessary approach within the creative design-research process that also operates much better in addressing full scale physical prototypes. For operating such a great amount of mixed transdisciplinary data, multi-media GIGA-mapping seems to be the most suitable tool at the moment, though the future development might fully merge all of these. This requires large interactive space with different agents and as discussed, public spaces seem to be engaging for such. This research is fusing the mixed media into generative time based endless co-design, which seems to address the future visions of a digital world becoming directly physical with no need of further discussion of these borders and translations. Today, creative design tools of participation and co-design often fail by not managing to communicate to the actors that do not have designer's reading and executive skills and confidence. Therefore, the research proposes improvisational opportunistic interaction of overall biotic as well as abiotic environment as opposed to *'making people think'*. From my observation, human participants seem to do well with GIGA-mapping but in fact all the agents are largely getting engaged by addressing physical objects, while having the opportunities of *'enactment'* and *'embodiment'* of its performative capacities. Therefore, the research searches for GIGA-mapping in the physical space of performative objects, involving all – biotic and abiotic participants. This is continuing Allan's discussion from 2001 of what architecture can do opposed to its meaning (S. Allen, 2011), while joining the media mix with physicality, being the real builder and constructor and, most essentially, crossing the disciplines' borders while interdisciplinary working through participation and co-design involving and generating the theory. In this way, the GIGA-map, prototyping and participation/co-design generates fully environmentally engaged, 'Rich Design Research Space' that is discussed by Sevaldson (Sevaldson, 2008, 2012c) as an ever evolving 'Time Based Design' (Sevaldson, 2004, 2017b) in public space.

7 The Material in Relation to Environment

7.1 Abstract

This chapter covers the discussion on material selection from its **eco-systemic, resource and material performative properties perspective.** Analysing the eco-systems of the **forests** of research's location and the **material's micro-climatic and biotic interactions** in relation carpentry of it lead to extended number of interviewing, observations, sampling and registering. Data for such **design-research** were not available and if they were, they merely differed from of what was registered on samples or discussed with experienced craftsmen, wood material scientists or traditional open air museum's research and preservation staff, most likely for its simplification. It exemplifies the ***'programativity disadvantages'*** of the use of solid wood but also the in depth investigation to **its conclusion**. However, this topic is rather theoretically concluded in closing chapter of this thesis in relation to its **eco-systemic application**.

7.2 Introduction

This thesis is a case study in the field of responsive wood within the field of sustainable Performance Oriented Architecture through a Systems Oriented Design approach. Therefore, a deeper look at the material, its origin and relation to environment was crucial. While analysing more closely the forests ecology of Central Bohemia, which is the central location of the research, the conclusions on the sustainable selection of species applies to a much broader region, but definitely should not be taken as a general rule for selecting only one species for whatever purpose and ecology. This selection was also evaluated through species specific wood – environment interaction, zooming into its properties. More complex environment-material interaction data has not been published in this field and therefore much of that had to be observed on the samples and prototypes. In addition, often what was published did not correspond to what was observed on the samples or experiences of engaged disciplines/professions shared through personal conversations. This area definitely requires larger research extension within broad transdisciplinary team. By now, only the data relevant for direct design practice sustainable application in relation to suggested designs are elaborated, as this is the topic of the thesis.

I would argue that each project requires this or even deeper analysis when selecting the material. The disadvantages of LCA were discussed in the LCA Analysis Comparing Solid Wood and Laminates subchapter. For this topic, I think it is more relevant to discuss future speculations. Furthermore, LCA has only a chemistry perspective and not all the consequences might be predicted through such when it comes to its biotic interaction. In my mind, there is not really any suitable simulation of this kind at the moment, though many efforts have been done. For this project, the forestry data was related with material performance in selection through GIGA-map (see Methodology: Systems Oriented Design and Research by Design while 1:1 Prototyping chapter), that took part all the way through design research process.

7.3 Ecology of Forests and Trees in Central Bohemia in Relation to Material

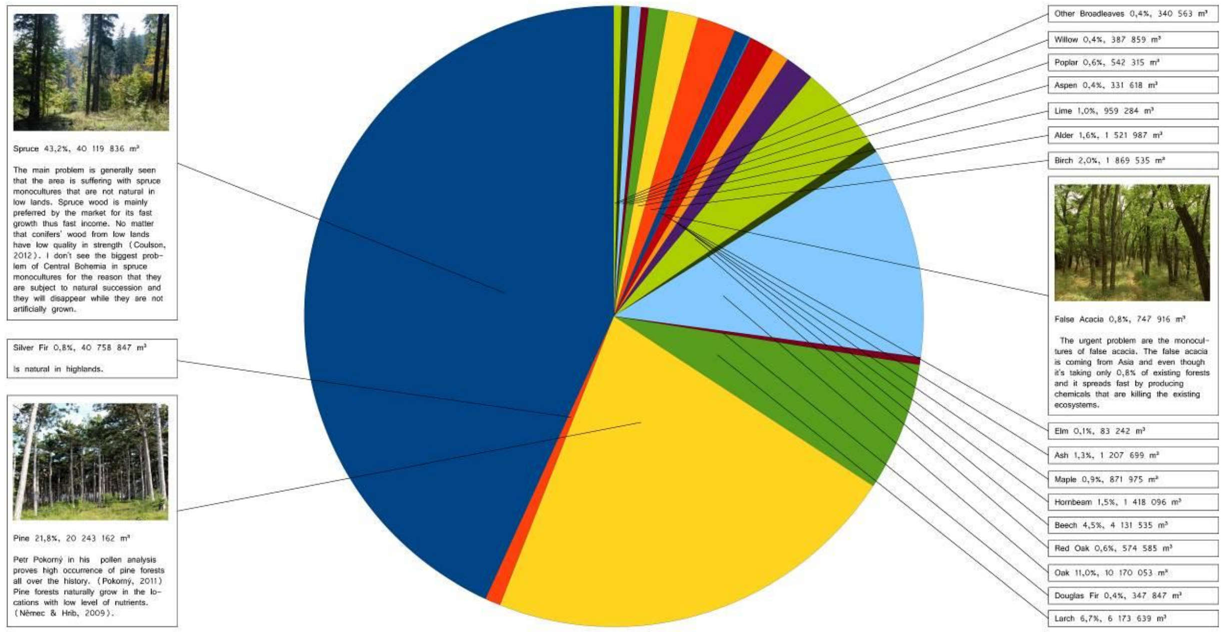

Figure 58: The Percentage of Tree Species in the Forests of Central Bohemia (diagrammed by Davidová 2013; data used from Forest Management Institute Brandýs nad Labem, 2012)

To design a truly sustainable product it is necessary to look at which wood is good to harvest in relation to forestry-material aspects. The importance of an increase of biodiversity in forests is discussed in the European Union's biodiversity strategy for 2020 (European Comission, 2011). The aim is addressed by Fares and coll., discussing this issue in reference to climatic change, proposing biodiverse forests adaptation while supporting local suitable species also accepting those from locations of more extreme regions. Fares and coll. are specifically naming pine wood as suitable for harvesting forestry in this context (Fares, Mugnozza, Corona, & Palahí, 2015). This direction of introducing external species to keep biodiversity makes sense only in very sensitive selection. As discussed later, unsuitable invasive species may create serious harm to local biodiversity and turn into extensive monocultures. Also, in some cases of grounds and climatic conditions, monocultures may be natural as a result of more adaptive species to certain conditions. It would therefore be hard to force biodiversity through a non-adapted species, thus invading local ecologies that may cover different, environment-specific biodiversity.

Since Prague is the central location of my research, I was looking closer at the forests of Central Bohemia (see Figure 58). The long lasting governmental plan of forest management in Central Bohemia is focused on renewing beech and oak forests that are natural to the environment (Němec & Hrib, 2009). The main problem is generally seen in the fact that the area is suffering from artificially grown spruce monocultures (43.2%, 40 119 836 m³ (Forest Management Institute Brandýs nad Labem, 2012)) that are not natural in lowlands which are common in many large areas of Central Bohemia. Spruce wood is mainly preferred by the market for its fast growth resulting in fast income. It was, and often still is, an ignored fact that usually conifer wood from low lands have low quality in strength due to fast growth (Coulson, 2012). I don't see such big problem of Central Bohemia with spruce monocultures for the reason that they are subject to natural succession, since these events according to Bellasen and Luyssaert are insignificant over decades and at the global scale, though having large socio-economic and ecological impacts regionally (Bellassen & Luyssaert, 2014). And in this case, the local ecological impact would be positive. Spruce monocultures will slowly disappear while they are not artificially-grown, as the rejection of their promotion in their unnatural locations is covered in the long lasting plan of governmental forest management in the Czech Republic (Němec & Hrib, 2009).

The urgent problem is widely experienced in the monocultures of false acacia. The false acacia is coming from North America and even though it is taking only 0.8% (747 916 m³) (Forest Management Institute Brandýs nad Labem, 2012) of existing forests, it spreads fast by producing chemicals that are killing the existing natural eco-system. The false acacia was grown in the past for honey production. According to the Forest Management Institute Brandýs nad Labem, most of the trees are about 70 years old (Forest Management Institute Brandýs nad Labem, 2012). This means that they are ready to be harvested and if the roots are removed, it will no longer propagate.

By observing the behaviour of the samples of false acacia, the material performed unexpectedly. Some samples cut in the same circumstances were swelling and some were shrinking. Based on personal conversations in 2012 with wood scientist Aleš Zeidler from FLD CZU and axeman Josef Kudrna, this was caused by the reason that the samples were made of reaction wood. Having a closer look at the false acacia monocultures in Central Bohemia, it was discovered that many of these trees are most likely to be reaction wood for the reason that they invade mostly on inaccessible slopes where they are not so much attacked by human forestry activity. This property leads to the conclusion that they are not suitable for my design purpose for the reason that the reaction wood is behaving unexpectedly. Němec says that the wood of false acacia has no use in the industry for its curly growth (Němec, 2005). However, this fact can be questioned for different purposes and also the unprogrammable behaviour may find its use. In Czechia, only one company sells false acacia wood, that is in fact popular for outdoor urban furniture and playgrounds for its durability. However, this wood is not local but imported from Hungary.

Surprisingly, pine monocultures are not considered in the governmental plan, though Petr Pokorný in his pollen analysis proves the high occurrence of pine forests in Central Bohemia throughout history (Pokorný, 2011). Pine forests naturally grow in the locations with low levels of nutrients even in low lands (Němec & Hrib, 2009). Coulson explains that the softwoods from warmer climates have lower density due to the wider spaced rings (Coulson, 2012). However, Saranpää states that in softwoods with abrupt transition from early wood to late wood the growth rate has little influence on density (Saranpää, 2013). This is the case of the Czech pinewood species. As a result, the faster growth of pines in low lands should not affect the wood’s properties in such extend. In addition, Schweingruber explains that trees growing on the sites with low level of nutrients don’t grow fast (Schweingruber, 2007). Therefore, also in reference to ongoing climatic change in our region, following the fact that pines are one of the most adaptable tree species, they seem to be, among others, suitable to grow and harvest. The pine wood properties are known to be soft and with good qualities suitable for the building industry, largely criticized and avoided for its movement. The last quality is the subject prompting the analysis in this research.

7.4 Wood's Material Properties in Relation to Moisture Content

Though a lot of research has been done on microscopic moisture-biological performance and interaction of the material, its behaviour research in this architectural application scale and purpose was largely insufficient. These two scales in close relation to its *'environmental dimensions'* (Davidová, 2009) are greatly interdependent. And it seems from samples observations that wood's performance closely relates its cellular behaviour with its form both how the wood is cut as well as how the material is distributed through its biological growth. Through the measures, it also appears that additional life on the material can affect this performance as well.

7.4.1 Overall Perspective

According to Hoadley, wood always remains hygroscopic (Hoadley, 1980). This means that it is absorping or releasing water in relation to relative humidity and temperature.

Based on this fact the wood shrinks, swells or moves and warps. Since the wood always remains hygroscopic, it can be expected that it also always remains warping. However, it is important to note the hysteresis effect that entails that the wood is less hygroscopic after the first desorption from the green wood, when the initial resorption is the lowest (Skaar, 2011).

Wood shrinks and swells or moves in relation to relative humidity and temperature based on the species and the grain orientation (see Figure 59). The greater shrinkage is associated with greater density (Glass & Zelinka, 2010). Dinwoodie explains that wood is anisotropic in its water relationships. It is due to the vertical arrangement of cells in timber and to the particular orientation of the microfibrills in the middle layer of the secondary cell wall between tangential and longitudinal shrinkage. And due to a) restricting effect of the rays on radial plain, b) increased thickness of the middle lamella on the tangential plane in comparison with the radial plane, c) difference in degree of lignification between the radial and tangential cell walls, d) small difference in microfibrillar angle between the two walls, and e) the alteration of early wood and late wood in the radial plane, which, due to the greater shrinkage of latewood, induces the weaker early wood to shrink more tangentially than if it would be isolated, between the tangential and radial sections (Dinwoodie, 2000). From green wood to air dried, the pine shrinkage is 6,8%, 3,8% and 0,201%, and swelling is 5,72% 3,04% and 0,076%, in tangential, radial and longitudinal section, respectively (Němec, 2005). Reaction and juvenile wood may shrink even 2% in the longitudinal section from green wood to oven dry (Glass & Zelinka, 2010). These facts are a cause of but are not equal to wood's hygroscopicity – movement after the wood is dried. The design research elaborates on different stages of moisture content, transiting from greenwood to air dried wood for manipulating the prototypes' performance. For this reason, the drying shrinkage also had to be considered.

Dinwoodie specifies three cases of moisture flow in timber, which are: a) free liquid water in cell cavities giving rise to bulk flow above the fibre saturation point, b) bound water within the cell walls which moves by diffusion below the fibre saturation point, c) water vapour which moves by diffusion in the lumens both above and below the fibre saturation point. Generally, the pines are much more permeable than the spruces, firs or Douglas fir (Dinwoodie, 2000).

The effect of change in moisture content, and thus of movement in wood that differs in different sections, is warping. There are four cases of warping: a) The most common warping occurs in the tangential section as a cup, which is caused by higher shrinkage on the left surface, b) a bow, which is not that common, occurs for the reason that the grain that is closer to pith shrinks more in the longitudinal direction, c) a crook, which is caused by reaction wood, d) a twist, that is caused by the spiral grain (Knight, 1961). In this research only cup warping is applied and elaborated.

Hoadley demonstrates that the wood cut in the tangential section from the centre of the tree warps more than the boards cut from its border (Hoadley, 1980) (see Figure 60). This fact was used and observed on my prototypes of Ray 2 and 3 which are applying in design such conditions for generating a water resistant system (Davidová, 2013b) (see Figure 12 and Figure 17)

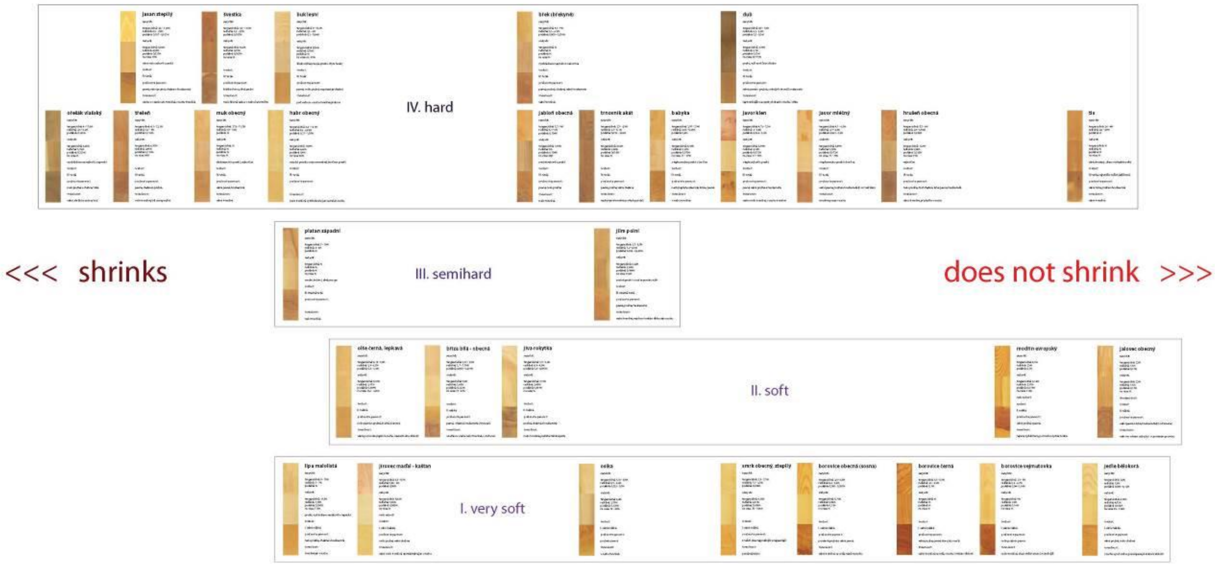

Figure 59: Davidová 2012: Map of Shrinking and Warping of Different Local Wood Species
(data and most of the images from: Němec, 2005 used with the courtesy of Grada)

The research was often criticised for low durability of untreated wood and it was stated by many across the profession that the untreated wood will fully disintegrate upon being exposed to direct environmental conditions at this thickness within three years. Therefore, preservations through different stains were discussed and sampled in cooperation with Pavel Kašpar from Acolor, s.r.o. According to Dinwoodie water-repellent preservative stain or exterior wood stain, that is a natural finish based on resin solutions of low viscosity, lets the water vapour pass through, while it is protected from water ingress and photochemical attack. Compared with a paint or varnish it allows the wood to dampen and dry at a much faster rate. This paint is not transparent. Also, water born exterior paints have a high level of permeability. Those are based on acrylic or alkyd-acrylic emulsions and protect it from the passage of liquid water (Dinwoodie, 2000). After considering several options and looking at different permeable treatments, in the end, my research lead to protection through salt water souse used in Norwegian traditional architecture that seems to be the most natural and least harmful to the environment. According to Jon Bojer Godal from Nordmøre Museum, Norway, such treated panelling can last 200 years or longer. For more information on this see section Ray 3: The Performative Envelope (8.2.2). Of what was discussed with Pavel Kašpar from Acolor, s.r.o., it seems that this treatment has no concurrence also when it comes to durability, as the chemical stains have to be renewed every twenty years.

It is important to state that as of now the three-year-old untreated prototype Ray 2 hasn't experienced any environmental harm, but has gained beautiful patina through weather and growth of blue stain fungi, algae and lichen. These species don't cause any biological decay to wood.

Figure 60: The Severity of Cupping in a Board is Related to its Position in the Log
(photo: R. Bruce Hoadley from: Hoadley, 1980; with the courtesy of Taunton press)

7.4.2 Wood Warping Observations

My research focused on the tangential section, which warps into the cup. There is not much literature elaborating environment-wood in tangential section interaction in detail and also the little which was found was questioned by my observations. I was registering samples of false acacia and pine wood, cut in the tangential section into the shape of a square, a trapezoid and a rhombus of thicknesses of 0.3, 0.5 and 1 cm in the same environmental conditions (see Figure 61). In all the cases, the rhombus shape performed approximately twice as much as a square and the trapezoid was in between in reference to the thicknesses (see Figure 62). This could be caused by the anisotropicity of the material's hygroscopic performance, discussed in the above section. Due to the material waste, the rhombus shape was replaced by two triangles later during the design process. Of course, the thinner the sample is, the more it warps and reacts faster to environmental changes.

In the false acacia case, the wood was warping in both directions (left and right side) on different samples in the same environmental conditions. The samples were cut from one tree at the same time, with the same moisture content, temperature and relative humidity. The ratio was one to one. Discussed with the wood scientists, carpenters and one axeman, it was found out, that it is probably for the reason that the samples were cut from the reaction wood.

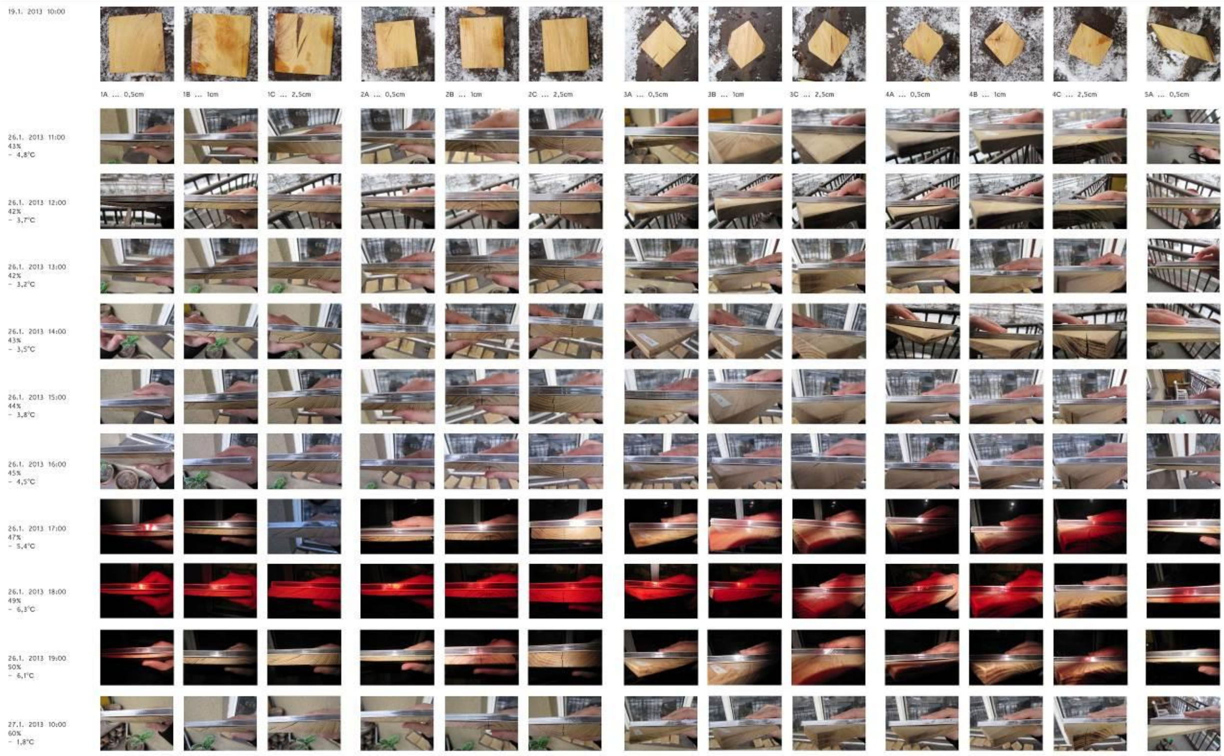

Figure 61: Samples with Different Thicknesses and Shapes of False Acacia Measured from One Morning to an Other (Davidová 2012)

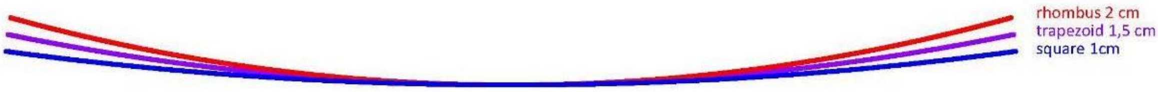

Figure 62: Warping of 0.5 cm Thick Pine Samples in 10% RH and 21°C (Davidová 2013)

According to Barnett and Jeronimidis, gymnosperms and angiosperms have generally adopted different strategies for coping with the mechanics of active change of curvature and bending stresses. On gymnosperms, the reaction wood is formed on the lower side of the stem, which is under compression – so called compression wood. It can eventually restore the stem to vertical alignment. On the lower side of the branches of gymnosperms compression wood is also formed. With angiosperms the situation is the opposite, the reaction wood is formed on the upper part of the stem which is in tension – so called tension wood. The branches of these trees also develop tension wood on its upper side for maintaining their angle of growth (Barnet & Jeronimidis, 2003). Compressive values are also found in young soft woods with a normal strain pattern, shifting to usual tensile values in the adult stage. Also, the growth eccentricity is much more common in softwoods while it has lower risk of cracking (Thibaut & Gril, 2003). A high amount of compression wood can also be found in juvenile wood of fast grown trees (Bendtsen, 1978). However, Thomas states that compression wood in juvenile wood has little influence on its properties (Thomas, 1984). As discussed earlier, the reaction wood is caused by the environment. So, though it might be more common on softwood than on hard wood, if we compare the locations where pine woods and false acacias woods grow, the result should be opposite. This fact is supported by samples observations, though it cannot be used as an argument as not a large enough extension of samples was observed. If Schweingruber is correct, pine woods in Central Bohemia don't grow fast, therefore they grow in the locations with low nutrients (Schweingruber, 2007) and therefore, there should not be higher occurrence of compression wood even in its juvenile wood.

The same occurrence as with the tension wood of false acacia was observed on the straight pine wood with 10% of the samples but this effect disappeared after a while. The explanation is that after the cutting of the tree some stresses remain in the fibre but they narrow down with the cut over time (personal conversation, Zeidler from FLD CZU 2013). The same behaviour was observed in detail on 275 triangular samples of the pareSITE pavilion and more generally on other prototypes.

The research then continued on narrow pine wood. The samples of green wood (over 30%MC) and dry wood (10%MC) were compared. At the beginning, the samples performed the same but after a certain time the samples from the green wood were warping much more, even in the humid weather.

To program the warping of tangential cut solid wood panels, samples in different moisture contents were cut every two weeks from a drying trunk of 18%, 20% and 22% as moisture content was observed in natural climatic conditions. This relation was proved and specific moisture content when cutting was assigned to panelling of prototype Ray 3. This is elaborated closer in section Ray 3: The Performative Envelope (8.2.2).

When oscillating between use of 0.5 and 0.8 cm thick panels and samples, 0.8 thickness was assigned to a durable solution with enough performance and was applied on both prototypes of Ray project. No panel ever broke on 0.8 cm thick while observed for three years on the Ray 2 prototype which reacts fast enough within the mostly slow changes of weather conditions in Czechia while we experienced a minor amount of cracking on 0.5 cm thick panels of pareSITE pavilion after one year. However, it was two panels out of 275 caused by unsuitable joinery that was used. For joinery experiments and the solution see section Ray 3: The Performative Envelope (8.2.2) in prototypes projects chapter (8). There was a bit larger cracking on Loop pavilion prototype, but it was caused by the spatial organisation of the design, that was underdesigned for such large material expansion after extreme summer storms that occurred in summer 2014 in Prague.

7.4.3 Factors of Moisture Content

Wood's moisture content (MC) depends on relative humidity (RH) and temperature (t) (see Figure 63). Relative humidity is defined by Fathy as water-vapour content of air at a given temperature that can be expressed as the ratio of the portion of the total atmospheric pressure contributed by water vapour to the portion necessary to cause saturation at that specified air temperature (Fathy, 1986).

According to the Climate Atlas of Czechia, the average relative humidity in the Czech Republic culminates the most in low lands in the summer seasons, where it reaches the lowest points in the afternoon while in the winter in the mountains it stays high and almost doesn't change at all. The highest relative humidity is during the nights while the lowest occurs in the afternoon in low lands during the summer (Tolasz & Coll., 2007) (see Figure 64). Therefore, designs have to be specific to their locations while also considering micro climatic conditions. As the pavilions' prototypes were moving to different environments – city heat islands and the outskirts of Prague, asphalt, stone and grass on the ground surfaces – different performances were observed.

Another factor is the temperature. Dinwoodie's diagram shows that wood with 5% MC is obtained from the green wood in 16% RH and 15°C as well as in 50% RH and 100°C (Dinwoodie, 2000). Therefore, the world orientation also plays its role. It was measured on the pareSITE pavilion (see Figure 15) that the main effect on warping could be also caused by the direct sun radiation. It is caused by the shrinkage of the upper surface. While the 0.5 cm plates, originally cut from the green wood, in 40% relative humidity and 21°C bent inside (right side of the tangential section) by 1 cm with 14% MC in the shadow at the North orientation, on the South it was warping outside (left side of the tangential section) by 3 cm with 7% MC under the direct sunshine. This shows that the situation is more complex and other factors besides the relative humidity have to be considered.

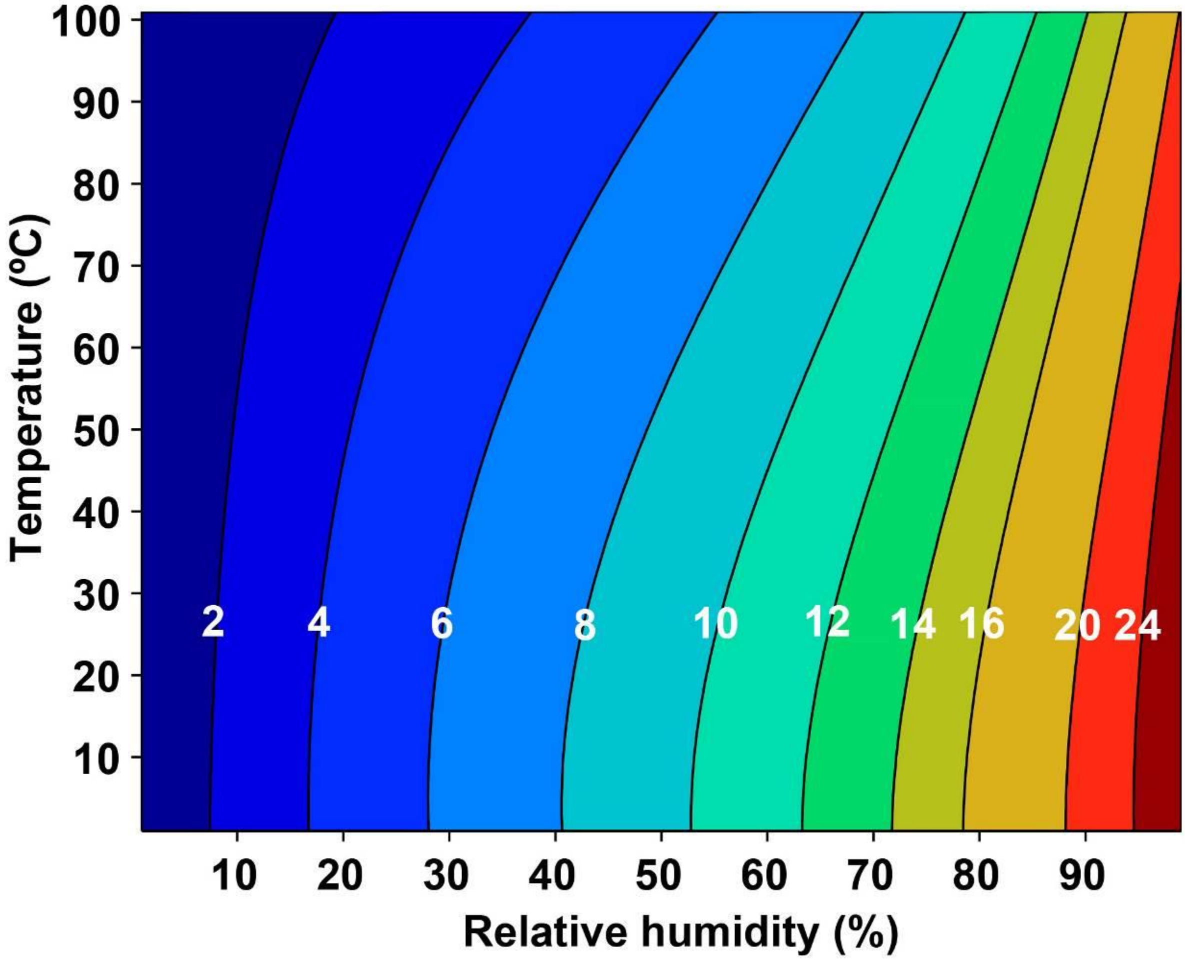

Figure 63: Equilibrium Moisture Content of Wood (labelled contours) as a function of relative humidity and Temperature (Glass & Zelinka, 2010 – used with the courtesy of USDA Forest Products Laboratory)

The speculation that different organisms affect the wood moisture content was observed on algae. It was measured that the algae surface on one particular wooden fence lowers the moisture content of wood by from 2 to 4% in the equal climatic conditions (see Figure 65). Two types of local algae, Apatococcus and Klebsormidium, were artificially grown on ash, false acacia and pine wood for six months. While there was success documented with the Apatococcus on all the samples, Klebsormidium failed to grow. Generally, the algae were growing best on the ash samples and on the false acacia the pine wood the worst (see Figure 66). This is as a result of the chemical content of each wood species, as pine wood is the most acidic. This is also the reason why this wood is not often inhabited by decaying fungi and mold. However, the Ray 2 prototype is inhabited directly by blue stain fungi and by algae and even lichen after three years of exposure to biotic and climatic conditions in the courtyard next to the forest rocky slope in Štěchovice near Prague (see Figure 12). I consider this feature to possess crucial potential for future exploration in Performance Oriented Design. Wider ranges of material co-habitation will have to be tested, explored and experienced. By now the research is avoiding biological decay through salt water souse on Ray 3 prototype (see Figure 17) and it will be observed if it still will be inhabited by non-decaying organisms. The hypothesis is set, that this is possible as these species don’t digest wood’s biological material, therefore it should not be problem that sugar and amyl are washed out by salt water.

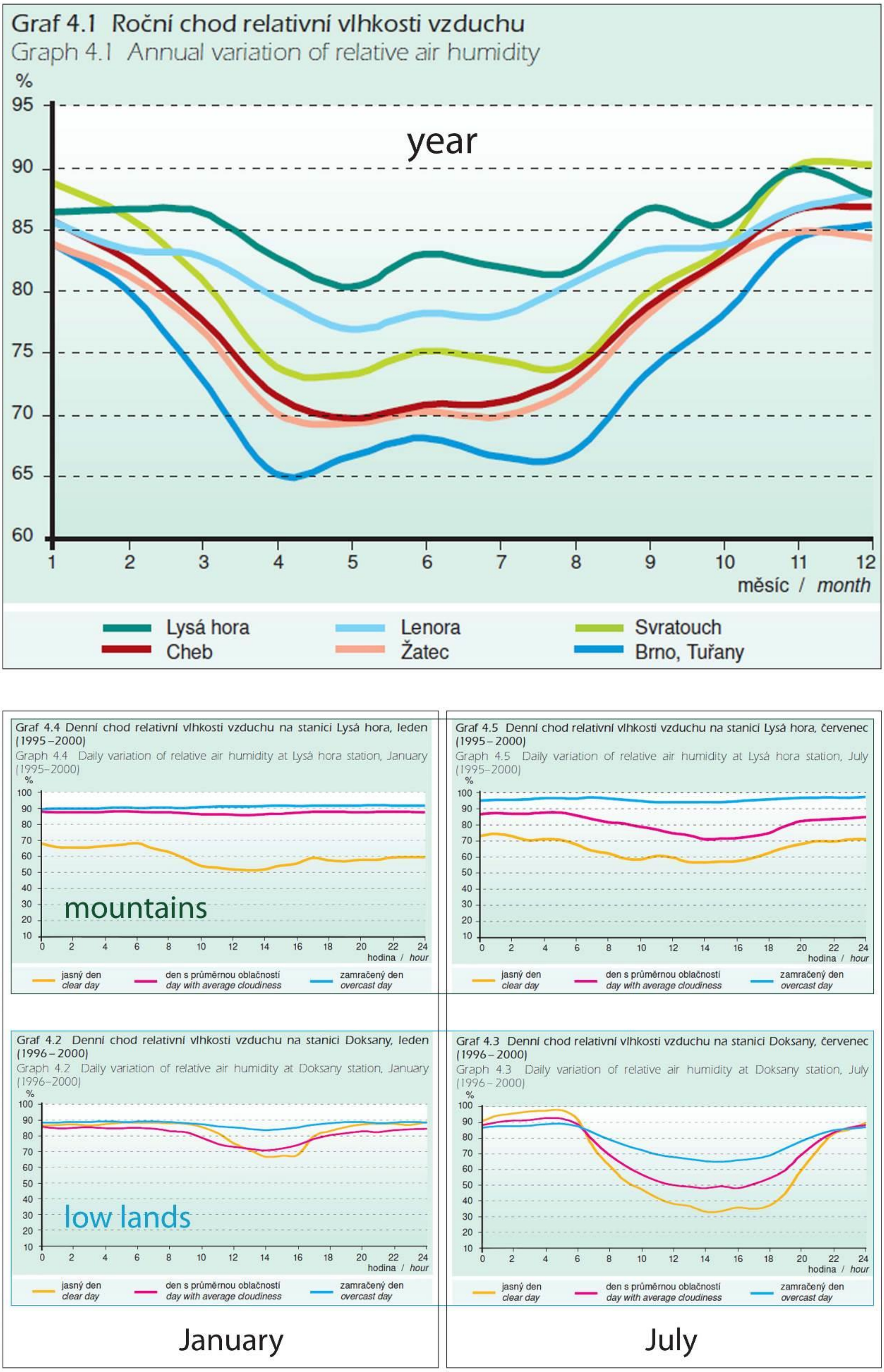

Figure 64: Relative Humidity Graphs (Tolasz & Coll., 2007 – used with the courtesy of Tolasz; sorted by Davidová 2012)

Figure 65: Fence with and without Algae Measured with Moisture Meter, Nové Město nad Metují (photo: Davidová 2013)

Figure 66: Samples of Artificial Growth of Apatococcus and Klebsormidium (from up to down) on a) Ash; b) False Acacia and c) Pine Wood from - Left to Right, Respectively (photo: Davidová 2013)

7.5 Conclusions

Local pinewood species seem to have most suitable material properties for the design-research as well as future application goals while generating forests natural to local eco-systems of wide spectre of areas. It would be difficult to use wood of false acacia that grows as an invasive species in Central Bohemia, as there is a high risk of abundance of reaction wood due to its monocultures forests locations. It seems that the stresses within the material, followed by its growth material distribution have direct relation to wood's hygroscopic behaviour, namely its warping. Though reaction wood doesn't seem to be applicable for solid wood solution of researched design case for the reason it has no narrow forces involved, it could find other design or art applications, namely in the responsive wood research on ply-wood (see Placement of My Research into State of Art in Reference to Material, Types of Prototypes and Location chapter), where the potential of higher shrinkage can be an advantage. The necessity of false acacias forests harvest is already accepted fact. What is missing is the search of its material application and in common practice it is used only as fuel, though it has undiscussable quality when it comes to hardness and durability.

Though it seems to be common practice in reaction wood samples, about 10% of the samples of non-reaction wood warped in the other direction for a certain time after the wood was cut, which might be due to the possibility that the stresses of the overall tree stays in the material. There doesn't seem to be a literary reference to this observation, but it was referred to as an undiscussed fact by the people from material science and craftsmanship practice.

Not only the thickness of the material, but also the angle of the plane cut in reference to the fibre direction affects resulting cup warping of the observed samples. This might be caused by the differences of evaporation along the grain. However, to claim this causal hypothesis would require extended observations in a laboratory.

It seems to be the most sustainable, ethical, aesthetic and performance supporting material protection against biological decay to soak it in salt water before application. However, the untreated prototype Ray 2 didn't experience any decay despite being exposed to weather and biotic conditions for over three years. This is for the reason of relatively highly acidic basis of pine wood. In addition, it was observed that algae habitation has a decent effect on material's moisture content which in my view can find an application in Performance Oriented Architecture with non-anthropocentric perspective.

As observed on the samples, the material performative behaviour can be designed by setting certain moisture content when it is cut. This has required a larger extension of the timeframe for the observations as the systemic relations of this performance change over time within cca. the first three months.

In this overall way, the research seems to oppose the work of offices such as Eragatory[43] by focusing on fusion of the material properties and the way it is *'formed'* (in this case cut) for generating its performance. It is also offering a local, site-specific material-technology, while its loss was discussed by Leatherbarrow in the entry of this millennium (Leatherbarrow, 2000). In my observation, the society has, at least in discussed location, shifted since, claiming always a local product option.

[43] Bloch states that form can prevail independent of material or textural properties while texture dramatically affects our sensorial understanding of a primitive or complex form (Bloch, 2016). My research claims that these relations are interdependent both ways.

8 Prototyping Design-Research Projects

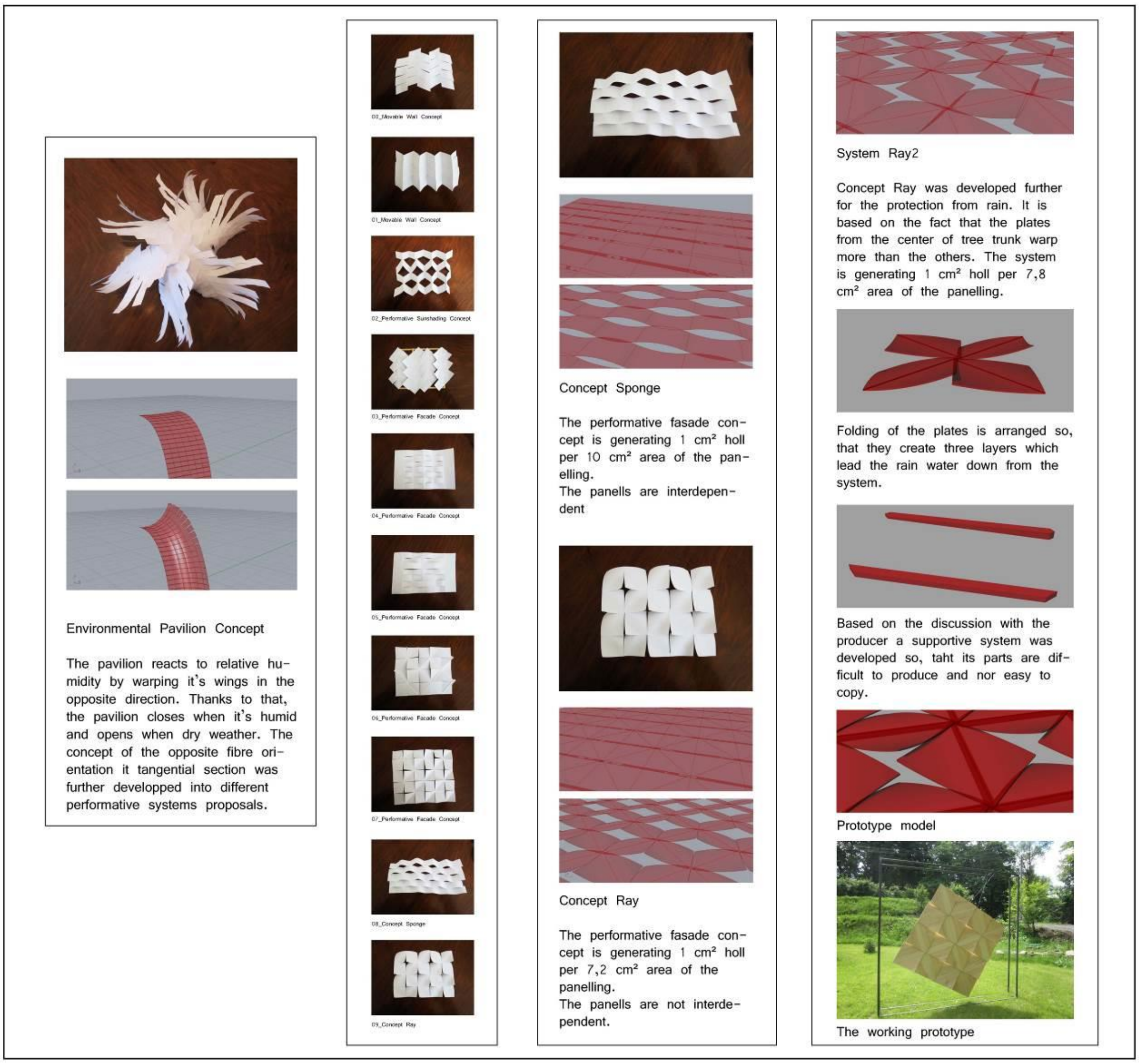

Figure 67: Conceptual System Development (Davidová 2013)

This chapter explains all **prototypes' projects** and their **development performed throughout the research**. Previously, several concepts of the wood relating to **relative humidity** and **temperature** were drafted in a creative, **non-critical mode** (see Figure 67). Afterwards, they were undertaken through criticism and developed or put aside. Though **Environmental Summer Pavilions** project and project **Ray** keep a certain level of **independence**, they serve to each other as a **different scale, environmental complexity, timeframe and detailing level case studies for observations and design development, informing following** prototypes, using **everlasting *'thinking hand'*** (Pallasmaa, 2010) as well as all the other senses (Pallasmaa, 2005) in **feedback loops**. Within the project, ***'beauty'*** (Hensel, 2008) is also considered as a **factor of architectural performance**, engaging a pleasant **experience** and **emotional relationship** to it of its creators, users and visitors, thus also engaging them for **curiosity** in the research that often **extends into discussion**, thus **design-research's development in co-design**. This factor also serves as a **protection from vandalism**. Beauty is meant here in depth of its **holistic complexity** of the design as a ***'performative synthesis'***[44] (Hensel, 2008), somewhat as ***'atmosphere'*** (Böhme, 2006; Bratton

[44] 'The filigree designs and the dramatic display of light and shadow create virtual spaces within rooms. Screenwalls and similar building elements have already consolidated what Reyner Banham called the Western tradition of substantial architecture with

& Diaz-Alonso, 2006; Leatherbarrow, 2009; Pallasmaa, 2016; Rahm, 2009; Zumthor, 2006a), not just an outlook. This ***'affect'***[45] in the means of Kipnis' discussion from 2005 (Kipnis, 2011) is used as **an endless tool for holistic environmental interaction** of ***'Time Based Design'***[46] (Sevaldson, 2004, 2017b) (see chapters Methodology: Systems Oriented Design and Research by Design while 1:1 Prototyping (6) and Practice Application Discussion (9)).

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the non-substantial one of societies who do not build substantial structures [but instead] inhabit a space whose external boundaries are vague, adjustable and rarely regular. Such elements constitute no less than the awesomely beautiful performative synthesis of the delineating material threshold and the environmental gradient.' (Hensel, 2008)

[45] Kipnis discusses that architectural concept is seen either as social action tool or the fusion of architecture and form or benefit. This divides architecture into two directions: 1. Phenomenology of perception; 2. Representation and the labelling significance. He then fuses the two as affects that are performing as a result of how architecture acts, so as an intersection of it experience and creation of its meaning (Kipnis, 2011).

[46] Sevaldson implies process based performance observations and creations that can be also co-designed as a design performance in real life, therefore co-lived (Sevaldson, 2017b).

8.1 Environmental Summer Pavilions

The **Environmental Summer Pavilions** project takes into consideration a **larger view on responsive wood performative capacities** through engaging **diverse** kinds of **public spaces** in its **overall complex eco-systemic conditions**. This required large **trans-disciplinary** and **trans-institutional** teams and **searches for methods suitable** to the project and **available technologies** through **trial-error approach**. Many **failures** have been encountered that have led to **new definitions of the parameters** involved. The project generally suffered from short time schedules and low budgets in comparison to similar projects in the field. However, I believe it brought new topics to the discussion anyway and served well as a **research tool for variety of performance**.

8.1.1 pareSITE: The Environmental Summer Pavilion I

(Davidová et al., 2013)

This project was explained in the paper: Material Performance of Solid Wood: Paresite, The Environmental Summer Pavilion, co-authored with Šichman and Gsandtner, published in Fusion – Proceedings of the 32nd eCAADe Conference – Volume 2. It is discussing the first experience of **1:1 scale transdisciplinary prototyping studio**, resulting in **built solid wood responsive pavilion** that was parametrically designed in the team in combination with prototyping in very short time frame. It serves as a **prototype of wood warping, twisting of solid wood in certain moisture content and social interaction**. The pavilion served as a **stage** and meeting point of **reSITE festival** in the **centre of Prague** and afterwards as **urban design furniture of Czech University of Life Sciences in Prague campus**, where the students who took a part in the course also took a part in its **social interaction observations**. Unfortunately, these observations are not discussed in this paper, published earlier than they were performed. However, they proved that the pavilion was **widely interacted by kids, lovers and party people from the academy as well as from the neighbourhood**. No part of the material or joinery was broken or stolen by this interaction which is in contradiction to the situation when the pavilion was dismantled and stored outside without covering any performance. This paper discusses mainly its material performance, digital design and structural design and fabrication of the prototype.

8.1.1.1 Abstract

The Paresite – The Environmental Summer Pavilion designed for reSITE festival[47], is a möbius shaped structure, built from torsed pine wood planks in a triangular grid with half cm thin pine wood triangular sheets that provide shadow and evaporate moisture in dry weather. The sheets, cut in a tangential section, interact with humidity by warping themselves, allowing air circulation for the evaporation in arid conditions. The design was accomplished in Grasshopper for Rhino in combination with Rhino and afterwards digitally fabricated.

This transdisciplinary project involved students from the Architectural Institute in Prague (ARCHIP) and the students of the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences Prague (FLD CZU). The goal was to design and build a pavilion from solid pine wood in order to analyse its material properties and reactions to the environment and to accommodate functions for reSITE festival.

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[47] The project was accomplished with the kind support of Skanska, Eurodach, Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences Prague, Lesy České republiky, reSITE, ARCHIP, Collaborative Collective and Oximoron.

List of Participating Students: Yuliya Pozynich, Jason Nam, Alena Repina, Daria Chertkova, Yana Vaselinko, Mikkel Wennesland, Dan Merta, Daniela Kleiman, Liv Storla, David Lukas, Christopher Hansen, William Glass, Jiří Šmejkal, Milan Podlena, Josef Svoboda, Tomáš Pavelka, Miroslav Runštuk, Ladislav Rubáš, Radim Sýkora, Anna Srpová, Ivana Kubicová, Gabriela Smolíková, Karel Ptáček, Jan Matiáš, Tomáš Mišoň, Lukáš Růžička, Jan Hyk, Marian Loubal, Jan Dostál, František Juhász and Jakub Vykoukal

The design was prepared within a half term studio course and completed in June 2013 on Karlovo Square in Prague (see Figure 68) where it hosted 1600 visitors during festival weekend.

Figure 68: pareSITE (photo: Wágnerová 2013)

8.1.1.2 Research Questions

- The main area of our occupation lies in the material performance of solid wood: Wood – Humidity – Temperature Interaction (subsection 'Material Performance').
- A second topic is the question of how to create a parametric model of the design and produce CNC fabrication data, leading up to the question: Can parametric design cover all the design tasks? Subsection 'Design Process in Grasshopper for Rhino 5'.
- To finish, we contemplate the structural possibilities of CNC fabricated design (see subsection 'Structural Design').

8.1.1.3 Material Performance

The tradition of building wooden summer pavilions has been established in many architectural schools. The most striking examples have been created at the AA School of Architecture in London and at the Institute for Computational Design – University of Stuttgart. Usually, they are built from ply-wood. On the contrary, the project is aimed at experimenting with the material performance of solid wood. The strength in the torsion of the planks and the humidity – wood interaction has been explored.

The form of the pavilion does not allow subdivision into planar surfaces, but anisotropic properties of the material support torsion. Several prototypes of the triangles with different plank thicknesses and moisture content were sampled. The angles of cuts hold the boards' torsion together in the joint. Because of its ability to bend, it was agreed to use green wood for the structure.

The Environmental Summer Pavilion is based on the concept of wooden oriental screens so called 'mashrabīyas' (see Figure 14). Mashrabīyas absorb moisture during the night when the relative humidity of air is very high and release moisture whilst providing shadow during the arid conditions of sunny summer days. The performance of 'mashrabīyas' has been explored by Michael Hensel. Hensel writes:

'Mashrabīyas are multi-functional elements that control light penetration, airflow, privacy and views, while operating on a synergetic relation between ornamental pattern and material distribution' (Hensel, 2011a)

Figure 69: Torsed Structure with Responsive Skin (photo: Zapletal 2013)

Figure 70: Responsive Skin (photo: Zapletal 2013)

Wood – humidity interaction systems (see Figure 69) have their origin in traditional Norwegian panelling (see Figure 4) and were later explored by Asif Amir Khan at the AA School of Architecture with a veneer based screen (see Figure 6). The research on performative wood is held by Michael Hensel at the Oslo School of Architecture and Design and by Steffen Reichert and Achim Menges at ICD University of Stuttgart. Most of the contemporary research has been done on laminated veneers to reach the highest performance of the material. Such structures have the best performance, but since the pavilion served for a festival in public space, they would have been too fragile. In the case of this pavilion, the air circulation was supported by warped triangles cut in tangential section. Warping in tangential section generates so called 'cup' across the fibre (Knight, 1961). It has been observed that most warping occurs on the plates in rhombus shape. Considering material waste, this figure in the project was replaced by two triangles (see Figure 70).

8.1.1.4 Design Process in Grasshopper for Rhino 5

The studio course Environmental Summer Pavilion was focused on generative concepts and algorithmic mechanisms for creating performance-based and interactive design systems. It was open to architects, designers and anyone interested in learning generative and algorithmic design techniques based on graphical algorithm editor – Grasshopper. The students learned everything from the basics to advanced coding and implemented several Grasshopper plug-ins into the design process. The LunchBox plug-in from the author Nathan Miller was used to design Environmental Summer Pavilion. The plug-in contained algorithmic geometry, panelling tools, structure and powerful utilities. It became the main tool to finish and create better workflow for the final definition.

For the initial surface it was decided to use a möbius surface with its logic of closed and vertiginous continuity. After the best spatial concept and the area solution was found, the final surface of two layers was developed. The first layer contained static structure presented by a triangular tilling creating torsional hexagon loops over the surface. The second layer was again a triangular tilling that was cracking each triangle of the first layer of the initial surface. The after effect of cracking was used to obtain a star perforation generating under diverse angle positions different views through the Pavilion.

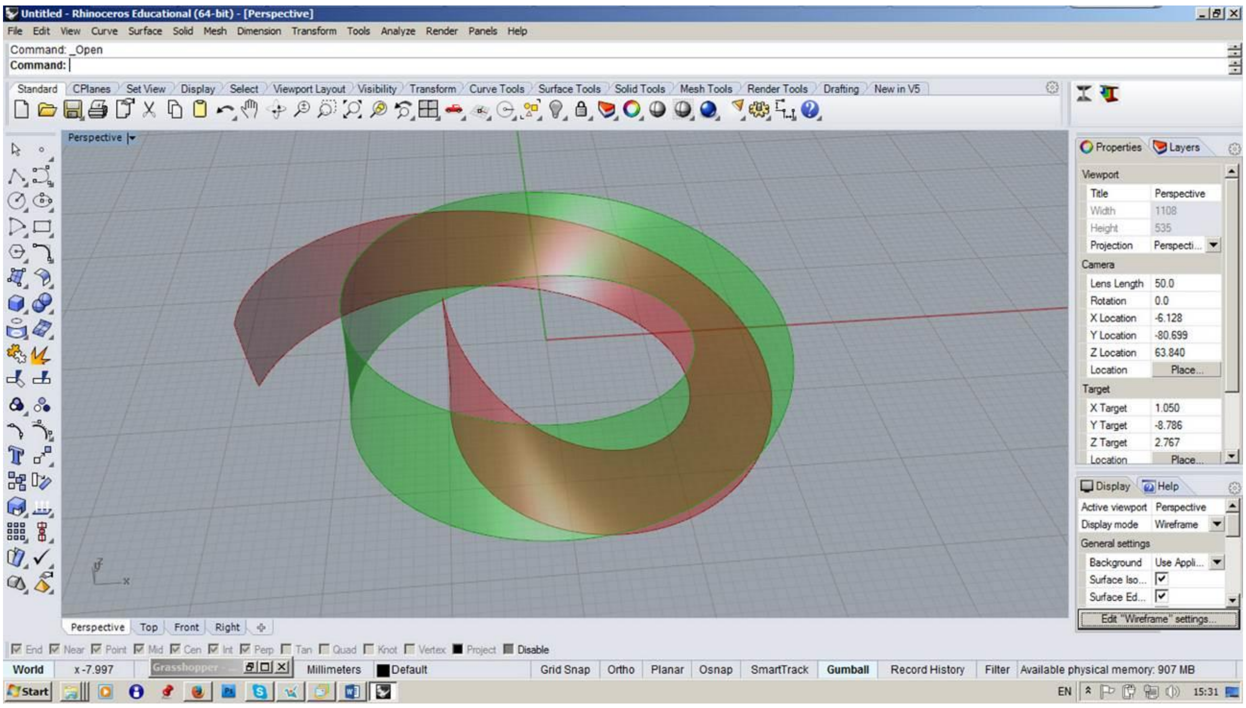

Figure 71: Möbius Stripe Offset (Davidová 2014)

Due to the geometry of the möbius stripe, the structure was not easy to generate. The initial surface was generated in Lung Box then edited in Rhino 5 afterwards offset in Grasshopper (see Figure 71). The ends of the surfaces had to be connected in Rhino 5 manually and the structure was loft between those two offset surfaces, through the panelling tools from Lunch Box.

Afterwards the main problem was that the planks in the structure were torsed. That time Grasshopper couldn't unroll into plains. The planks were unrolled and constructed back into objects manually in Rhino 5 while the component, written by Tudor Cosmatu for unrolling in planes was found on Grasshopper3d forum (Cosmatu, 2011). For the reason, that the structure could not be generated other way than offset (möbius geometry) the model of the pavilion was imprecise, not respecting the width dimensions of the planks. But it worked well for the generation of the fabrication data that were adjusted in Rhino 5 manually.

8.1.1.5 Structural Design

A triangular grid was chosen for the construction of the möbius shape because of its ability to mimic curvatures and stability features. The grid was offset inward thus defining shapes of planks which are generally perpendicular to the surface of möbius stripe. The shapes of planks were not planar, and they could not be generated as such while keeping general perpendicularity to the surface. Hypothetically, to achieve planarity, all of the joints axes would have to intersect in one point. In case of möbius stripe, parts where joint axes would be parallel with the surface would occur, making planks parallel too, and therefore weakening the rigidness of whole structure.

Figure 72: Production of Triangles (photo: Davidová 2013)

Figure 73: Ribs (photo: Davidová 2013)

Therefore, the experiment had to deal with twisted planks which introduced a new set of forces into the structure. Due to the rather unpredictable and complex nature of these forces, the decision was made to encapsulate these into triangular particles, preventing unwanted accumulation and interactions.

Planks were cut by a Hundegger Speed-Cut 3 cnc saw and put together to form triangular particles. Each particle consisting of three twisted pine 20 x 150 mm planks was connected by 0.6 mm metal sheet overlay on whole length of connecting edge tightened by screws (see Figure 72). These particles were afterwards connected with each other by 4 m8 bolts and large washers, hiding the metal overlay (see Figure 73).

The system presented good manufacturing options as particles or differently sized clusters could be prefabricated indoors and easily assembled on site later. However, a certain level of imprecision due to the twisted geometry of the planks was to be expected. Bolt connections allowed for a later distribution of imprecision throughout the surrounding structure, making it less disturbing. Each plank and joint (accept rim parts) was doubled, providing additional strength necessary for the use of green solid wood. The structure, once assembled, was covered by smaller 5 mm thick pine wood triangles creating moisture-reactive skin. These triangles were made using HOMAG Venture 06S 3-axis milling machine, Washers, hiding the metal overlay.

8.1.1.6 Conclusion

Figure 74: Responsive Skin (photo: Zapletal 2013)

Figure 75: Structural Stability Test (photo: Novák 2013)

Figure 76: pareSITE (photo: Wágnerová 2013)

Thanks to the material performance of untreated solid wood, the pavilion generated a pleasant environment for its visitors on hot days of the festival (see Figure 76). The skin (see Figure 74) reacted to the humidity changes as was observed on the samples. During the night the sheets were bent inwards while warped outwards in the day time. The relative humidity along the pavilion was higher compared to the other places covered with asphalt. This effect in its full performance takes time until the initial stresses from the tree trunk disappears. Therefore, the structure has to be ready at least one month before the expected performance.

Torque forces locked in triangles preloaded them and added rigidity, proving advantages of solid wood. The underlying structure proved to be rigid enough to sustain 200 kg weight on the highest not directly supported point (see Figure 75). Such load bearing capability was necessary for the public exposure of the pavilion (vandalism, children climbing, etc....).

However, we experienced some problems in very shallow joints after the winter season. This also could be as a result of using green wood at initial stage. This material disadvantage was discussed by Dinwoodie (Dinwoodie, 2000).

The structure itself was dynamic and it found its stable state which a bit differs from the digital model. Furthermore, the project itself is disturbing the concept of digital fabrication by the impossibility of generating precise Grasshopper model. This fact leads to the conclusion that the parametric modelling still has limits for designing experimental structures.

The combination of physical, parametric and digital modelling tools might be necessary in the design and fabrication drawings process. The use of solid untreated wood allowed for significant budget savings, making the price of all material, CNC cutting/milling and transport less than 5000 euros, and for creating a structure with no built in chemical agents.

The pavilion serves as a prototype for further development of industrial solutions for performative screens.

8.1.2 Loop: The Environmental Summer Pavilion II

(Davidová & Prokop, 2016)

The Loop pavilion was introduced by the author and Šimon Prokop in the article: 'Advances in Material Performance of Solid Wood: Loop, the Environmental Summer Pavilion II' the DCA 2016 conference proceedings. It is **further developing** the above concept merely in reference to **design** though which it is **increasing performance**. This new prototype takes in consideration the **spatial organisation of panelling** in **combination of the left and right side** of the plates as previously used in project Ray. In this context, **expansion and shrinkage** also had to be considered. It shows that the use of different **partial-design media**, such as specific simulation plug-ins and samples and prototypes, **may not perform** in the same manner as **the full complexity of overall full-scale prototype in relation to its outdoor environment**. The **GIGA-mapping** tool for the **transdisciplinary studio** and the performance towards **human and other biotic and abiotic behaviour, interaction and perception** are closer elaborated in the Methodology: Systems Oriented Design and Research by Design while 1:1 Prototyping chapter. This paper mainly covers its **material/design performance**, **parametric design** and **fabrication and structural design** of the **prototype**.

Figure 77: New Meets Old, Loop Pavilion (photo: Okamura 2014)

8.1.2.1 Abstract

Loop is a solid wood pavilion that adsorbs moisture during the night and evaporates it during hot summer days. Its panelling is warping in the sun and low relative humidity, thus supporting the circulation of humid air in its environment.

Loop is a contribution to the Research by Design on Responsive Wood started by Michael Hensel and Achim Menges at the AA School of Architecture in 2005 and is a second prototype of the first author's Environmental Summer Pavilions project that developed the previous one, pareSITE Pavilion, further. By spatial organisation of its panelling and the shape of the overall structure, we reached a much higher performance. The design was accomplished in Grasshopper for Rhino 5 and digitally fabricated.

The project is a result of a transdisciplinary, one semester long , studio course at the Faculty of Art and Architecture at the Technical University of Liberec and the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences in Prague lead by Marie Davidová, Šimon Prokop and Martin Kloda[48]. Architecture, environmental design and wood engineering students were involved in the project since transdisciplinarity is crucial in the field of Performance Oriented Design in general.

The pavilion served as a stage for EnviroCity festival in Prague during the summer 2014.

8.1.2.2 Research Questions

- The main area of our occupation lies in the material performance of solid wood: Wood – Humidity – Temperature Interaction. Can design push the performance further? (see subsection 'Material Performance').
- A second topic is the question of parametric possibilities of the design and production of CNC fabrication data: Subsection 'Grasshopper for Rhino 5 and Fabrication').
- To finish, we ask ourselves over the structural possibilities of parametric design from wood (see subsection 'Structural Design').

8.1.2.3 Material Performance

The studio course took advantage of the first author's Research by Design in Responsive Wood that aims to be applied in building industry. The research covers facades and screens for non-discrete spaces that breathe and operate the indoor and outdoor environment. The data from sample and prototype observations were shared among the overall team. Loop is a second prototype in Environmental Summer Pavilions project, following the pavilion pareSITE (see Figure 76).

… [The text is shortened for explanation. Please, see PareSITE, the Environmental Summer Pavilion I section (8.1.1)]

… Concluding the project of the pareSITE pavilion, we asked the question whether the specific design may heighten its performance. Both of the pavilions are inspired by the concept of oriental screens, so called 'mashrabīyas' (see Figure 14). Among other properties mashrabīyas absorb moisture at night, when the relative humidity of air is high and evaporate it during hot summer days. This performance was studied by Michael Hensel:

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[48] List of the Participating Students: Alena Novotná, Anna Hrušová, Antonín Hůla, Barbora Slavíčková, Jakub Kopecký, Jiří Fáber, Jiří Pokorný, Petr Tůma, Tereza Jílková, Radim Sýkora, Eliška Antonyová, Tereza Lišková, Filip Janata, Tomáš Kytka, Marie Kortanová, Vojtěch Holeček, Martin Vaníček, Jakub Hlaváček and Petr Havelka

This project would never happen without a kind support of the Faculty of Forestry and Wood Sciences and the Czech University of Life Sciences in Prague, the Faculty of Art and Architecture at the Technical University of Liberec, Stora Enso, Rothoblaas, Nářadí Bartoš, Eurodach, Lesy ČR, Natura Decor, Easy Moving, and Collaborative Collective.

> '*…these (mashrabīyas) consists of wooden lattice work and are characterised by a range of integrated purposes or functions: they regulate in a finely nuanced manner the passage of light, airflow, temperature and humidity of the air current, as well as visual penetration from the inside and the outside.*' (Hensel, 2013)

According to Fathy:

> '*Water will evaporate from a wet surface if it is exposed to air with a dew point lower than the surface temperature. The rate at which water evaporates from the surface depends on the relative humidity of the neighbouring air, the surface temperature, and the velocity of air movement. Thus, for a wet surface at a given temperature, a reduction in relative humidity or an increase in air velocity both increase evaporation*.' (Fathy, 1986)

The PareSITE pavilion was reaching better performance of this concept through warping of its panelling from plates, cut in a tangential section in triangular shape (see Figure 74). The concept of wood warping has been originally used in traditional Norwegian panelling (Larsen & Marstein, 2000) and has been further explored by many authors in this century. The first recent century prototype (see Figure 6) was published by Hensel and Menges in Morpho-Ecology publication with a comment:

… [The text is shortened for explanation. Please, see Morpho-Ecologies Project at AA School of Architecture section (5.1.2)]

… Compared to the Norwegian origin based on the tangential section of the trunk, the current research, except the one performed by the author, is using either laminated timber sheets or plywood. The LCA comparison, made for similar prototype in Czech conditions, by Vladimír Kočí from the University of Chemistry and Technology Prague, Dept. of Environmental Chemistry with the first author clearly talks for the use of solid wood for its environmental sustainability (Davidová & Kočí, 2016).

Figure 78: Panelling (photo: Davidová 2014)

From the samples observations, the triangular shape warps twice as much as the rectangular one (Davidová, 2013b). In the Loop pavilion we tested the spatial organisation of the panelling and combination of left and right side of the plates (see Figure 78) which resulted in a propeller when warping. The sheets were also shortened by solar analysis to equalize the wood shrinkage and expansion. However, extreme conditions were not considered. The expansion data was also not taken from the samples of identical material used for the pavilion as this was impossible to arrange with the material supplier due to the industrial processes of the production as well as the evaporation of sap from former green wood material.

The looping shape of the overall structure was speculated to support the performance next to the spatial organisation of panelling.

Within this task, the architectural students took the main part in the design of performance and the wood engineering students in the discussion on wood properties, structure, fabrication and building.

8.1.2.4 Design Process in Grasshopper for Rhino 5 and Fabrication

The pavilion was designed and built by all member of the team, including students and tutors. Its concept was a result of competition among the students, where the students were asked to deliver a concept sketch model and a concept research diagram. The winning concept sketch model, designed by Antonín Hůla was based on double curved folding of paper. Once the design was selected, all the members picked their responsibilities in the project, such as panelling, structure, shape, analysis, blog, the GIGA-map, photo documentation and so on.

After the introductory Grasshopper workshop a group of students started with modelling the whole pavilion. All the students were new to Grasshopper, but some of the architectural and environmental design students were familiar with Rhinoceros 5. Further design research was dedicated to finding the exact curves which the physical model exhibited after curved folding. However, thanks to the parametric approach in modelling other students could work parallel on the structure as well as the panelling even though the exact shape wasn´t yet found. Finally, a precise paper model was scanned by Micro Scribe (see Figure 79) to Rhinoceros 5 and further on parameterized and developed in Grasshopper for Rhinoceros 5. Due to the parallel work of different students on some areas of the design, some difficulties appeared mostly in data structuring. This was partially caused by the nature of scripting in grasshopper where visual control slightly overbalances other more thorough ways, speaking particularly about beginners.

Numerous versions of the structure and panelling were tested and discussed in the team and consulted with structural engineer. The code was shared by online file sharing and discussed in Facebook group next to the regular meetings over a physical GIGA-map. The concept of GIGA-mapping was introduced by Birger Sevaldson for mapping the complexity of the overall design from the study to the design outcomes. The decisions to be made in design were printed out and pinned to the board so that all relevant specialists could comment on it. By plotting time on the x axis of the GIGA-map, deadlines and time organisation was apparent at all times.

For structural analysis the team used plugin called Donkey developed by Lukáš Kurilla (see Figure 80). It utilises Final Elements Method (FEM) to evaluate efficiency of usage of each profile. Outcomes from this analysis guided the decisions about number of elements in the structure and also provided important insights regarding stability and seating of the pavilion. Even the author of Donkey doesn´t aim to replace detailed structural assessment methods (Svoboda et al., 2014) rather to provide architects and designers with a simple tool to be able to understand structural behaviour in early stages of design.

A plugin called Ladybug developed by Mostapha Sadeghipour Roudsari was used to predict exact positions of the sun and then the solar gain analysis. Again the analysis has to be done early in the design process to harness its true potential (Sadeghipour Roudsari et al., 2013). Each individual panelling plate was resized accordingly to its maximum possible solar gain (see Figure 81).

During construction the team faced several difficulties, one of which was maintaining order in the 1082 different pieces of the pavilion. The problems appeared early in the design phase. Because the script was created in a collaborative way by up to four people some irregularities emerged in data organising. Also the production numbering of elements at the 5-axis CNC sawmill was very different from the numbering the team used. After the delivery of cut pieces, manual measuring had to be done on a fraction of pieces to maintain order.

During the fabrication the team faced a challenge of putting two main skew wooden planks of every rib of the pavilion together in precise angle. A pair of unique 'rulers' with fitting slits had to be fabricated prior to the assembly of each rib. The fact that the CNC machine was to be operated exclusively by an antique Windows XP based PC with no maintenance over a few years was significantly user unfriendly.

Figure 79: Antonín Hůla with Micro Scribe (photo: Pokorný 2014)

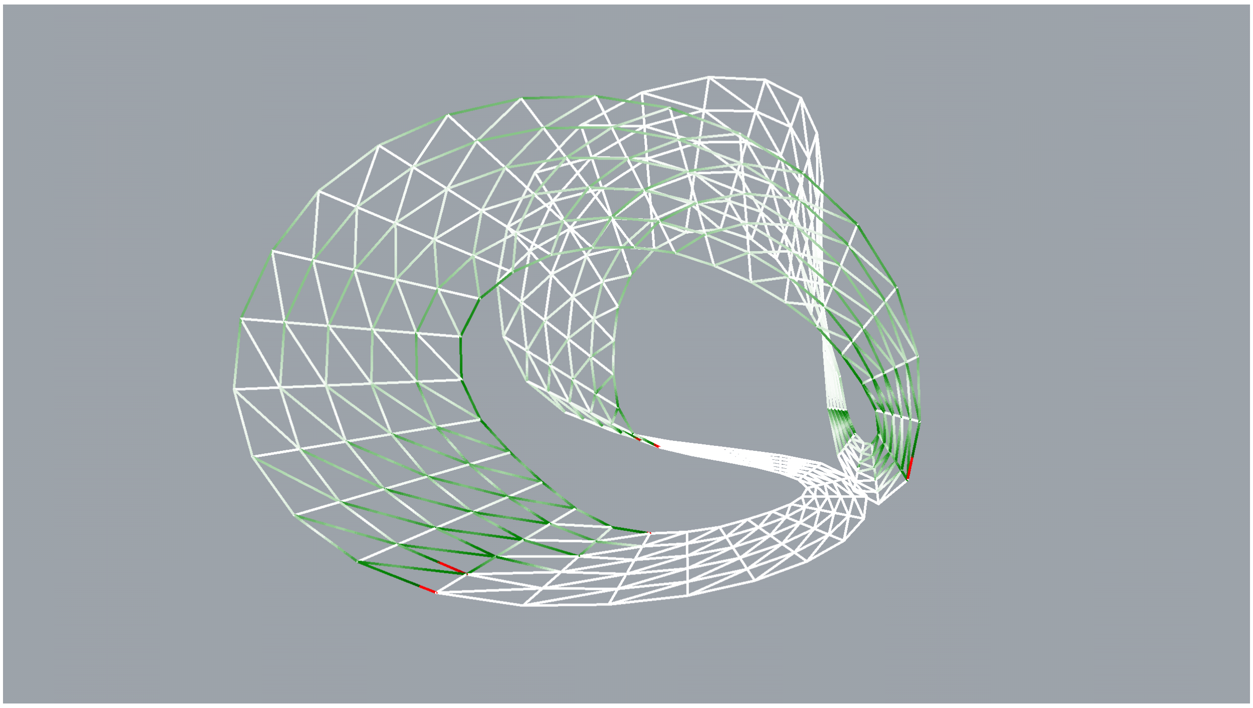

Figure 80: FEM Analysis in Donkey (Prokop 2014)

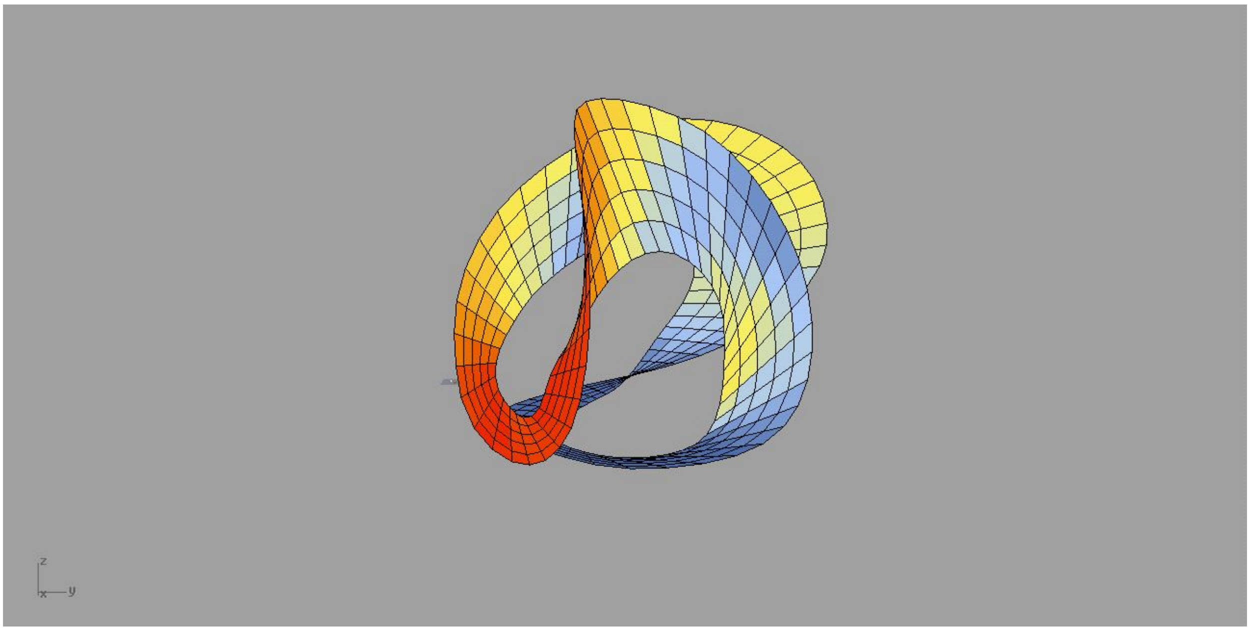

Figure 81: Lady Bug Analysis (Prokop 2014)

8.1.2.5 Structural Design

The structure had rather complex fashion when it came to forces. After the FEM analyses was processed (see Figure 80), several different prototypes of joints were tested at FLD CZU by Universal Testing Machine 50kN with software TIRA by Ing. Vlastimil Borůvka, Ph.D. at the Faculty of Forestry and Wood Sciences at the Czech University of Life Science in Prague to find the most suitable solution (see Figure 82). The results from FEM analysis and joints prototypes' tests were coming out well. However, we experienced problems in reality. In one of the most stressed planks cracking appeared and the most stressed joints were loosening.

Figure 82: Vlastimil Bořůvka is Testing a Joint Sample (photo: Davidová 2014)

Figure 83: Physical Structural Test (photo: Davidová 2014)

We were performing the pavilion's structural behaviour checks with the structural engineer on a weekly basis and placed steel belts over each joint. The problems seemed different than in the FEM simulation. Compared to the WIP Version 2015.11.5.0 of Scan and Solve plug in for Rhino released in 2015, FEM analysis by its nature does not consider neither fibre orientation nor joints.

As a first test, we built the single structure in front of the workshop before bringing it to the festival site (see Figure 83). At that point, we were not aware of any problems. The cracks appeared after two weeks on the site which is also tricky wood's structural behaviour similar to what was experienced by the students and the tutors in practice.

8.1.2.6 Conclusions

The design can support wood's material performance. The circulation of humid air was significantly higher than at the previous prototype of the pareSITE pavilion (see Figure 76). This fact was clearly perceived by all the visitors of the festival who had experience with both of the pavilions. However, closer attention has to be given to wood extension. In extreme storms, some of the panels extended more than expected, which resulted in their cracking due to its spatial organisation. Better combination of sampling for extreme conditions and solar analysis has to be achieved.

FEM analysis for solid wood is not yet that advanced which is most likely for its anisotropic nature as we experienced structural difficulties. The recently released WIP plug in Scan and Solve for Rhino that considers fibre orientation might lead to the solution. The physical structural test proved the importance of the fact, that wood's structural stability is time based. The pavilion's observations over a period of time were great learning tools for all participants among the disciplines in which everyone performed their part to a certain profession.

The transdisciplinary cooperation among the architect, environmental design and engineering students worked very well even though the schools were in different cities. All the files were shared and discussed online which enabled us to develop the design any place – any time.

Though the roles were not divided at the beginning, the architecture and environmental design students were more advanced in the design tasks while wood engineering students were more advanced in structural design, joinery and duties in the workshop. In this way, we utilized the creativity and talent of the students. It is a satisfying fact that the students who chose a responsibility which involved Grasshopper scripting became fully capable of using the tool to an intermediate level. The same happened with the site analysing, panelling design development, structure, detailing and joinery, fabrication data or, experienced by all fabricating and prototyping, GIGA – mapping and Systems Oriented Design in general and the most targeted topic of the course, the Material Performance was adopted by whole team.

8.2 Ray

Project Ray (Davidová, 2016f) is covering a **complexity of researched area in material-design research** on the contrary to the pavilions project, that are more focused on complexity of its environmental interaction. As roughly discussed in Methodology: Systems Oriented Design and Research by Design while 1:1 Prototyping chapter and discussed in larger detail in Sevaldson's upcoming publication Systems Oriented Design (Sevaldson, 2017b), it is necessary to **mix media** and **start prototyping in early design stage as an analysis of the project**. Ray 2 was **prototyped in very early stage** as a **source for observation** of the problematique within this very **short pre-given timeframe** of PhD research. Thanks to this, several samples, either separately or in **pavilions' environmental complexity**, were developed and researched. This led to way more developed Ray 3 prototype, that should be ready for application in practice.

8.2.1 Ray 2: The Performative Screen

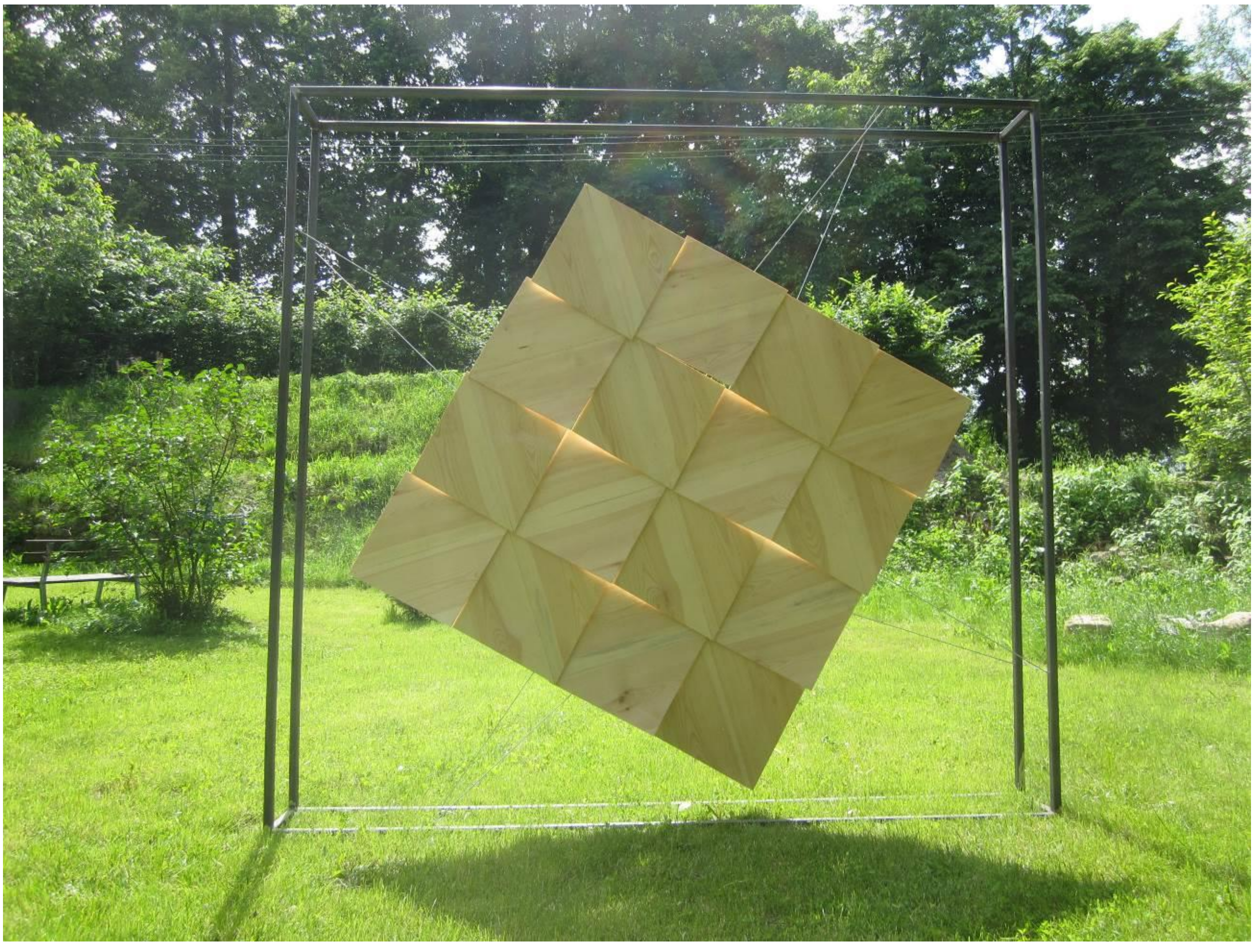

Figure 84: System Ray 2 Prototype (photo: Davidová 2013)

8.2.1.1 Abstract

Ray 2[49] (see Figure 84) is a **wooden environmental responsive screen** system full scale prototype that **reacts to changes in relative humidity and temperature**. Based on the material properties of wood, cut in the **tangential section**, the system **opens in dry/hot weather** thus **airing** the environment. Whilst in the **humid/cold conditions it closes**, not allowing the moisture into the structure. This prototype served as a ***'rapid learning'*** research tool discussed by Sevaldson in GIGA-mapping context to analyse the complexity (Sevaldson, 2013c) for **understanding the problematics through its failures** to generate the

[49] This project was kindly supported by Defio, s.r.o.

setup of **reality based design-research** questions as **no other research in responsive solid wood** has been done before this one.

8.2.1.2 Introduction

This prototype was elaborated in two papers: 'Ray 2: The Material Performance of a Solid Wood Base Screen' (Davidová, 2013b) and 'Wood's Material Performance: Ray 2' (Davidová, 2014e). Though widely cited in the thesis, non were suitable as a separate section for this subchapter. This section explains the performance and development finalised with prototype Ray 2. Its evolution after several conceptual sketching lead to two competitive proposals, concept Sponge (see Figure 85) and concept Ray (see Figure 87) which were simulated in Grasshopper for Rhino 5 (Davidson, 2016) and thus compared for their performance (see Figure 86 and Figure 88).

The system Sponge (see Figure 85 and Figure 86) has its advantage in the resistance to sudden rain. Its disadvantage is the interdependency of each plate, as the wood does not shrink in exactly the same way. Another problem is that the system shrinks in general. With 30 cm plates, the system shrinks by cca. 3 cm with 7 panels. For the height, the system extends 28 cm with eight panels of 20 cm height with 3 cm overlapping. This could be developed into a nondependent system, but the durability would be questioned anyway as the plates would move one on another.

It was simulated that the concept generates 1 cm² airing gap per 10 cm² of the surface in 10%RH and 21°C (see Figure 86).

Concept Ray (see Figure 87 and Figure 88), was not resistant to the sudden rain, while its performance was much better. According to the simulation for 10%RH and 21°C, it generates 1 cm² airing gap per 7.2 cm² of the surface area because of the use of the triangles that warp more than the rectangles. The system had overlapping from the lower parts of the boards and not from the sides. Getting back to the GIGA-map, the system was further developed into prototype Ray 2 which deals with the material properties of wood. Directly with the capacity of different warping based on the position of the tangential cut within the tree trunk, thus allowing overlapping by layering.

Being the first prototype of the Ray project (Davidová, 2016f), since the Ray 1 was only digitally simulated, it demonstrated many failures in complex thinking that led to further research, samples observations and the Ray 3 prototype (Davidová, 2016g). As it seems to be the first current prototype of this performance made of solid wood cut in the tangential section and no literature or knowledge is available for its historical references, these failures are not overly surprising and they served very well as a research tool for defining the parameters of the project.

8.2.1.3 Design

Ray 2 was developed from the concept of Ray 1 founded on the fact that it resists sudden rain. Based on the properties of tangential cuts from different positions of the tree trunk, the plates are combined in diagonal directions. In 10%RH and 21°C, the concept generates 1 cm² airing gap per 7.8 cm² of the surface area which is good enough for planed performance. This fact was first simulated in Grasshopper for Rhino 5 based on measured samples (see Figure 89) and afterwards measured on the prototype (see Figure 93).

The system Ray 2 is based on two triangles fit together into a rectangular shape while each of them has a different orientation of the tangential section. The upper one warps outwards and the lower one inwards, generating a large gap within the system for airing (see Figure 89). Within the grid, based on two diagonals, one direction is based on the rectangles coming out from the centre of the tree trunk and the other direction from the border pieces. The direction of the boards that warp more (the one from the centre of the tree trunk) is in one plane. In the other direction, the board is fit under the layer of the first direction on the top while fixed on the top of the first direction on its bottom (see Figure 90). This ensures that the boards overlap within the whole system (see Figure 92) and therefore offer protection from the sudden rain when the system does not react immediately.

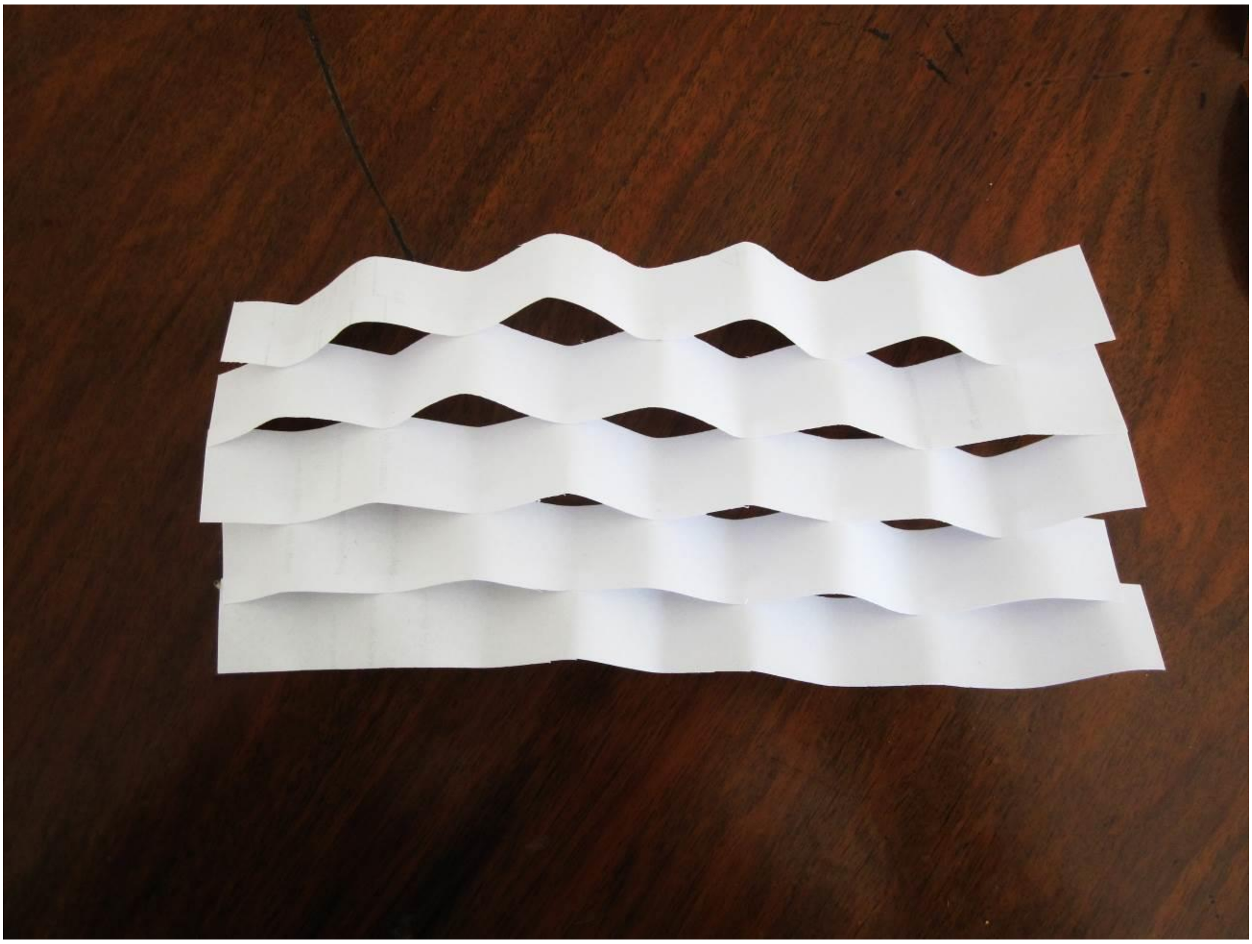

Figure 85: Concept Sponge (Davidová, 2013)

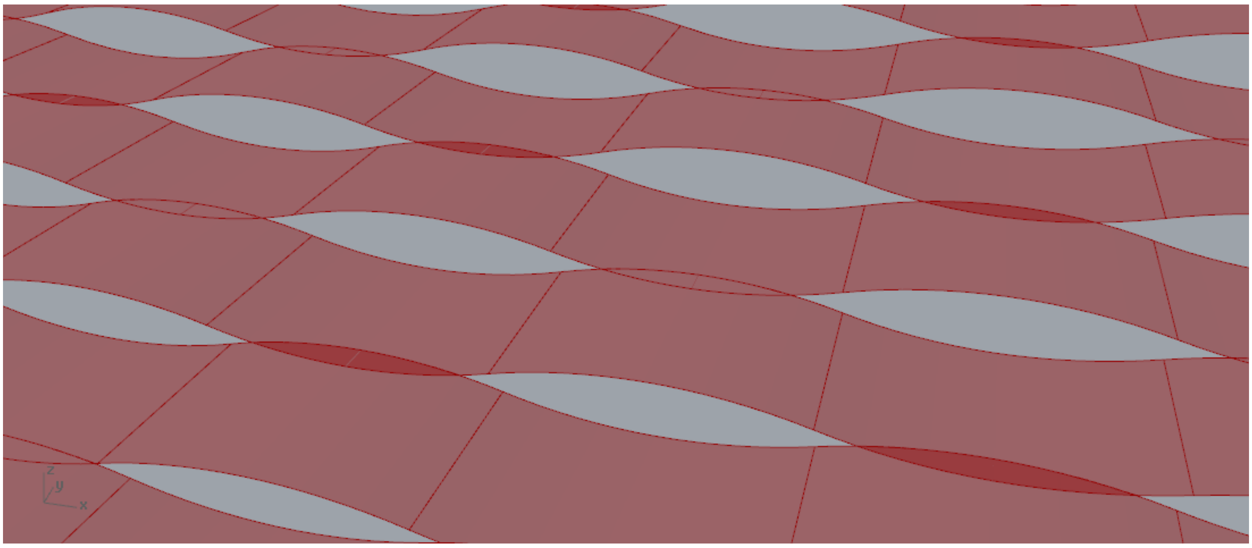

Figure 86: Concept Sponge Parametric Model (Davidová 2013)

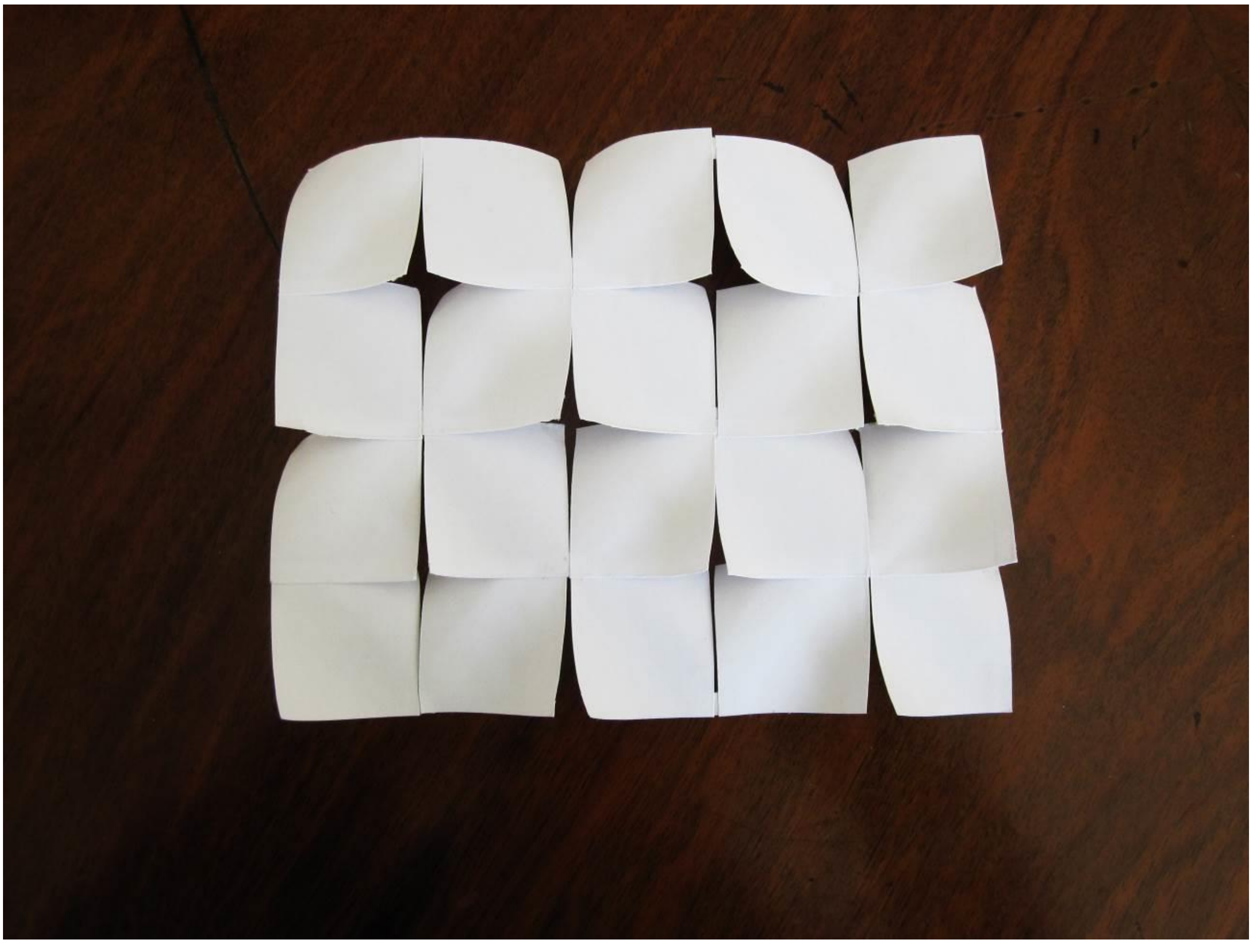

Figure 87: Concept Ray (Davidová, 2013)

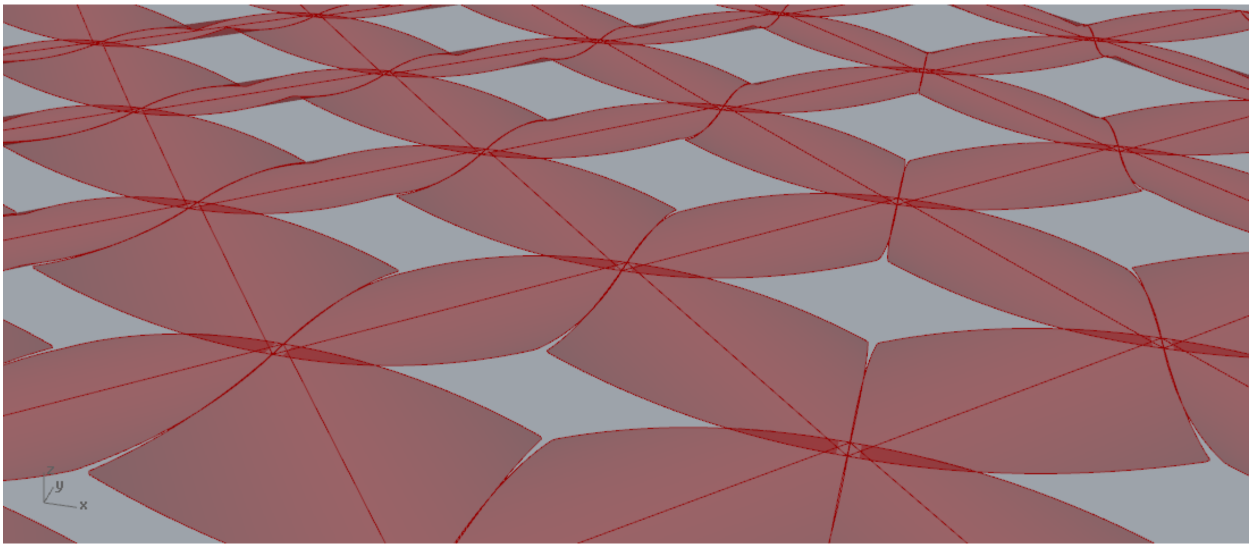

Figure 88: Concept Ray 1 Parametric Model (Davidová, 2013)

From the discussion with the producer, it was concluded that the design should cover some specifications of the production that are not easy to copy. The bases of the plates were developed under the certain angle that fit the structure into plane (see Figure 91). It was also agreed on using 0.8 cm thickness instead of first planed 0.5 cm and filleting the edges for durability reasons.

After this discussion with the carpenters, the prototype was produced and it was agreed that the product will be offered as a roofing and facade system on the market and other uses will also be explored.

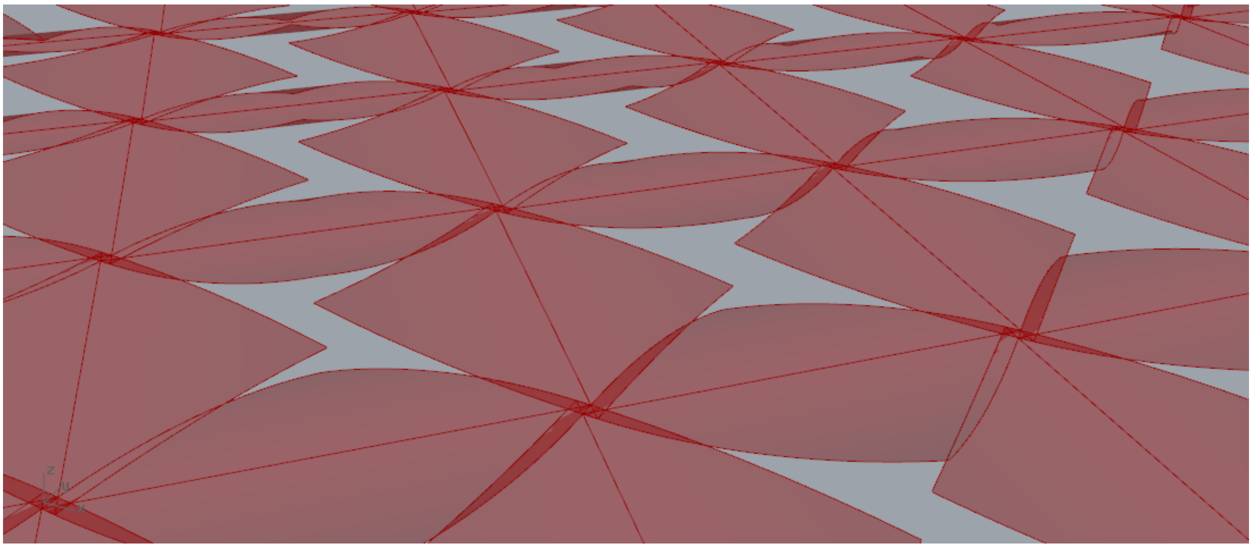

Figure 89: Concept Ray 2 Parametric Model (Davidová, 2013)

Figure 90: System Ray 2 Layering (Davidová, 2013)

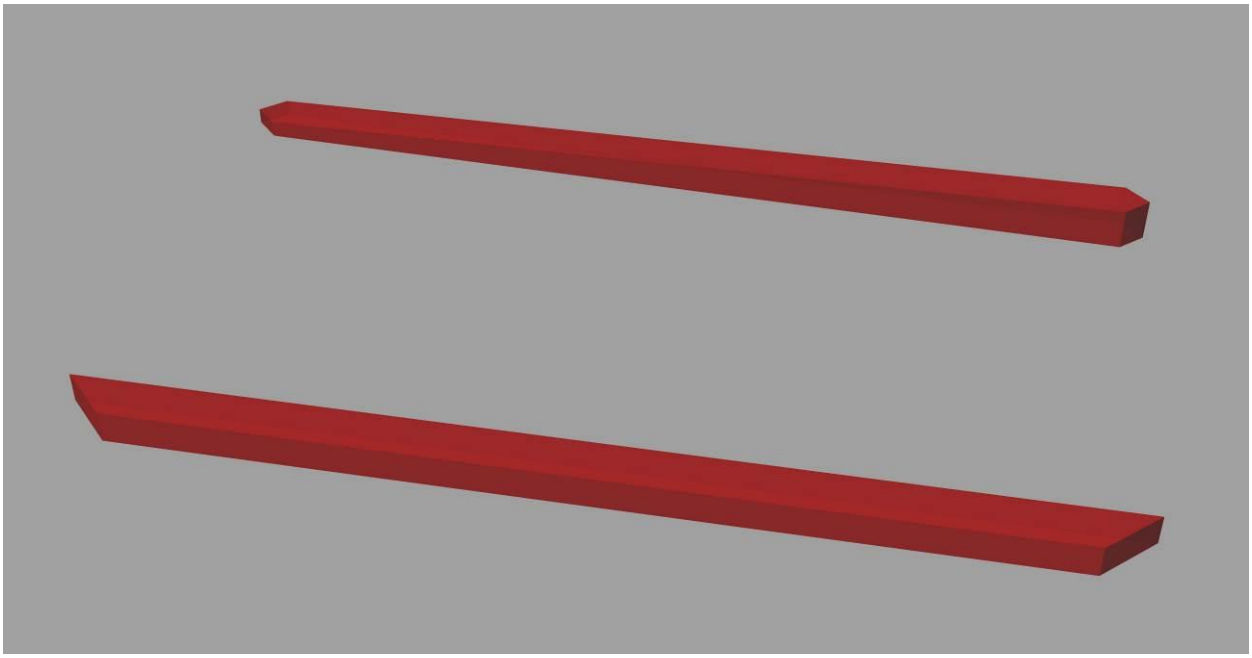

Figure 91: System Ray 2 Base of the Plates (Davidová, 2013)

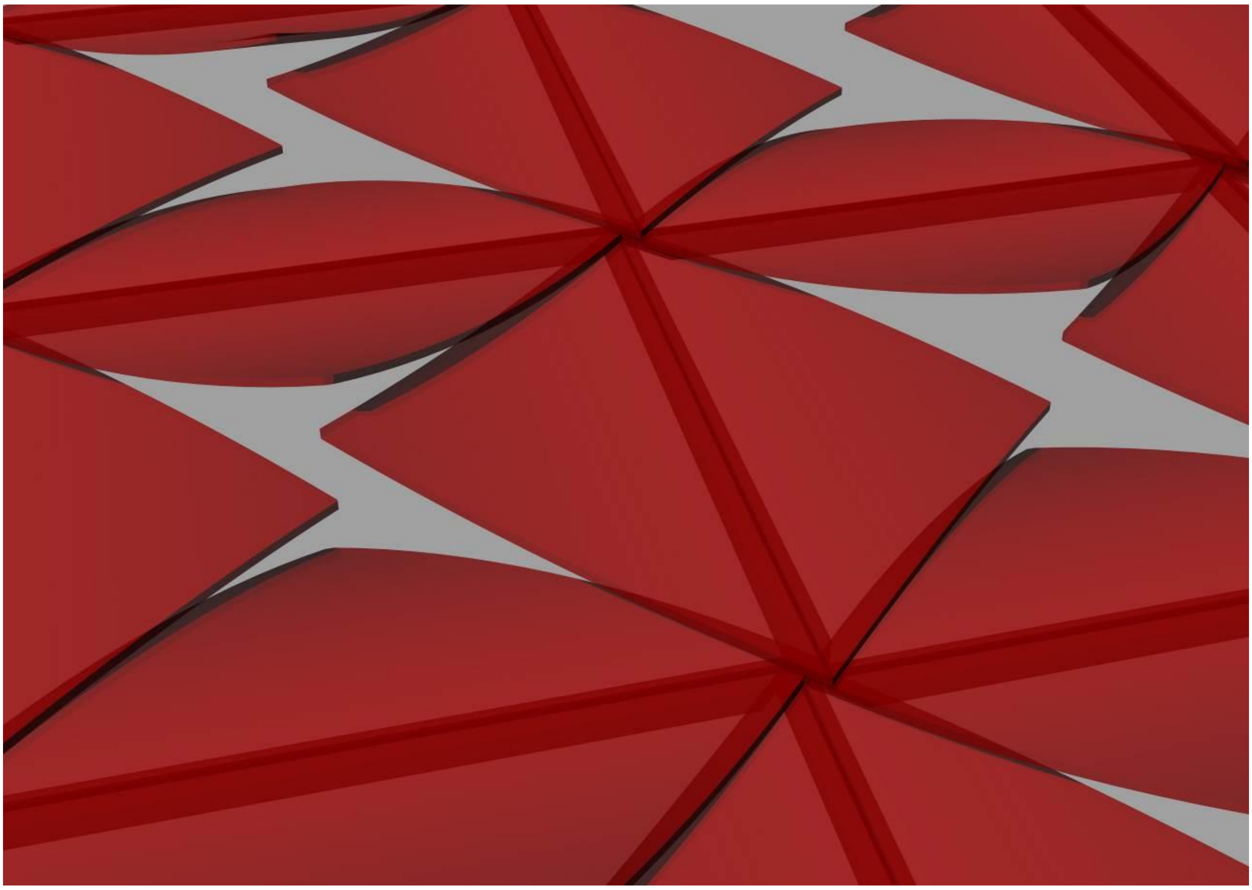

Figure 92: System Ray 2 Model of the Prototype (Davidová, 2013)

8.2.1.4 Discussion and Conclusions

The prototype served as an excellent kick-off tool for further design-research as it was continuously measured. It was discovered that 2 cm overlapping is not sufficient for heavy summer rain from storms that are common in the researched location, while the gaps at 85% relative humidity are not yet fully closed. Samples with different moisture content were therefore measured for their performance, which lead directly into the next prototype. The used joinery that was not fully considered in this prototype was not thoroughly resistant and sustainable in relation to the durability of the panelling, neither for its future recycling. We experienced problems during low-cost transportation by cart on the local Czech roads when not securing the prototype. This fact, and also the eagerness for durable sustainable solution, lead to the further research discussed on the application in prototype Ray 3 (see Figure 94).

As mentioned in the material chapter The Material in Relation to Environment (7), the triangles that were initially warping in the opposite direction behaved smoothly after the first summer – within roughly a three-month period. The prototype didn't experience any significant environmental harm during the years it was exposed in outdoor conditions. It gained beautiful patina and has been inhabited by blue stain fungi, algae and lichen that don't have any decaying effect (see Figure 93). There is large discussion on CO2 absorption of such but it is also argued that the exact amount of CO2 that was absorbed is released when the organism dies. It could be of course argued back, that these organisms reproduce. However, the discussion in co-operating and co-designing the performance as an active agent, discussed in Factors of Moisture Content section (7.4.3), as well as the general discussion on being part of overall eco-system, discussed throughout this thesis, namely in the Practice Application Discussion (9) chapter seems to be rather more relevant.

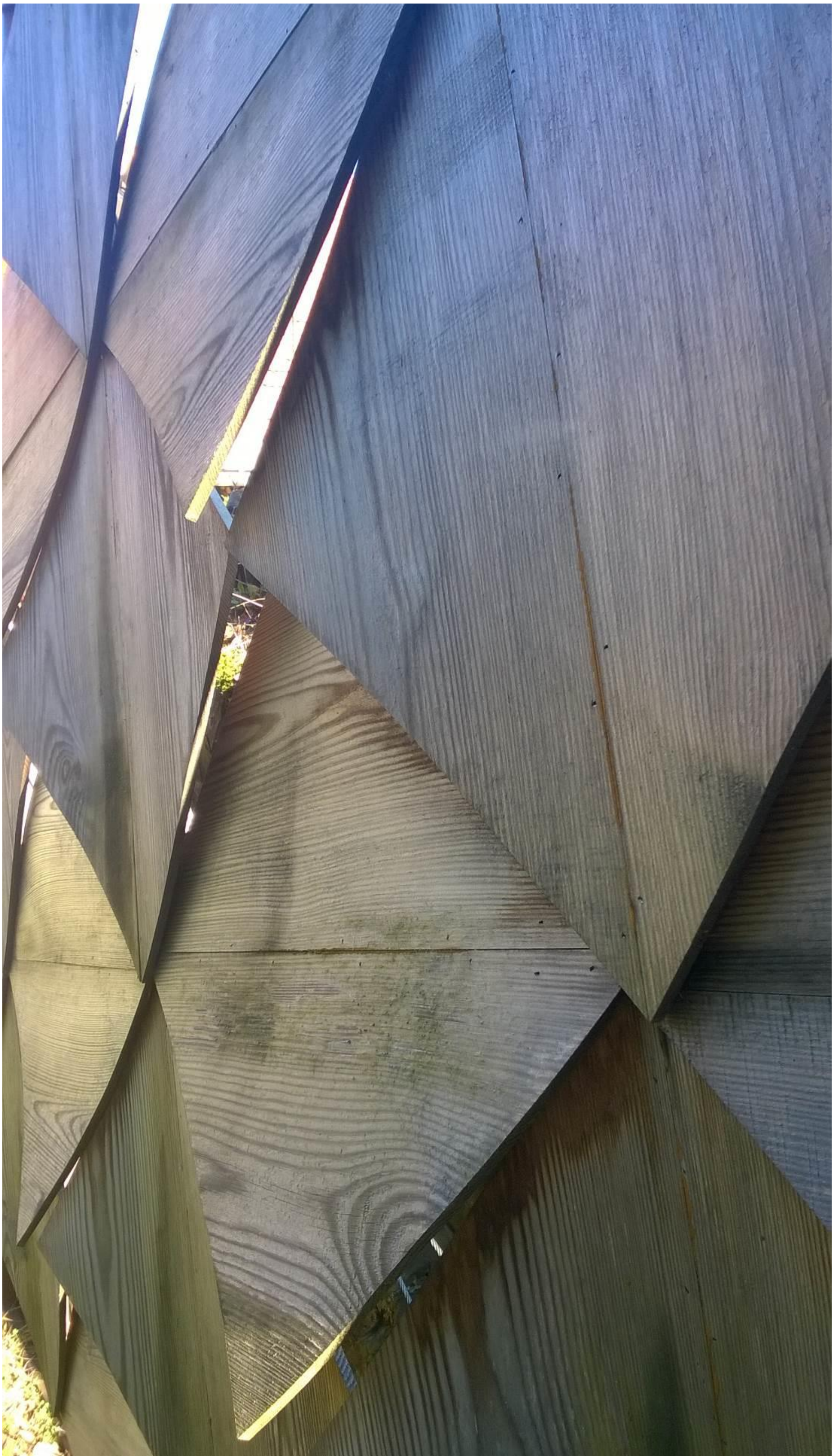

Figure 93: Prototype Ray 2 Performing after Three Years of Being Exposed to Climatic Conditions, Detail (photo: Davidová, 2016)

8.2.2 Ray 3: The Performative Envelope

(Davidová, 2016g)

This paper was published in the DCA 2016 conference proceedings. It develops the options for a) **partial programmability**, b) **durability**, and c) **potentials of thermal comfort** and the d) **joinery** question brought about through the Ray 2 prototype while discussing the possibilities and intentions of the application as well as its borders set by **today's market**. Though the **application example** is shown on the Collaborative Collective's project that is localised to Norway, not Czechia, the discussion is targeted to the **systemic approach** of **layering spaces** within the **onion principle**, in this case in correspondence of specific environment needs that are highly relevant to this application, rather than the discussion of the site-specific environment-material interaction. The 'På Vei' project, designed with my colleague Krištof Hanzlík in my practice network **Collaborative Collective** with other external collaborators in 2011, fostered a great part of my/our **motivation to undertake this PhD research project**. The prototype is new and will have to be observed over several years. As mentioned in several parts of the thesis, the full scale prototypes often showed different performance or design problems than the observed samples or simulations. In addition, other **unexpected difficulties can appear over time**.

Figure 94: System Ray 3 – Prototype (photo: Davidová 2016)

8.2.2.1 Abstract

Ray 3[50] (see Figure 94) is a fully functional envelope that reacts to relative humidity and temperature of air. Based on the material properties of pine wood, it is allowing dry air into the semi-interior while closing in humid weather. This is due to the tangential section of the panelling that warps based on the different fibre density on the left and right side of the plate in low relative humidity percentage and high temperature. The envelope is meant for non-discrete architectural spaces, namely the spaces between the exterior and interior.

[50] This research would never happen without the kind support of Lesy České Republiky (the Forests of the Czech Republic), Defio, s.r.o., AZ TECH, s.r.o. and Collaborative Collective, o.s.

This design is a continuation of the proposal Ray 2 (Figure 93), The Performative Screen. Compared to the previous prototype of Ray 2, Ray 3 is fully analysing the performance and durability and is equipped with solved joinery and a thermal, humidity permeable solution.

Recent samples observations are leading to currently produced prototype that will close its panels at 75% relative humidity level, and also will be treated by salt water against biological decay and fastened by plugs attached at lower moisture content to the construction frame. The glass bubbles based thermal comfort solution, performing on reflection, originated from NASA technologies was selected instead of any kind of thermal insulation.

This partly trans-, partly inter-disciplinary project, next to the architects involving carpenters, forest and wood engineers, wood preservation architectural and ships historians, environmental engineers, insulation material engineers as well as climatologists or even marketing engineers, suggests future applications for built environment and reflects upon the past. However, the conclusion has to be made that material-based building industrial practices are lagging far behind contemporary trends in different disciplines.

Figure 95: System Ray 2 – Prototype Detail (photo: Davidová 2013)

8.2.2.2 Introduction

Wood belongs to so called 'self-x materials' described by Speck, Knippers and Speck as:

> '*…materials that show – typically in addition to their main mechanical or protective functions – intrinsic properties that enable them to react to external or internal stimuli or disturbances. Examples include: self-organisation, self-adaptation, self-healing and self-cleaning. Self-x materials are suitable for many technical applications and are currently becoming of increasing interest in materials and biomimetics research.*' (Speck, Knippers, & Speck, 2015)

Its self-organisational capacities of warping related to humidity and temperature has been used in traditional Norwegian panelling over generations on solid wood in tangential section (Larsen & Marstein, 2000) and are explored today through Research by Design at academic institutions. The first published prototype of recent research realized by Asif Amir Khan at AA School of Architecture under the leadership of Michael Hensel and Achim Menges in 2005 was mentioned in Morpho-Ecologies publication in 2006 (Hensel & Menges, 2006). That time, it was a screen made out of laminated veneers. Since that time, the research under Michael Hensel at the Research Centre of Architecture and Tectonics at the Oslo School of Architecture and Design developed into experiments with ply-wood, also enabling a double-curvature (Haugen, 2010; Hensel, 2011a, 2013) and the research lead by Achim Menges at the Institute of Computational Design at the University of Stuttgart leads towards creation of synthetic material of similar properties and exploration of solid wood, cut in a tangential section (Menges & Reichert, 2015) as proposed by the author for the durability reasons (Davidová et al., 2013). The ply-wood solution is durable but the results of LCA comparison of solid wood and plywood for Czech environment, performed for prototype of screen Ray 2 by Vladimír Kočí and the author suggest, that use of solid wood is more sustainable, when it comes to given product in given location (Davidová & Kočí, 2016). Prototype Ray 3 (in fabrication) is following prototype Ray 2, explained by the author as follows:

> '*Ray 2 is wooden environment responsive screen system that reacts to changes in relative humidity. Based on the material properties of wood, cut in the tangential section, the system opens in dry weather thus airing the construction. Whilst in the humid conditions it closes, not allowing the moisture into the structure.*' (Davidová, 2014e)

Cut from green wood, Ray 2 prototype closes when already wet not in latter proposed 75%RH. When fully wet, the panels warp in the opposite direction, while overlapping is not enough. The coming prototype uses the data from samples and the previous prototype observations. Programmed for certain relative humidity levels combined with temperatures, it should also solve wood's durability issue and temperature permeability of 0.8 cm thick panels.

Proposed for generating non-discrete architectural spaces, the envelope is designed to exchange the environmental conditions between exterior and interior when suitable. As shown on the example of the application on 'På Vei' project, designed by Collaborative Collective as competition entry for Sogn and Fjordane Muzeum and Depository in Norway, it has its meaning in Hensel's and Turko's proposal:

> '*…we propose grounds and envelopes as potentially correlated spatial devices that can give rise to approaches towards non-discrete architectures for the purpose of a spatially and performatively enriched build environment. As this shift is predicated on grounds and envelopes as a way of staging spatial organization and transitions, it involves careful consideration of sectional articulation and organization of such architectures, including the way in which these are embedded within their specific local settings*.' (Hensel & Turko, 2015)

A bit of a different approach is suggested by Reichert, Menges and Correa, by putting their interest in

> '*...opening roofs for semi-interior spaces, such as sports stadiums, and adaptive facades for fully enclosed buildings.*' (Reichert, Menges, & Correa, 2015)

8.2.2.3 The Panelling

8.2.2.3.1 The Wooden Layer

Wood in the tangential section generates a so-called cup when warping (Knight, 1961). The project Ray is using this property to close the system in high humidity and open it in dry weather. The previous prototype of Ray 2 is closing at an excessively high level of relative humidity based on the fact that it was made from green wood. Plates in the exact dimensions of the panelling cut from one trunk in the period of March and April 2015 per two weeks have been observed to find out in which moisture content the wood should be cut so that it's narrow at 75% RH. It has been previously observed by the author that the greener the wood is, the more unstable it reacts (Davidová, 2013b). The samples were measured from June to November 2015. While in June, it seemed that the plates cut in 18% moisture content (MC) were the most appropriate, later it became stabilised on the samples cut in 22%MC that seem to be narrow from around 70%RH up and from around 10°C lower.

The samples were treated with salt water, as according to Jon Bojer Godal such wood can last for more than 200 years in the dramatic environmental conditions of Nordmøre in Norway as sugar and amyl had been washed out (Godal, personal correspondence 2015), and tested for its hygroscopicity performance. In Mari Sand Austigard's report from Mycoteam as for Røros Kommune, the samples of pine wood samples were sank in salt water for four month (Mycoteam As & Austigard, 2014). As my pine samples were 0.8 cm thick, one week period was tested. The samples seem to sustain their hygroscopic properties such as warping and moisture content.

The wood properties have been widely consulted at the Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences and with Jon Bojer Godal from Nordmøre Museum, Norway.

8.2.2.3.2 The Joinery

The joinery is inspired by Erwin Thoma's Holz 100. Holz 100 is panel such as CLT but joined by oak plugs dried to 0% moisture content when fastening instead of polyurethane glue (Thoma, 2006). Pine wood plugs were dried in microwave oven and tested in natural environmental conditions on panelling samples by the carpenters from Defio, s.r.o. producing the prototype (see Figure 96). Different radiuses in circular or oval shapes of plugs were tested in relation to different moisture content of the samples. In the end, the 0.8 cm in diameter, circular shape was selected, as there never appeared cracks on 0.8 cm thick panels' samples.

8.2.2.3.3 The Thermal Comfort

The 'insulation' AZ ThermaCoat (see Figure 97), based on the micro glass bubbles M3 from NASA technologies, was selected due to its thinness, sustainability and revolutionary concept. By generating great thermal comfort by having a warm surface, the inner temperature doesn't need to be so high. In a way, it is not really thermal insulation as the concept works not only on low thermal penetration of the hollow glass bubbles (from 0.05 to 0. 26 W/mK at 0°C) that cover 90% of its ingredients, but most importantly, on their reflection of electro-magnetic heat radiation. The paint is vapour permeable and should keep elastic enough for warping of the 0.8 cm pine wood board, therefore perfectly suitable for the task. It is applied in a thin layer of approximately 0.5 to 1.0 mm that does not evaporate any chemicals, is harmless to health even when recycled and fully washable. The company AZ Tech, s.r.o. will apply their product directly on the prototype with their technology and will cooperate on the development of the product, solving its possible failures.

Figure 96: Test of Plugs in Natural Environmental Conditions (photo: Bouma 2015)

Figure 97: Test of AZ ThermaCoat Paint (photo: Davidová 2015)

8.2.2.4 Vision for Possible Application

Non-discrete spaces, the spaces between the exterior and interior, are common in vernacular architecture also in colder climates (Hensel, 2013; Hensel & Turko, 2015). For the author, the 'Onion System' is of particular interest. The Onion System covers an unclimatised, more or less ventilated, space between an exterior and climatised interior divided from the exterior by a semi-permeable envelope. It could be something such as a veranda or a winter-garden or a working semi-interior space, as shown on the pictures from Norway (see Figure 98). The upper example of the Lillehammer farm seems to be equipped by open ventilation, compared to the lower image of the city house in Tønsberg that has windows.

Similar proposal could be applied for example to competition proposal for museum of vernacular culture by Collaborative Collective (Collaborative Collective, 2012) 'På Vei' (see Figure 99). As the gallery artefacts were very sensitive to relative humidity and temperature, we proposed an onion system between the exterior, the unclimatised gallery space that receives warmth from the climatised neighbouring offices with facilities for researchers and administration in the ground of the sloping valley between two hills, lightened by fans. The gallery, and in accordance to it, also the attached spaces, is designed as path walk from ramps crossing the steep landscape between two mountains. The proposed envelope Ray 3 would do the best for the unclimatised gallery space that has to keep stable humidity and lower temperatures for the wooden artifacts. While the screen evaporates the moisture absorbed at night, when the relative humidity is high; in the time of too dry weather, it doesn't allow exterior high humidity into the semi-interior space. This space receives heat energy from climatised rooms attached to the mountain or green roof on the other side, which secures temperatures above zero (or not too high during summer), when thermal comfort for visitors is generated by the semi-interior side of the envelope.

Such conditions might be also well suitable for residential buildings, introducing a different approach to 'thermal loss' and different temperatures for different purposes in the house as in examples from Norwegian traditional architecture.

Figure 98: The Unclimatized Spaces, so called Onion System, in Norwegian Traditional Architecture (photo: Davidová 2015)

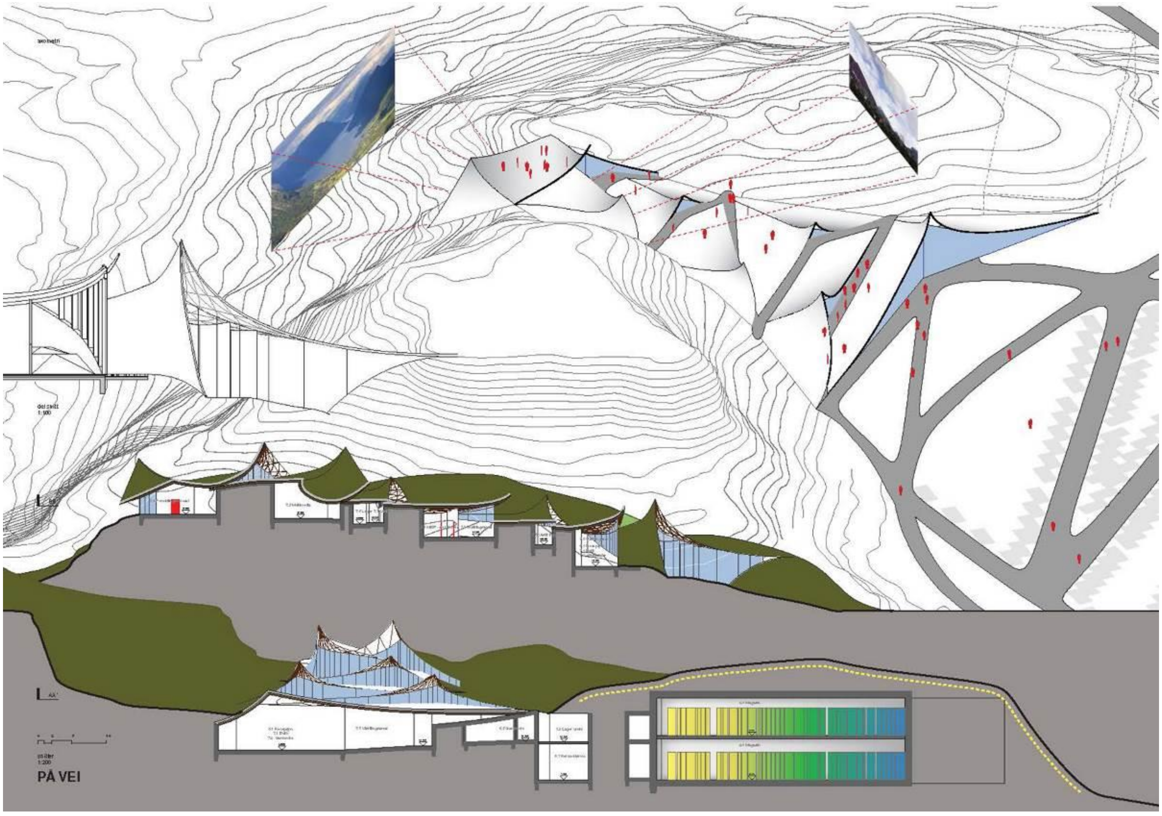

Figure 99: På Vei, from up to down: axonometry, detail and sections (competition entry by Collaborative Collective 2011)

The concept was proposed to marketing specialists from InovaCentrum, CTU in Prague, where the research was conducted at that time, for support and cooperation on the research with the creation of author's start-up. The marketing engineers, coming from different disciplines, seemed to be open to the topic. Unfortunately, today's building market in the Czech Republic is not open to long-term visions and the proposal was rejected by civil engineering reviewers who concluded it as a façade system that just brings disadvantages compared to existing ones and is more difficult for production.

8.2.2.5 Conclusions

Ray 3 (see Figure 94) is taking the concept of Ray 2 (see Figure 93) further by replacing the façade and roofing system with a fully functional envelope for non-discrete architectural spaces, while both of the products will be offered on the market.

The new prototype (in production) will have a programmed performance when it comes to warping, durability and thermal comfort through the wood cut in 22%MC that will be treated by salt water and connected to the frame by wooden joinery in 0%MC of circular shape 0.8 cm in diameter (see Figure 96) and painted by environmental-friendly product with reflection of electro-magnetic heat radiation (see Figure 97). Thus, the project keeps its sustainability of the material and its future recyclability.

The cooperation among the disciplines of architecture, carpentry, forest and wood engineering, wood preservation architectural and ships history, environmental engineering, insulation material engineering, climatology as well as marketing engineering was fruitful for the project that could not happen otherwise. The project was only facing the wall when it came to the engineers neither from research, nor from fabrication industry, but private practice related to academy as no fast income in accordance to building laws was seen. In the parts where the cooperation is transdisciplinary, the co-working becomes more enthusiastic as each of the professions searches for the purpose of the research. However, not all of the professions can be involved at such a level as some of the disciplines are represented based on consultancy of, for the experts, trivial information that is creatively used by other field of research. It was surprising to meet such interest from the production side of the fabricators.

The speculations of future applications, as well as the historical references, sound promising but the approach of building laws and industry will have to change in order to accept such concepts. The square meters of built up area are considered valuable only when fully climatised. It is an unfortunate fact that even the non-discrete spaces of historical buildings are getting thermally insulated by thick layers of either toxic, or at least unsustainable materials, when renovated, disabling any exchange of the exterior with the interior. Such tendencies are even financially supported by the government of the Czech Republic. This leads to the conclusion that the practice of our profession is far behind contemporary trends of interaction through the boundary condition such as Internet of Things in Service Design. Furthermore, the presented research is just using primary resources based on the bio-morphology through material's self-organisational capacities. More popularisation has to be done in the topic.

9 Practice Application Discussion

This chapter is discussing **today** and **past practice examples** of **non-discrete architecture** in the means of **'*active-agency'*** of **'*context-specific participation'*** (Hensel, 2012c), arguing for **penetrable layers of peals within onion principle** (Davidová, 2016g, 2016m), somewhat in the sense discussed by Alexander as a *'…design with a number of nested, overlapped form-context boundaries'* (Alexander, 1964). But it differs from Actor Network Theory by Latour that though bringing non-human agents into play, there is strict differentiation of role among a) human and b) non-human, means biotic as well as abiotic, agents (Latour, 2006). In the last point, this design-research's understanding differs from how it defined by Hensel in his PhD thesis (Hensel, 2012c).

The two selected papers for this chapter argue for **larger equality** of both, **biotic** – including human, as well as **abiotic** factors and actors within the **eco-system** and **environment**, that at the end is also most beneficial to humans. The human world has believed in larger importance of human among the other factors and actors in environment[51] and biosphere[52] for many past years. Therefore, it seems we have reached the point we are now discussing its **future existence**. Governments across the continents, such as Czechia, Norway, Canada, USA and Turkey developed strategies for **climatic change adaptation** (Czech Republic Ministry of the Environment & Czech Hydrometeorological Institute, 2015; Flæte et al., 2010; Republic of Turkey Ministry of Environment and Urbanization, 2012; Richardson, 2010; U.S.Department of State, 2014). All of those I got to study, those that are mentioned, are lacking **holistic transdisciplinary perspective** and if architectural design is discussed, is usually done in the means of increase of impenetrable insulations for most possible enclosed interiors – ***'discrete objects'*** (Hensel, 2012c), though it is commonly questioned by environmental engineers in practice, that such requirements are reducing any energy consumption. In opposition to non-discrete architectures, such properties are unfortunately even got required by **building codes** of many countries, including Czech Republic where this document is even discussing renovations of traditional architectures in this context (Czech Republic Ministry of the Environment & Czech Hydrometeorological Institute, 2015). **Architectural relation to eco-system** in these documents is represented only by green roofs and possibly facades use recommendation at maximum, not even looking at possible **eco-systemic performance** of this option. **Do we really believe that this will reasonably support our adaptation to predicted climatic changes, such as high and low temperature extremes, extreme droughts or floods, snow or rain storms, etc. mentioned in introduction chapters of all these documents?**

[51] 'Environment is physical and biological surroundings of an organism. The environment covers non-living (abiotic) factors such as temperature, soil, atmosphere and radiation, and also living (biotic) organisms such as plants, microorganisms and animals.' (Oxford University Press, 2004)

[52] Biosphere is 'irregularly shaped envelope of the earth's air, water, and land encompassing the heights and depths at which living things exist. The biosphere is a closed and self-regulating system (see ecology), sustained by grand-scale cycles of energy and of materials—in particular, carbon, oxygen, nitrogen, certain minerals, and water. The fundamental recycling processes are photosynthesis, respiration, and the fixing of nitrogen by certain bacteria. Disruption of basic ecological activities in the biosphere can result from pollution.' (Lagasse & Columbia University, 2016)

9.1 Socio-Environmental Relations of Non-Discrete Spaces and Architectures: Systemic Approach to Performative Wood

(Davidová, 2016i)

The 'Socio-Environmental Relations of Non-Discrete Spaces and Architectures: Systemic Approach to Performative Wood'[53], presented at the Relating Systems Thinking to Design 5 symposium was placed into ***'Human-Centred Settlements'*** session. This fact, as it was so confusing to me, helped me to sharpen its point**: To design with having human benefit in the centre of mind, means to design for and with the overall environment, its biotic and abiotic factors. Only this way, we can design truly human centred settlement.**

This paper places the research into overall reflection concerning examples of **my projects in the Performance Oriented Design field** in relation to its **boundary conditions** and **performed biotic** and **abiotic interaction** utilised in **GIGA-map**, a case study example mapping relations in architectural type in reference to world axis, human behaviour and use options, placement and macro and micro climatic conditions of the exchange of exterior, semi-interior and interior in non-discrete spaces in Norwegian traditional architecture, so called ***'svalgangs'*** and through this analysis, the project's application in the context of the **contemporary living environment in Czechia** for its **climatic adaptation** discussion on today architectural practice.

9.1.1 Abstract

The paper puts into the context of practical applications my case study research of responsive wood located in Czechia, being inspired by Norwegian and oriental traditional architecture. Approaching the field from a socio-environmental perspective, the article relates human, social and biotic behaviour with climatic and geographical data, addressing interactions in the performance of architectures and its additional issues in urban design. The opportunistic activities, use or habitation of spaces and objects, meets its performance through environment – material and/or design interactions. The paper claims that, at least in observed climatic locations, semi-interior, or so called non-discrete architecture addressed by Hensel and others, are the grounds for and generators of individualistic and social activities in public and public-private spaces, securing environmental comfort. In this time of increased weather extremes coming with climatic change in certain locations, noise, light pollution, etc., the topic is gaining greater relevance.

Inspired by Library of Systemic Relations for GIGA-mapping introduced by Sevaldson (Sevaldson, 2016d), the relations of such in GIGA-maps required its own coding or update and/or combination of the existing proposed library. The maps are expressing different ranges and intensities of behaviour or performance in relation to placement or designs that are represented by informational layers of images. Relating gradients within (S. Allen, 2011; Banham, 2009; Hensel & Menges, 2009; Hight, 2009b)and among the fields, thus generating a matrix of interlinked information where zooming, sequencing or feedback looping appears. This way somewhat develops the core ideas of Allen from 1997 on matrixes and fields (S. Allen, 2009). The three thematic GIGA-maps are in fact developed ZIP-analyses (Sevaldson, 2016e) of each other, zooming a problem of the theme's topic. The semi-interior or non-discrete spaces as a climatic, sound, etc. and biotic – including social gradient – are complex interlinkings of outside and inside environments and have implications for activities and forms of life. Therefore, a systemic approach is needed to fully understand it.

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[53] This paper was developed under the Systemic Approach to Architectural Performance project (Davidová, 2016g) that was kindly supported by EEA and Norway Grants (EEA and Norway Grants, 2016).

9.1.2 Introduction

> *'Architecture is a material practice. Materials make up our built environment, and their interaction with the dynamics of the environment they are embedded within results in the specific conditions we live in.*
>
> *Moreover, culture and the way materiality and materials are understood and instrumentalised mutually condition one another.'* (Hensel et al., 2008)

I have expressed my understanding of environment in relation to interaction in space and time in exploratory paper for NORDES in 2009 as an exemplification of the difficulty of imagining space which is, for instance, traditionally defined by three dimensions x, y, z, but there is no light there making possible to see anything (and perhaps there is also nothing to see either), there is no heat you could feel, nothing to hear, no smell, etc. Pointing out that it is as difficult to imagine that this space is happening in time. Arguing that, from the architectural view, the word environment could be defined as space which is enriched by interaction and that we could say that the space as such does not exist in time and that the space-time dimension is defined by interaction, concluding that the space-time with interactors then forms the environment. This is supported by the fact that to design in relation with light, sound, wind, weather or stars position, politics, etc. has been common throughout architectural history whether in symbolic, metaphysical, pragmatic, phenomenological or other manner, which leads to the fact that these factors are important dimensions of the environment (Davidová, 2009).

This seems to be supported by Oliver, who emphasizes that the concept of space is not universal and, i.e.:

> *'In the Navajo world view, all is in motion and all is changing within an overriding concept of order and harmony. Space is related to movement,…'* (Oliver, 2006)

Though considering himself a modernist, Frampton called for an environmentalist direction in architecture's future development several decades ago in the early eighties (Keneth Frampton, 2011), discussing the poetical approach of the relationship between humans and nature in an interview with Mitášová in 2010 (Kenneth Frampton & Mitášová, 2012). In my view, humanity is fully part of nature, and therefore I would rather discuss the relationship of the individual and its environment – living or non-living-which involves their evolving interactions. Reconsidering regionalism, Heat stays:

> *'For example, some practitioners study the built environment through a culture concept, whereby regional landscapes become sources for exploring the manner in which human populations around the globe create, adapt, and transform their environments in response to personal beliefs, human interactions, situational opportunities and constraints, traditional and evolving technologies, and forces of the natural environment.' (Heat, 2009)*

This seemed to be exemplified in the following study of Norwegian semi-interior spaces 'svalgangs' (see Figure 102), where different alterations of openness and closeness appear even on one building, reflecting climatic and site orientations and locations as well as opportunities of use and social interactions. Furthermore, in some cases their aesthetics, often decorated by carvings, securing special climatic conditions through environmental exchange has an almost spiritual character, while other parts are unfoldable for more down-to-earth activities such as material loading.

Jan Gehl categorised three types of human activities that, in my opinion, also must cause various layers of interactions in outdoor areas: 1) necessary, 2) optional and 3) 'resultant' social activities, arguing that the two last appear way more frequently in good quality of physical environment. (Gehl, 2011) 'Good quality of physical environment' or I would better say suitable environmental conditions, are in large degree operated by weather or other physical aspects such as sound and light. Therefore, in most of the climatic locations semi-interior, so called non-discrete architectures defined by Hensel (Hensel, 2013), take place. Discussing the spatial transitions from exterior to interior, Hensel is for instance mentioning canopies, screenwalls and full enclosures. (Hensel, 2015)

Vegas and coll. expresses their performance from socio-cultural perspective as such:

> *'… – but in-between spaces that generate relationships, places for sociocultural exchange. Just as it occurs in nature, where life does not flourish as much in a homogeneous habitat as on the borderline between two different habitats, they are architectural sites with a great wealth of cultural and social activity, which often foster life and promote personal, familial, social and other relationships.'* (Vegas, Mileto, Songel, & Noguera, 2014)

Such spaces operate on public – public-private – private transition levels, often increasing self-confidence of anxious individuals to interact with the outside world. The analysed projects that have been presented involved observations and interviews with the participants of various age, gender and disciplines/professions, while enacting and interacting with the designs. Working in the experimental field, the children's play and socialization observation, complained to be seriously under-researched by Oliver (Oliver, 2006), played a crucial role next to the artistic enactment and embodiment of the performative objects or architectures.

The modern history and theory of well-tempered environment in relation to social context was discussed by Hight, concluding with a call for conversion of ecology and environmental issues from technical problems with engineering solutions into engines for innovating and opening the discipline (Hight, 2009b), which has been the aim of this research from start to completion.

Within the Czech region, these questions were not fully addressed by local practices. To my knowledge, the only exception is my own practice Collaborative Collective (Collaborative Collective, 2012) and ORA – Original Regional Architecture office (Zmeková, Hora, & Veisser, 2016), both mainly integrating social and/or cultural with physical environmental performance.

9.1.3 Design's Boundary Conditions in Relation to Environmental Interactions

Searching to understand the dialogue of a design and its environment, I GIGA-mapped the interactions of some examples of my designs, organized in range from fully open to almost completely closed.

GIGA-mapping has been proposed by Sevaldson as a tool in Systems Oriented Design and expressed as follows:

> '*For each design case the phenomena at hand is deeply researched, starting with a very rapid learning process with a very steep learning curve. This process starts with visualisation: large maps are used for systematizing and interrelating the knowledge, preconceptions or speculations we already have of the subject. This needs to be done to an extent that produces several hundreds of items on the maps.'* (Sevaldson, 2013c)

In all these, in certain degrees performative projects, the local environmental conditions meet human sensory through poetics discussed by Frampton (Kenneth Frampton & Mitášová, 2012). It is interesting to note that the designs with larger non-human act responsiveness seem to be engaging humans to interact through generating ideal settings for opportunistic use without their involvement. Furthermore, it seems that the parasitic semi-interior spaces, enabling openly programmed environmental exchange, are motivating different individual and social activities to generate a pleasant environment in larger diversity of conditions.

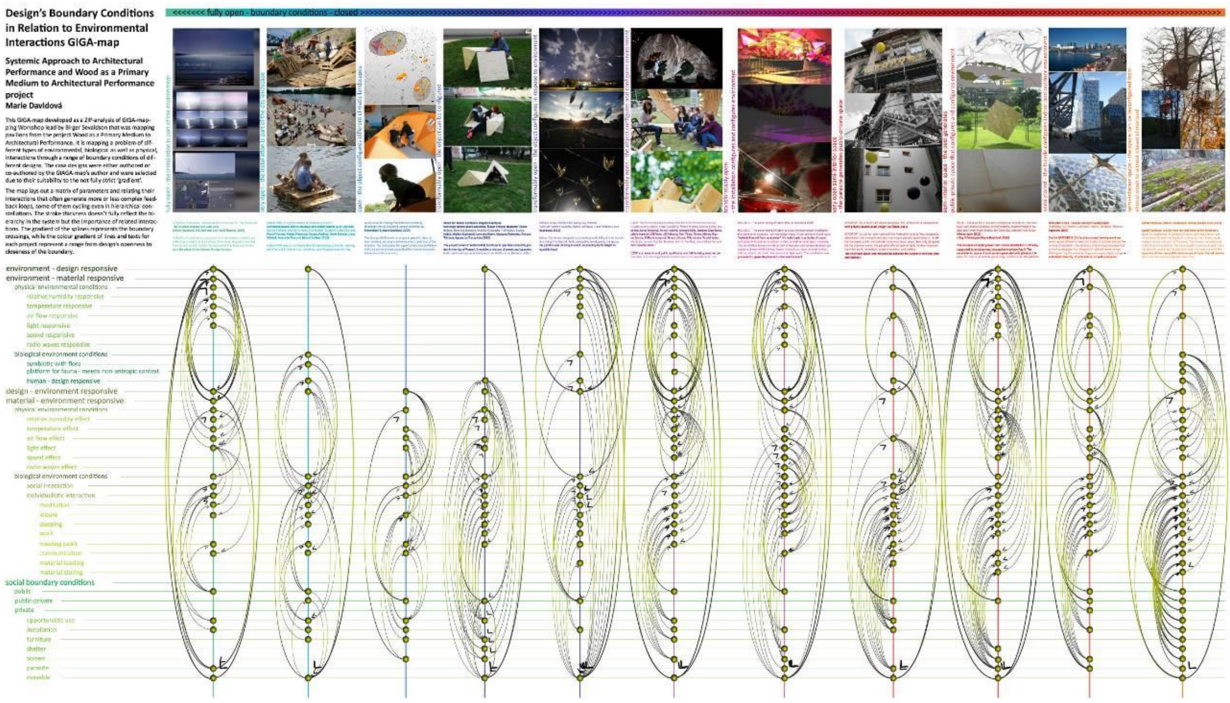

Figure 100: Davidová: GIGA-Map of Design's Boundary Conditions in Relation to Both, Abiotic and Biotic, Including Social, Environmental Interactions, Mapping the Spaces Organized from Fully Open to Almost Closed 2016 – please, zoom in at SAAP blog or in RSD5 proceedings (Davidová, 2016a, 2016c)

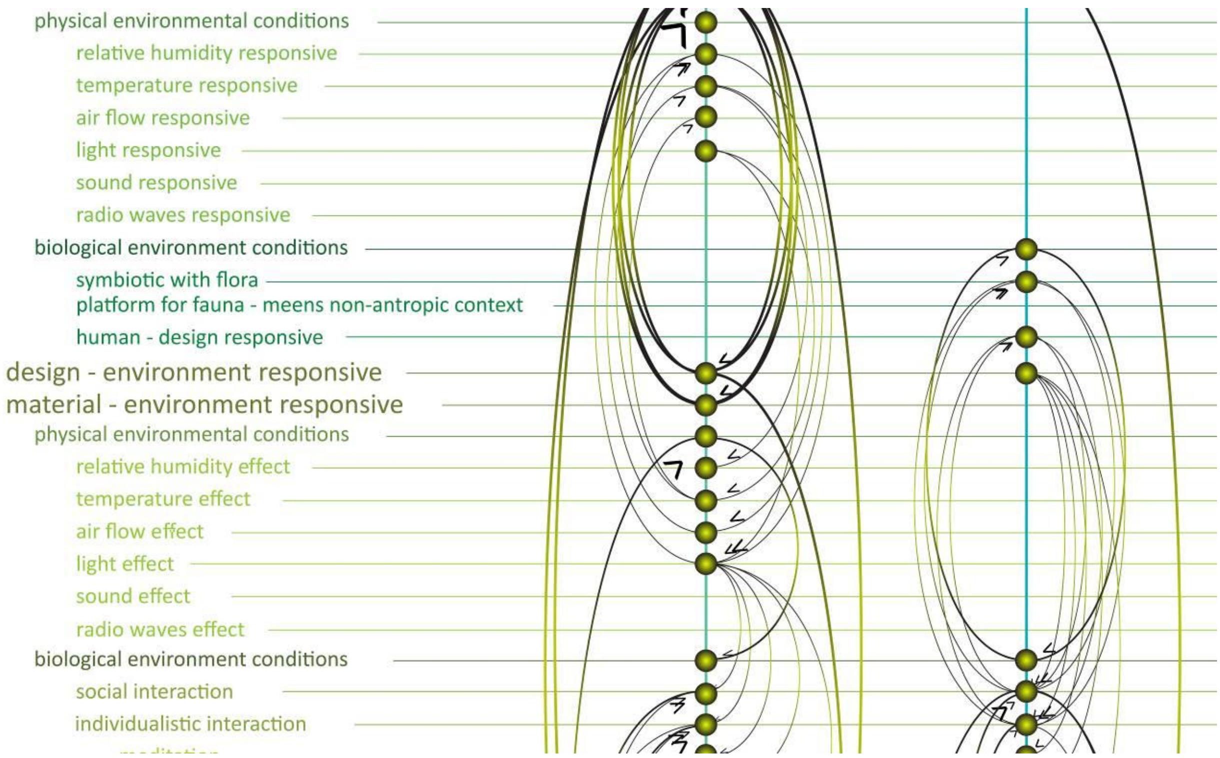

Figure 101: Davidová: Detail of GIGA-Map of Design's Boundary Conditions - showing different interactions, levels and hierarchies in feedback looping among interactions of different parameters through the boundaries. 2016 – please, zoom in at SAAP blog or in RSD5 proceedings (Davidová, 2016a, 2016c)

The following GIGA-Map of Design's Boundary Conditions (see Figure 100) was developed as a ZIP-analysis, which is defined by Sevaldson as a simple method for developing GIGA-maps through finding and zooming in potential areas for interventions and innovations (Sevaldson, 2016e), of GIGA-map of a workshop lead by Birger Sevaldson at the Faculty of Art and Architecture at the Technical University of Liberec that was mapping pavilions from the project Wood as a Primary Medium to Architectural Performance. It is mapping a problem of different types of environmental, biological as well as physical, interactions through a range of boundary conditions of different designs. The case designs were either authored or co-authored by me and were selected due to their suitability to the not fully strict 'gradient'.

The map lays out a matrix of parameters and relates their interactions that often generate more or less complex feedback loops, some of them cycling even in hierarchical constellations. The stroke thickness doesn't fully reflect the hierarchy in the system but the importance of related interactions. The gradient of the splines represents the boundary crossings, while the colour gradient of lines and texts for each project represent a range from design's openness to closeness of the boundary. The detail (see Figure 101) shows feedback looping documenting, i.e., sound, visual or climatic aspects through and by specific media effect on different biotic, i.e., human, behaviour and/or perception and returns to the effect of the later on the former.

9.1.4 Svalgangs

The unclimatised spaces between the interior and the exterior, generating the onion principal of the building (Davidová, 2016g, 2016m), securing to different extents visual, sound and climatic penetration through its boundary conditions have its place in almost all traditional architectures, functioning as its energy exchange with the surrounding environment. Nice examples from around the world are, for instance, discussed in the article In-between spaces, borderline places by Vegas and Coll. in the publication entitled Heritage for Tomorrow: Vernacular Knowledge for Sustainable Architecture (Vegas et al., 2014). This publication, next to, i.e., Sustainable Environment Association (Hensel, 2011b) and many others argue for studying and learning from traditional examples as they are source of knowledge of architectural environmental interaction developed through generations.

'Svalgangs' (see Figure 102), the semi-interior spaces in Norwegian traditional architecture that give various opportunities of use and serve as public-private and indoor-outdoor interface, developed in high potentials of articulation with different or even gradual degrees of permeability in relation to socio-environmental conditions were analysed and speculated through GIGA-mapping (see Figure 103).

The GIGA-map relates such spaces in the context of their original climatic location, opportunities for use or inhabitation, options of penetration of overall environment and spatial dimensions, its distribution enveloping the interior spaces and measurements of micro climatic exchange and moisture content of the material within the onion principle. Similarly, microclimatic research of 'exchange of different strata' was proposed by Hensel already in 2010, mentioning it as pending for advances (Hensel, 2010a). The overall mapping requires both soft and hard data as discussed by Sevaldson:

> '*In design we most often are looking at composed perspectives. This means that we are navigating complexities that are crossing technological, biological and social realms. We deal with both deterministic and unpredictable systems, framed and tamed ones as well as wild and wicked ones. This implies that we might find ourselves at both soft and hard ends of the systems approaches*.' (Sevaldson, 2015)

The GIGA-map is zooming into various scales, relating data and their development through colour coding gradients, their intensity through dashed lines and weights, themes through curvature degrees (see Figure 104) and arrows suggesting the process of the performance. Generating a matrix of 'micro systemic relations' (Sevaldson, 2016d) while placing in sequences spatial evolutions ranging from open to closed spaces, while paying attention to options of penetration density and its aesthetics character, in relation to regional site location, orientation, macro and micro climatic, social constellations and opportunities of use, the map serves as an analysis for proposing new architectural spaces and atmospheres.

Figure 102: Svalgang of Hjeltarstua from 1763, recently placed in the Maihaugen Open Air Museum in Lillehammer (photo: Davidová 2016) shows the opportunity of indoor-outdoor environment including the range from social to climatic interaction while working actively.

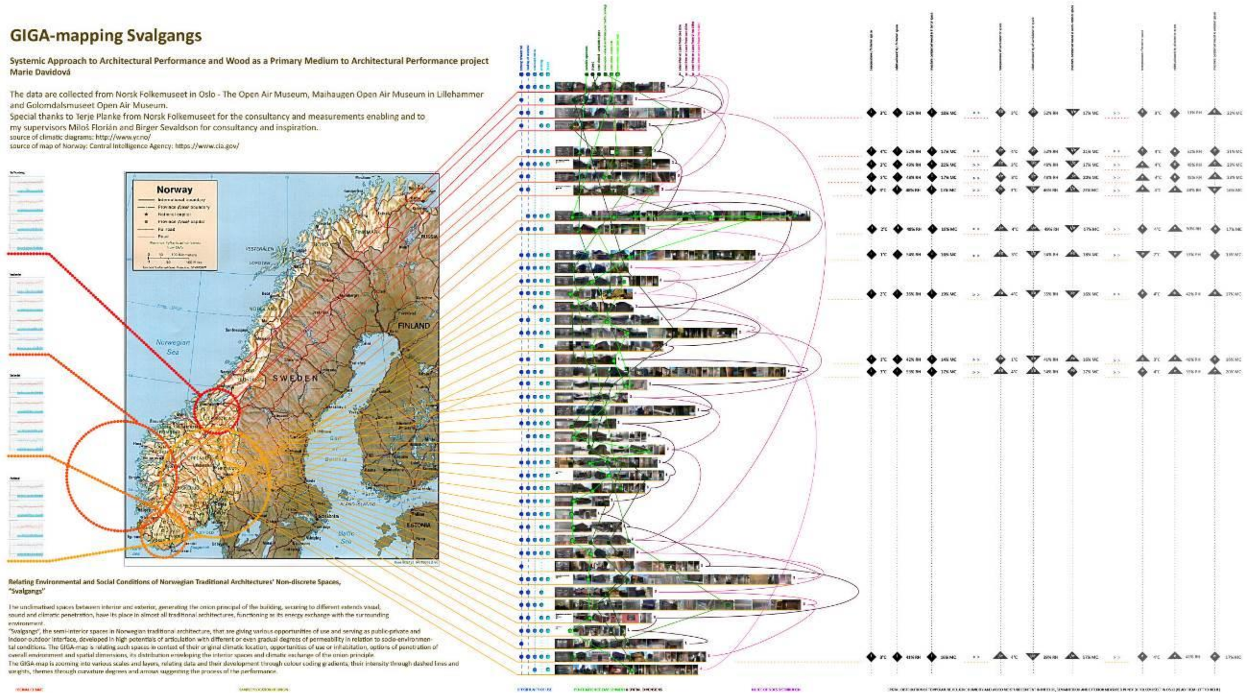

Figure 103: Davidová: GIGA-mapping Svalgangs 2016 (the map of Norway is a public source from: Central Intelligence Agency: https://www.cia.gov/ the macro climatic diagrams are used with the courtesy of yr.no reached at yr, 2016) – please, zoom in at SAAP blog or in RSD5 proceedings (Davidová, 2016a, 2016e)

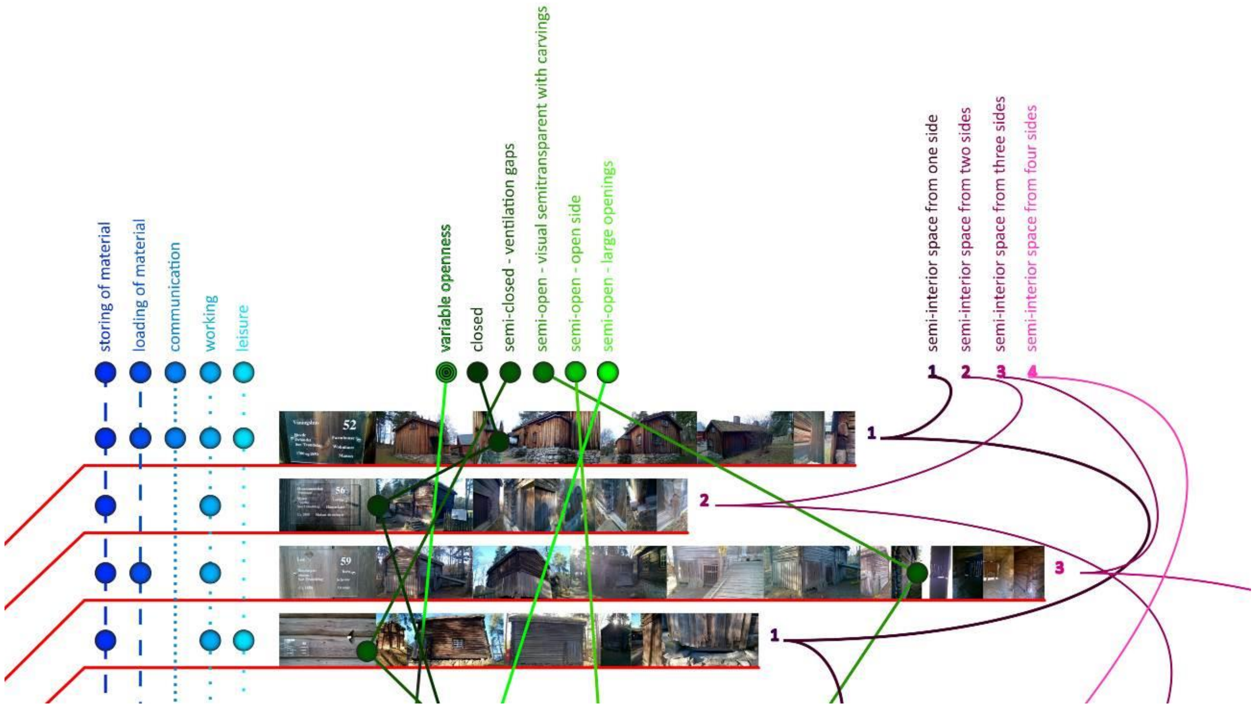

Figure 104: Davidová: Detail of Svalgangs GIGA-Map showing differentiation in relations mapping 2016 – please, zoom in at SAAP blog or in RSD5 proceedings (Davidová, 2016a, 2016e)

The map relates data, such as if the boundary can retransform or how the exchange is secured, for instance through carving, if it generates space for which periodicity of leisure, work, etc., how such is distributed along the interior space and what the climatic and wood moisture content data is of the interior, semi-interior and exterior (see Figure 104). The researched buildings are from Norsk Folkemuseum Oslo, Maihaugen Open Air Museum, Lillehammer and Glomdalsmuseet, Elverum. However, their original locations are known and were mapped and linked with their macro climatic data, as such must have had crucial effect on their design and redesigns. A lot of 'svalgang' spaces were added to the original building later on, often after a century of its use (Berg et al., 2011; Hauglid, Hosar, Krekling, Mathisen, & Songli, 2005; Sveen, 2016). The interiors were not heated and the data were measured after a period of very cold temperature within one afternoon in February 2016 in Oslo Folkemuseet. Therefore, the interiors are mainly the coldest but variations are obvious, though the data cannot be precise for the reason that the climate was changing also with the progress of that particular afternoon of measurements. The moisture content was not measured on the original wood of the buildings, as the preservation does not allow it, but on the wooden objects in particular spaces or wooden elements that replaced the old ones through reparation.

Reading from the map, the spaces with better variety of penetration options and spatial distribution along the building, thus offering different levels of biotic and abiotic exchange, seem to offer more opportunities of use activities. Svalgangs certainly serve as climate control of the interior spaces that are aimed to be climatised, generating an extra layer of energy exchange over time. There is not much literature regarding 'svalgangs'. For the consultations and enabling the measurements, I would like to thank Terje Planke from Norsk Folkemuseet, Oslo.

9.1.5 Wood as a Primary Medium to Architectural Performance Project

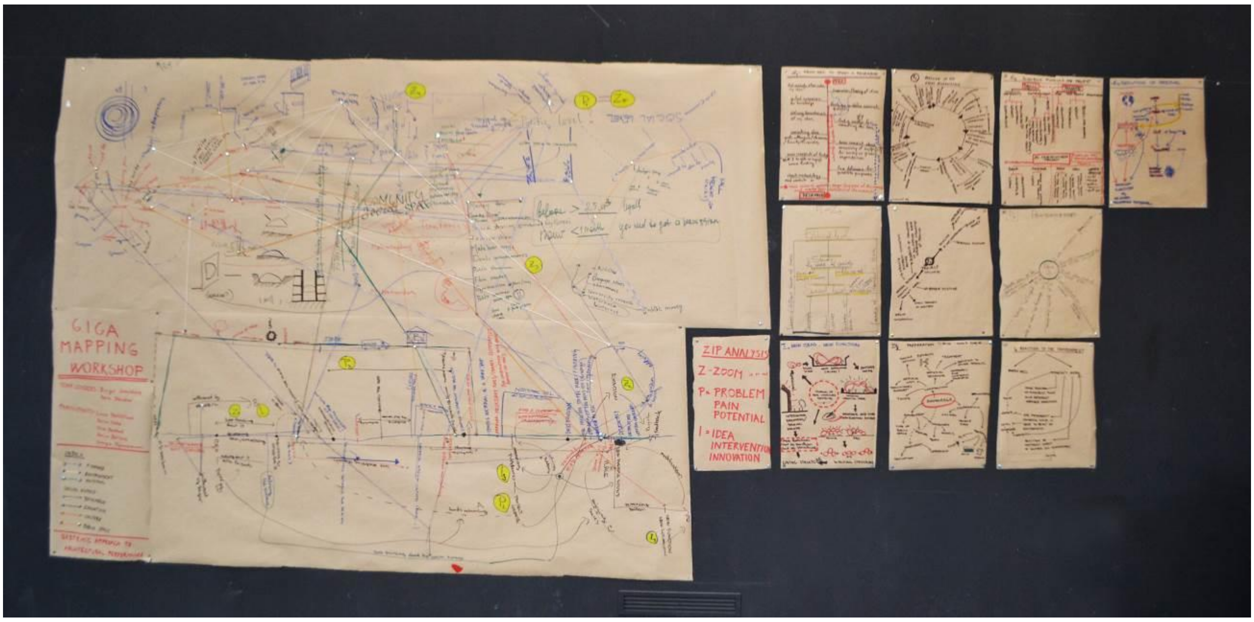

Figure 105: Sevaldson's GIGA-mapping Workshop Result (photo: Málek 2016)

Following the 'bottom up' approach, the project Wood as a Primary Medium to Architectural Performance started on the side of material science, craftsmanship, forestry and meteorology while having speculative imaginations of its applications, thus slightly combining it with a 'top down' approach. Through one part, the Environmental Summer Pavilions projects, pareSITE (Nam, 2013) (see Figure 76) and LOOP (Slavíčková, 2014) (see Figure 77), originally planned mainly as a more complex study for the environment responsive envelope Ray project, it immediately reached a social dimension. As opposed to Katarína Boháčová's doctoral thesis classifications (Boháčová, 2012), the pavilions joined both purposes, design-research experimentation as well as public social activities generator and prototype. Its relations have been mapped (see Figure 105) at Birger Sevaldson's GIGA-mapping workshop[54] (Davidová, 2016b) at the Faculty of Art and Architecture at the Technical University of Liberec (FUA TUL, 2016), that developed more complex understanding/questions also in relation to its multileveled opportunities of use and social aspects.

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[54] Birger Sevaldson's Workshop Participants: Mirka Baklíková, Lucie Pavlištíková, Martin Málek, Maria Borisova and Georgia Papasozomenou; assistance: Marie Davidová

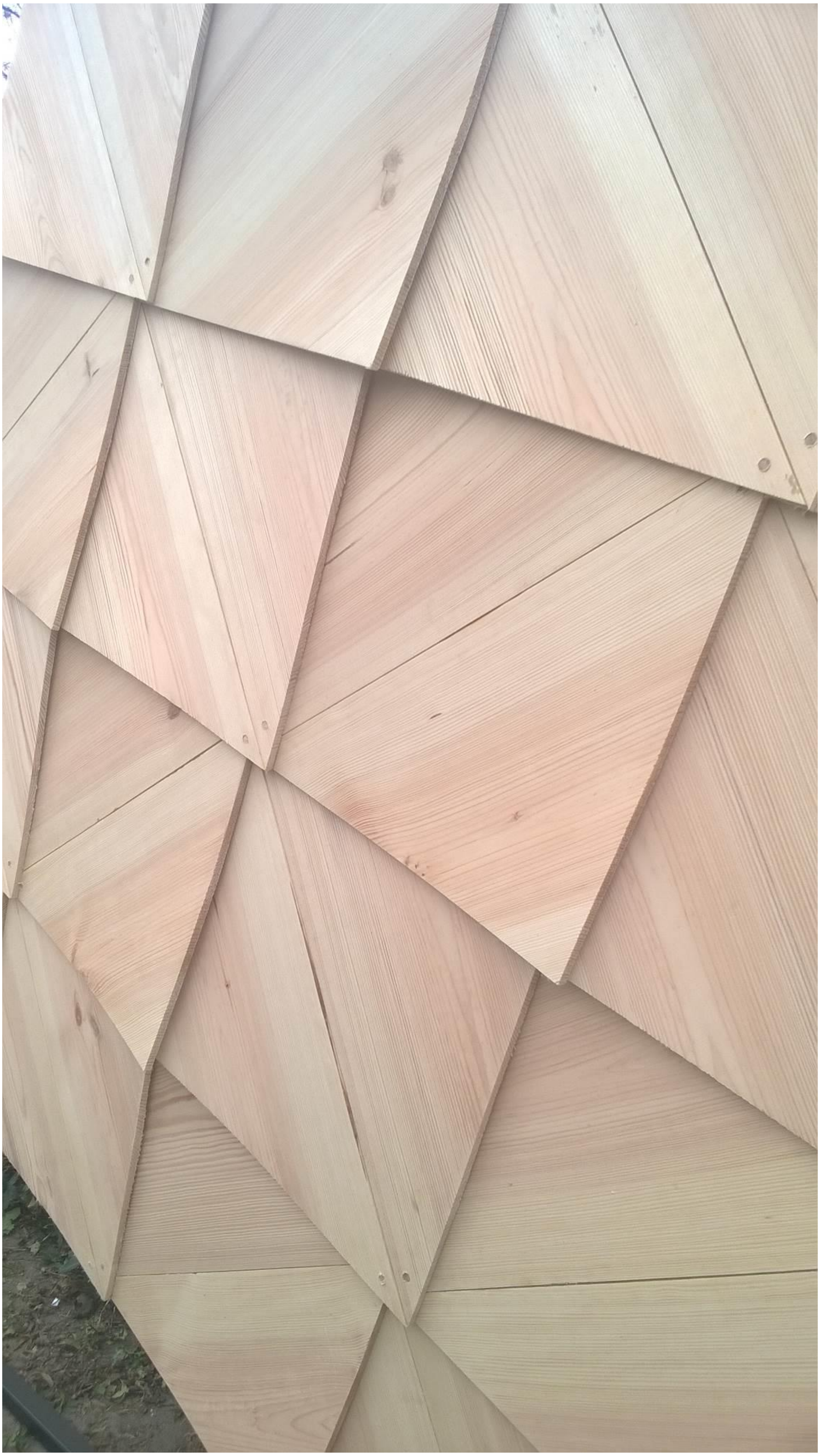

Figure 106: Ray 3 (photo: Davidová 2016)

Figure 107: Ray 2 Performing in the Sun, Being Inhabited by Algae after Three Years in an Outdoor Environment (photo: Yildirim 2016)

The GIGA-map with several ZIP analyses' takes into consideration the overall process, introducing feedback loops. The color-coded threads and markers were employed in mapping with a highlighter for zoom points.

The pavilions served as more complex material-environment interaction prototypes for the development of the performative envelop Ray project while following their own biotic – human and social responsive agenda. Generating a pleasant climatic environment for both its festivals' (Barry, 2016; Davidová & Kernová, 2016; Kernová, 2014) events as well as for individual opportunistic use, the pavilions provided data for interrelated interactions of actors and their physical environment (Davidová & Sevaldson, 2016b). Freely inspired by the performance of oriental screens, so called 'mashrabīyas' (Fathy, 1986; Hensel, 2010b, 2011a, 2013, 2015d), the pavilions generate humid air circulation evaporated out of its material on dry, hot summer days lately typical for the city of Prague. Such performance for the outdoor interaction is also taken into consideration by Ray project.

The envelopes Ray 2 and 3 (Davidová, 2013b, 2014e, 2016g, 2016m) (see Figure 106 and Figure 107), proposed as, in a way parasitic, screens for semi-interior spaces of the so-called onion principle in the environmental design field, generates public-private, semi-outdoor social and physical interactions as known from 'svalgangs'. Ray 2 and 3 has performative capacities through material-environment interaction for regulating the non-discrete space's comfort in relation to climatic conditions, not letting in moisture in high relative humidity exterior conditions, while airing in dry warm weather. In addition, Ray 3 is heat reflexive, thus generating by its warm surface thermal comfort in lower temperatures, while the preceding prototype Ray 2 (Davidová, 2013b, 2014e) is more permeable, thus, a different range of spatial properties might be reached.

This research proposes a shift from recent trends in architecture and the building industry that aims for impenetrable insulations of spaces, in addition often through toxic or energy consuming produced materials (Davidová, 2009). Instead, it introduces case study solutions for non-discrete spaces to be applied as urban design architectures or as a boundary within the 'onion principle' of habitable buildings. It serves to generate rich variations of living environments for different opportunistic use and human/biotic activities through indoor-semi-indoor-outdoor interaction of the climatic or generally physical environment, as well as biotic, namely human, agents.

9.1.6 Summary

This paper sets the case study research Wood as a Primary Medium to Architectural Performance into the context of architectural and urban design practice. It proposes a different approach to built environment than what is widely-used and supported by today's building laws and markets through suggesting sustainable applications for performative environments and atmospheres. It is exhibiting a range of variety of possibilities of boundary conditions on my, or co-authored by me, today designs/realisations, showing where the research's case projects take place. Such ranges have been common throughout the history as climatic or other physical agents as well as social or practical use adaptation to environment through gradients of boundary conditions. As seen from the 'svalgangs' mapping example, some of these spaces have been also widely transformable according to current need/suitability and/or use. These solutions were developing over generations through a 'trial error' approach while modernism cut this link in most of its specifications and adaptations. I would agree with Jan Michl, that, i.e. functionalism was a merely special aesthetics movement rather than related to any use or general performance (Michl, 2003). This loss causes issues on any liveable aspect, starting from social performance through good physical as well as mental state and/or comfort, understanding an individual's belonging to nature and universe, ending with negative effects on environment that generates feedback loops to all the other aspects. I am not even mentioning the loss craftsmanship's knowledge that relates to all of this and my research had to face it through all its stages. This research does not exclude the relevance of emotional states/interactions, tacit and subliminal knowledge/behaviour of individuals and groups from relation to hard data measurements, that to be honest, in all the cases are rather informative than exact due to the complexity of the conditions.

The four constructed research by design prototypes of Wood as a Primary Medium to Architectural Performance project suggest various range of opportunities for boundaries and its environments, while the latter ones involve the findings of the former ones, thus generating feedback loops within the design research process. These prototypes haven't been just produced, but also actively observed for performance. This includes all different aspects of behaviour, ranging from artistic and other living expressions of its enactment and embodiment (Merleau-Ponty, 2002), through social behaviour observations, to its weathering and aging (Mostafavi & Leatherbarrow, 1993) and 24 hours hourly measurements with a weather station, moisture meter and calliper in various weather/seasonal conditions.

The research claims that this soft and hard collected data are interrelated while none of them are really exact when seen from holistic perspective that can never be completely realized. Therefore, it is also in the interest of collecting subliminal knowledge in GIGA-maps, such as various uses of recordings, including photography. The majority of data that are linked to our/others interaction with the surrounding environment cannot be truly quantified due to its complexity. Therefore, new ways in relation to particular projects and their observations had to be developed and improvised through the process, not really following any pre-set, as justified by Sevaldson for such situations (Sevaldson, 2005). This covers the methodology of Systems Oriented Design (Sevaldson, 2013b), Research by Design accompanied by full scale prototyping (Hensel, 2012c, 2013), while involving NGOs (Davidová & Sevaldson, 2016b) and combining physical with digital design techniques (Sevaldson, 2005), social, individual and hard environmental data observations. Thanks to this and also to the researched topic, a new line of GIGA-mapping as well as other research methods and methodologies were performed and developed. The research ranges from programming the material behaviour to how it is perceived and what impulses it generates into endless feedback loops set in matrixes, proposing a shift from today's common approach to building environment, suggesting a small but applicable part into the discussion of generating rich varieties of environments for the researched location, that ferly relates to today's climatic changes and its implications.

9.1.7 Conclusions

If we agree with Jan Gehl that the natural starting point for the work of designing cities for people are, next to human mobility, most importantly the human senses because they provide the biological basis for activities, behaviour and communication in city space (Gehl, 2010), we have to consider variations of non-discrete, or semi-interior spaces of different levels of interactions through its boundaries discussed several times by Hensel and others (Hensel, 2009; Hensel & Menges, 2009; Hensel & Turko, 2015). Such spaces are common in different regions over the world, always designed for local climatic conditions. Dry, hot summers and cold winters of high relative humidity level are common in the Czech Republic (Tolasz & Coll., 2007). These extremes are even more and more increasing every year with climatic change (CzechGlobe – Global Change Research Institute of the Czech Academy of Sciences, 2016). The Prague Institute of Planning and Development (The Prague Institute of Planning and Development, 2016) has already joined the international Urban Heat Island project focused on recent microclimatic urban phenomenon of overheated cities in Central Europe (Urban Heat Island, 2016) some years ago. Several deaths are reported during the summers and winters due to climatic conditions every year. Such environment certainly does not generate a pleasant ambience for individual or social activities. Therefore, the discussion that the region could benefit from the concepts of architectural performance from both, arid and northern climates while adjusted to local settings seems to be relevant. This seems to support Michael Hensel's argument for 'schools of thought' that are not local in terms of their location, yet in their determination' (Hensel, 2015d). At the moment, except shopping arcades, the alternative of non-discrete architectural spaces are not mentioned in Prague's Public Space Design

Manual released by The Prague Institute of Planning and Development (Prague Institute of Planning and Development, 2014). Also, these values are not considered by property marketing, where only fully indoor spaces are calculated into selling square meters. Though not that common in so many alterations as elsewhere, also not totally alien to Czech traditional architecture these spaces, in different site specific iterations, will become necessity for living cities and/or generally, habitation in the location. Wood as a Primary Medium to Architectural Performance project offers one of many site specific possibilities of spatial climatic performances and atmospheres to be adjusted in design and its site specific settings.

When mapping the different systemic relations in interactions happening in time and space, different agents are involved in feedback loops. Furthermore, these agents are often interchangeable by transformation of the boundary conditions and the environment that is caused either by biotic or abiotic force involvement. This enables more opportunities for use and inhabitancy of all exterior, semi-interior and interior, as they are modulated through different layers of boundary crossings and reflections of the onion principle with different peels. It is clear from the shown GIGA-maps (see Figure 100 and Figure 103), that the more non-human, biotic as well as abiotic, factors are involved in the design, the more human interactions and use opportunities it generates. Introducing a soft systemic matrix and gradients in ranges and actions and sorting activities through curvature degrees while applying Sevaldson's codification of relations by line fonts and weights (Sevaldson, 2016d) proved to be suitable tool for mapping of such. Each of the GIGA-map mentioned here is in fact theme specific ZIP-analysis (Sevaldson, 2016e) of each other, mapping the problem in detail.

9.1.8 Future Visions

The research study: 'Wood as a Primary Medium to Architectural Performance: A Case Study in Performance Oriented Architecture Approached through Systems Oriented Design Methodology' covers a small part in the field of Performance Oriented Design (Hensel, 2015c). Its main contribution is in sustainability and in relation to practice application for lively built environment through systemic approach, relating both hard and soft data enabled through Systems Oriented Design methodology (Sevaldson, 2013c).

The research discusses down-to-earth strategies such as the moisture content when the wood is cut as well as its systemic relations to climate adaptations. This means that we cannot exclude ourselves from the discussion of the previously mentioned transformations necessary for the building environment of our future. The relationship of micro-macro climatic conditions starts to be common while its social or biotic aspect within the urban area are rarely discussed in detail, except the dehydration warnings for elderly people, common for at least 15 years or the previously mentioned Urban Heat Island project (Urban Heat Island, 2016).

Through employing new, or actually old, visions of the present, I would like to suggest a search for a wide range of designs in different fields with different boundaries penetrations. Not excluding ideas of systems that are, i.e., through wood's moisture content locking into its sockets in high humidity levels, thus totally closing the environment, in the same time accepting designs that are just transferring reflections or even memories or thoughts through air or other media.

While proposing the use of solid wood for the discussed performance in the discussed location at the present time, I believe that all different variations and applications within the field might be relevant in the future and/or today, in reference to different performance, product, location and technology. This suggests more explorations in all discussed fields, from microscopic to macroscopic; soft and hard data levels, employing environmental performance in all of its aspects, biotic – including social, as well as abiotic and most importantly, their relations. This seems necessary to be handled through methodologies covering complexities such as Systems Oriented Design (Sevaldson, 2013b) and Research by Design while full scale prototyping (Hensel, 2013). As discussed in paper 'Systemic Approach to

Architectural Performance: The Media Mix in Creative Design Process' that is in reviewing process of Systems Oriented Design special issue of FORMakademisk, this all, together with participation (Hensel, 2012c), could be handled in 'Rich Design Research Space' (Sevaldson, 2008, 2012c) in the future.

9.2 Responsive Transformer: The Bio-Robotic Adaptive Architecture

(Davidová et al., 2017)

The today **practice application of the research-design** project Ray boundary exchange (see Figure 108) was discussed in the **integrated** context of **eco-systemic settlement** in transdisciplinary paper: Responsive Transformer: The Bio-Robotic Adaptive Architecture, presenting a **competition entry** for design of administrative building for the Forests of the Czech Republic (Lesy České republiky, 2016). The paper questions both, the architectural design – process and 'result' as well as the notion of the architectural profession.

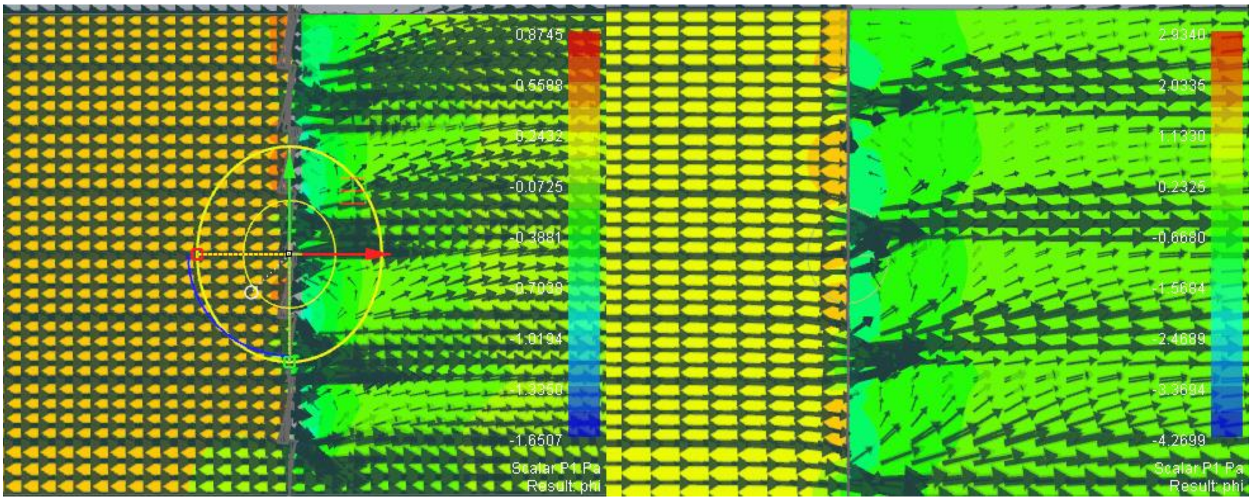

Figure 108: RhinoCFD Fluid Dynamics Simulations Illustrating the Exchange between Exterior and Semi-Interior Spaces through Ray Envelope; a) to the left: situation of dry and hot weather when the screen is open; b) to the right: situation with higher humidity and lower temperature when the envelope slowly closes (Davidová 2017)

Figure 109: Responsive Transformer (Collaborative Collective 2016)

9.2.1 Abstract

The paper discusses a result of transdisciplinary cooperation of architectural practice and association Collaborative Collective (Collaborative Collective, 2012, 2016) structural and mechanical engineering practice Experis DSKM (Experis DSKM, 2012, 2016) and ecologist association CooLAND (CooLAND, 2016a, 2016b) on competition entry project for an administrative centre of the Forests of the Czech Republic state company (Lesy České republiky, 2012, 2016): the Responsive Transformer (see Figure 109). The core of the call was innovative use of wood, flexibility in development over time, energy efficiency, sustainability and environmental approach, taking in consideration adjacent forests and villa like area.

Throughout the history, vernacular built environment was tested and modified according to abiotic as well as biotic, including socio-cultural, context over time, generating onion principle of different layers of climatic environments with different penetrations in relation to each other (Davidová, 2016g, 2016m). The project is applying different peals exchanges through bio-morphing wooden screens responsive to weather conditions, coexistence with local, micro-climate modulating eco-systems as well as ground excavated climates. As in the past, such settings were constantly rebuilt for new needs in time, recent fast climate, society and technology changes call for equal response in natural and built environment adaptations. Inspired by the R&Sie(n)'s New Territories pioneering project in the field (R&Sie(n), 2014; Roche, 2010), the project suggests options for its robotic architectural retransformations (Petrš, 2016) towards fully adaptable design, combining both, biological and material responsiveness with physical computing for the parts, that are not transformable through biology in the current state of research for application in today practice.

9.2.2 Introduction

Traditional architecture has been covering different climatic layers all through its history across the climates, continents and cultures, where their boundaries and thresholds greatly varied in relation to their symbolic connotation and functional specificity, engaging the environment and offering a broad range of different degrees of connection, openness and closeness, and provisions for habitation (Hensel, 2012c). This has been often reached by the option of retransformation or rebuilding in reference to actual usage and climatic needs, i.e. Norwegian wooden semi-interior, non-climatised spaces, so called svalgangs (Davidová, 2016m) or Cappadocian caves in Turkey (Davidová & Uygan, 2017), respectively. This project has been mainly inspired by such performance, generating interchangeable onion principle (Davidová, 2016g, 2016m), manipulated by shafts, inspired from Cappadocian underground cities (Davidová & Uygan, 2017). Learning from the biology, cells to reach photosynthesis have to have organized polarity of the receptors, covering different membranes of different penetration exchange among different organelles (Cavalier-Smith, 2000; Soll & Schleiff, 2004). Enclosable fluid transfer is performed through cells of pinewood (Dinwoodie, 2000). Sunflowers follow sun in their early development in order to gain maximum energy, while later stay east-facing before facing downwards (Meyers, 2010). This performance is based on the plant's own development and its surrounding's environmental changes throughout the seasons. The project's performance ranges from bio-mimetics, through material's bio-morphology to full use of biological systems, positioning it into eco-system of the adjacent forest and urban settlement.

9.2.3 Building's Climatic Performance

Our proposal is based on single mobile cells that can organize themselves into spatial organisations suitable to current climatic, biotic, including social, and usage performance. Each cell consists of two climatic layers, a) one part, that is fully enclosed, insulated through green roof/façade and climatised; b) and to it ambient semi-interior, non-climatised space, that is airing in dry hot weather trough wooden material-environment responsive envelope Ray 3, which closes in humid cold weather (Davidová, 2016g, 2016m). Through the windows in the green roof, it can generate natural ventilation. The cell can rotate towards prevailing wind and solar radiation, thus manipulate the indoor climate through the ventilation stream. The unclimatised part can also fully open itself and become fully exterior space. The cells are connecting through joints in a grid to service and ventilation shafts from underground spaces. The stream is cooling the above- and under-ground climates from infiltration pool at the lowest level and heating from underground forest wood waste incinerator. Underground spaces have best climatic conditions for computer rooms, meeting rooms, cantinas, sport facilities and archives, bicycle or car parking, while the aboveground spaces serve well for long term daily usage for work or habitation. The local forest species green roofs and ground surface not only manipulate the indoor and outdoor climate and keep the rainwater management, but also extend the surrounding eco-system. The campus is a gradient between villa like settlement and natural forest, positioning humans as one segment of the overall biodiversity. For its thinness, that is important for wooden construction of the cells, and sustainability of management, the company Living Green City Ltd. (Living Green City Ltd, 2016) was selected for next steps local species application cooperation. This architecture proposal aims to adapt to climatic, as well as biotic, including social, development. Therefore, we hope that no more tearing down will be necessary in closed future, such as in current situation.

9.2.3.1 The Cell Organisation

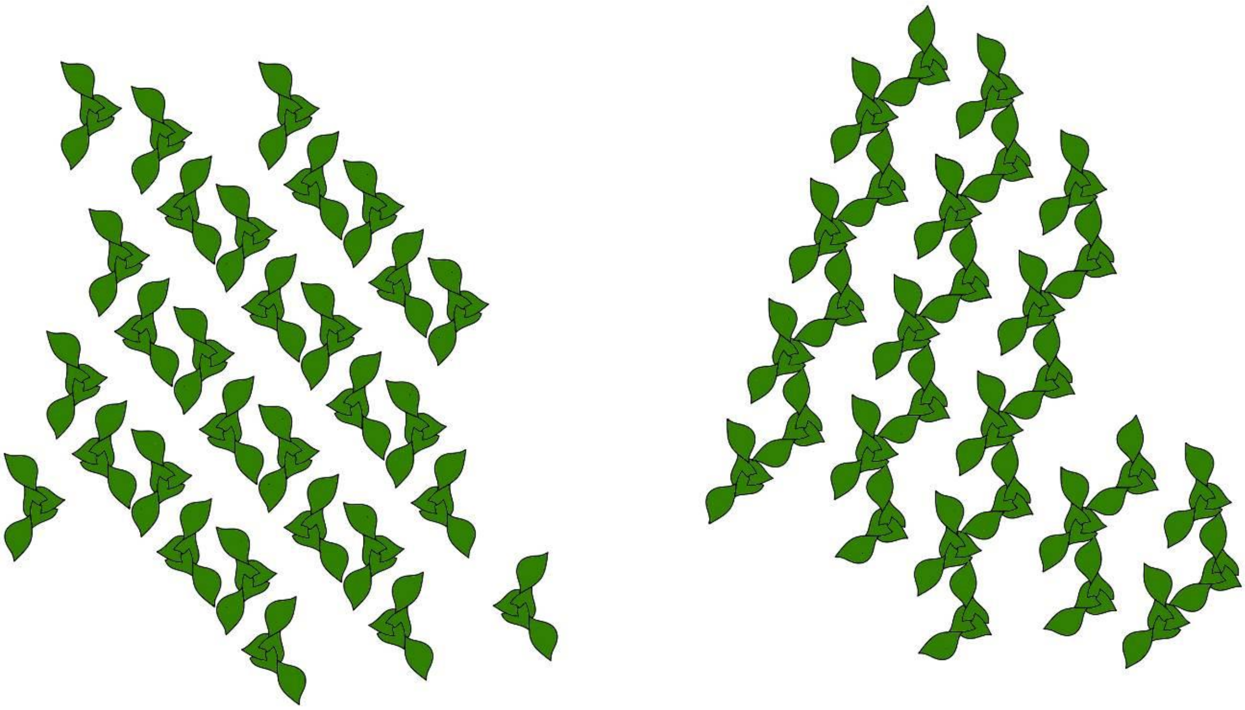

Figure 110: Responsive Transformer: Different Variations of Cell Organisation with Green Roofs (Collaborative Collective 2016)

The cell modular system organizes itself in reference to its climatic and biotic, including social, performance and relationship to pre-designed grid with connection to service shafts from underground. It is based on autonomous system, equipped by monitoring environmental sensors, reading the event's calendar of the Forests of Czech Republic company, while it can be freely hacked by its users. The cells can rotate themselves according to the prevailing wind, humidity and solar radiation to manipulate their and the exterior climate (see Figure 110). By generating enclosures, it can increase its microclimatic humidity level, supporting in-outdoor climate comfort in hot, dry summer days when the wind doesn't move. This is in reference to usage and biotic, including social, needs, relevant to public/private events, outdoor cantina in good weather, material loading, or needs of different species, grasses or bees and other insects i.e.

9.2.3.2 The Onion Peels

The transformable area has got several peels of climates (see Figure 111 and Figure 112). From the larger perspective there are several urban options of cells' organisation, generating squares, yards, streets and soliter urban fabric, all in combination with landscaping. These constellations offer variability of microclimates of enclosed, semi-enclosed and open outdoor environments (see Figure 111 and Figure 112) thus regulating wind streams, sunshine, and privacy and through the hygroscopic envelopes Ray 3, green roofs/facades and green ground, also the relative humidity level. The cell has got semi-interior space (see Figure 112), operated through the Ray 3 performative envelope as an exchange with exterior climate and heat leakage from the ambient climatised space (see Figure 113). The climatised, through green surface insulated space towards outdoor, space can open to the semi-interior and through its roof windows generate ventilation stream. In addition, it can reach cooling or heating through the underground ventilation shaft. The underground has forest waste incinerator for heating and energy and infiltration water pool of groundwater that serves as cooling ventilation, fire tank, as well as the water source for the area. The service spaces and spaces with low frequency of use are placed underground that insulates them, lit by the fans. While the cells relate to villa like area from the west side, the green surfaces are already part of the forest's eco-system. This transition is placing the human settlement back to nature.

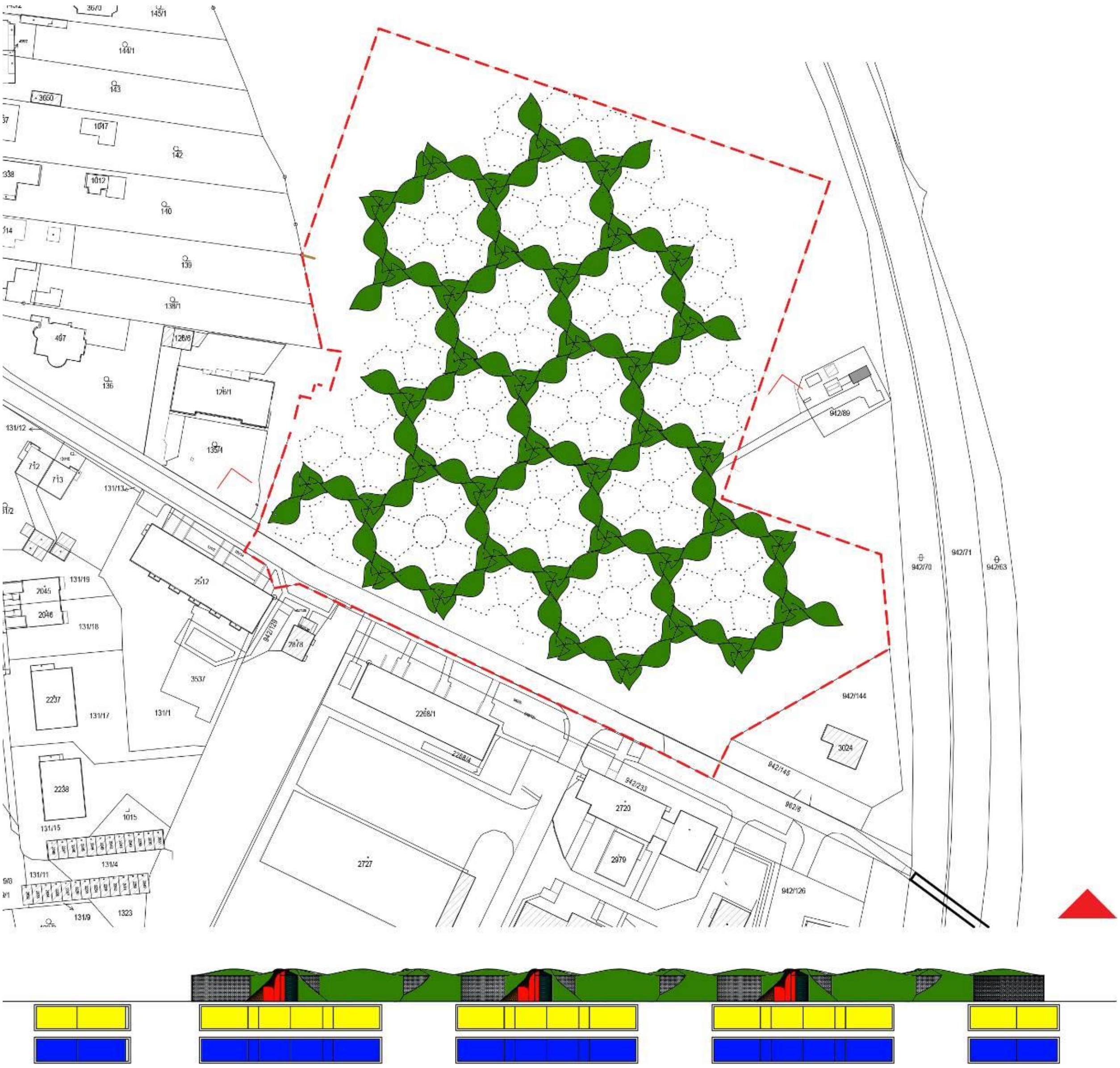

Figure 111: Responsive Transformer: Situation Drawing and Section Showing Different Bio-Climatic Layers (Collaborative Collective 2016)

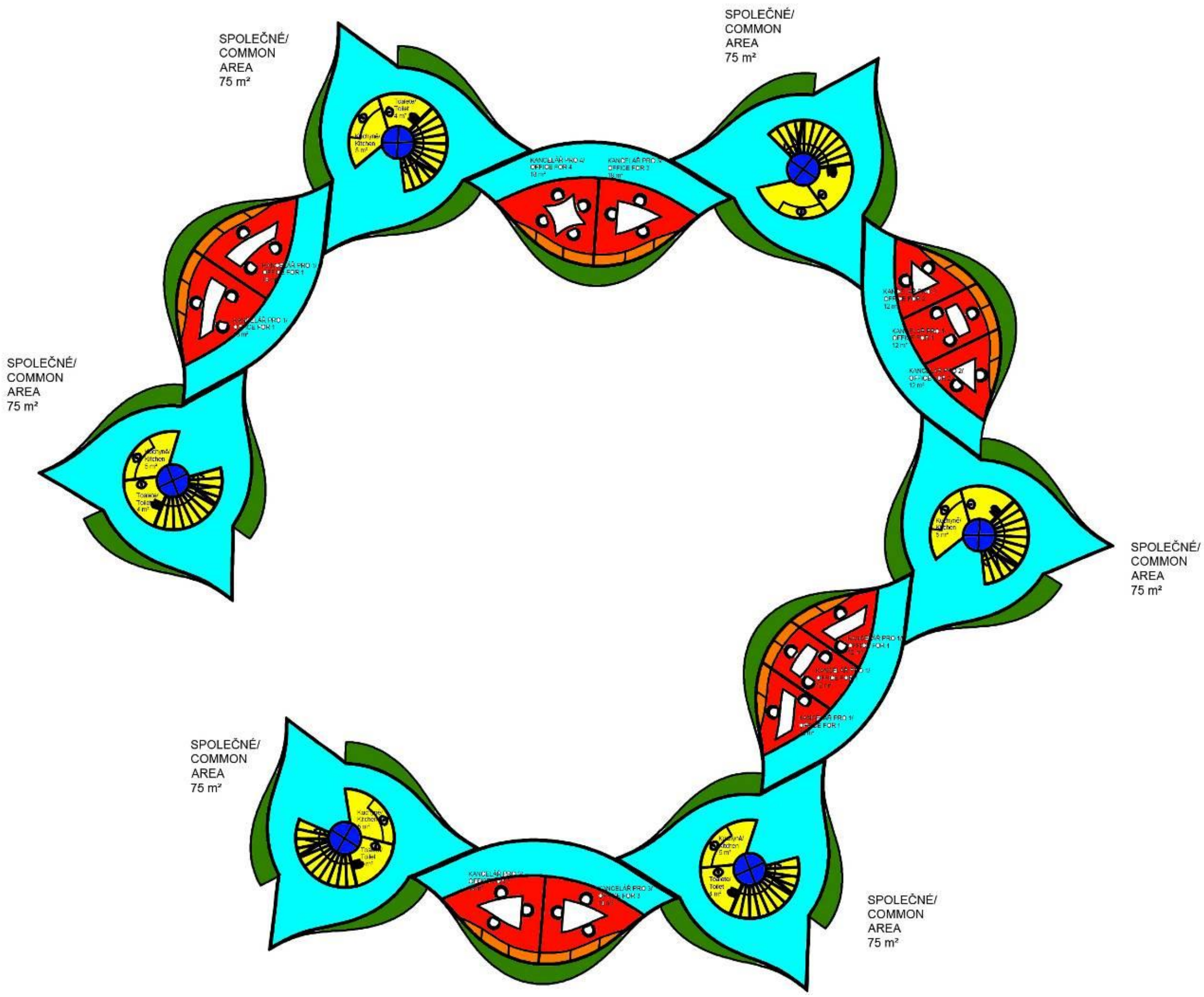

Figure 112:Responsive Transformer: Example of Offices Floor Plan Showing Peels of Bio-Climatic Layers (Collaborative Collective 2016)

9.2.3.3 Ray 3 Envelope

Ray 3 (see Figure 113) is an environment responsive pine wood envelope. Its panels are cut in a tangential section, therefore they warp in dry hot weather, while narrow down in cold humid conditions. They are organized so that the envelope is airing in targeted climatic conditions while in the other ones it is enclosing. Its semi-interior surface side is painted by thermo-insulation paint AZ – TR Coat that performs based on reflection of electro-magnetic heat radiation through NASA's technology 3MTM Glass Bubbles (AZ-TECH s.r.o., 2016). Its joinery is based on under-dried plugs that expand when exposed to relative humidity of the natural environment. The wood is treated by soaking it in brine, an old traditional Norwegian technology against biological decay. Such panelling lasts for more than 200 years even in the very wet oceanic climate of north-west coast of Norway. The product is fully recyclable, without causing any harm to the environment.

For achieving the highest level usage and social performance, the envelope can also robotically unfold when special events require it. Thus, the space becomes fully or partly open for occasions such as public/private festivals or material loading.

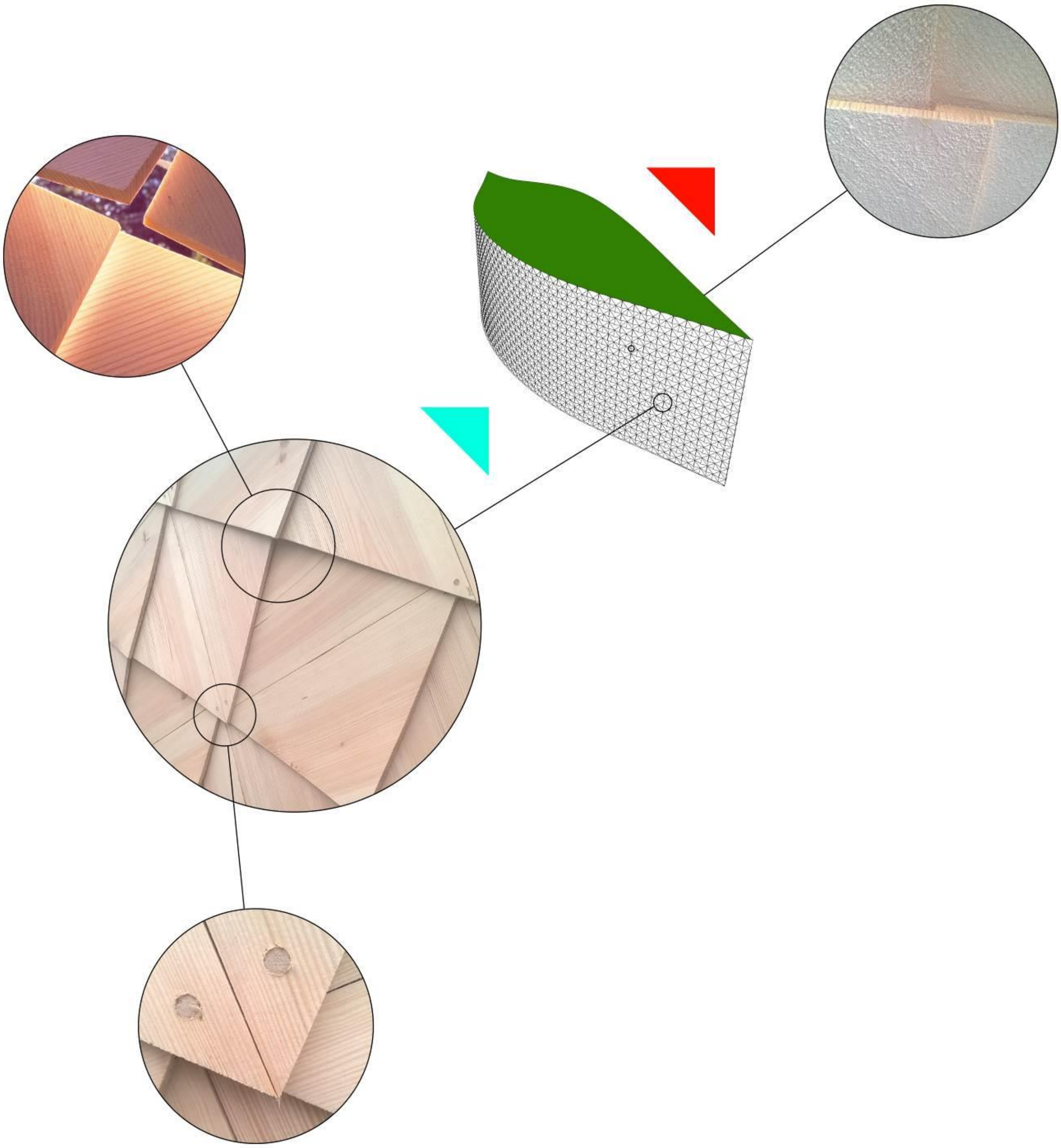

Figure 113: Ray 3 – Responsive Envelope Applied on Cell with Green Roof Showing the Natural Ventilation Stream: a/ top left: Open Airing Gap in the System Ray 2 Prototype; b/ central left: Ray 3 Prototype; c/central right: Ray 3 Applied to Cell: d/ top right: AZ TR Coat on Ray 3 Prototype; e/ bottom left: Joinery on Ray 3 Prototype (Collaborative Collective 2016 and 2013)

9.2.3.4 The Green Roof/Façade and Ground

Today 54% of people are living in cities while this number is expected to increase to 66% by 2050 (United Nations, 2014). Living in new urban environments means new challenges and increased pollution. A conventional car produces about 4.7 tonnes of CO2 per year. At the same time, up to 12,5 to 40 sq. m of living wall can cover annual oxygen consumption of one human being and absorbs up to 0,46 kg of CO2 per year (Office of Transportation and Air Quality - United States Environmental Protection Agency, 2014). Street-canyon vegetation may reduce concentrations of the two most harmful urban air pollutants, nitrogen dioxide (NO2) and coarse particulate matter (PM10), by as much as 40% and 60% respectively. Average reductions over a year ranges around 7–30% (Kessler, 2013). Latest development of hydroponic cladding systems provides also noise reduction by up to 15 decibels (Azkorra et al., 2015). Green surfaces are seriously reducing urban heat island effect through the material absorption and humidity evaporation (Wong et al., 2016).

As a cladding/roofing material we are proposing modular hydroponic cladding system made by Biotecture (Biotecture, 2016) in cooperation with Living Green City London (Living Green City Ltd, 2016). This 600x450mm modular system is based on plants fitted within rockwool panels irrigated by sophisticated remotely controlled irrigation system. The ground level uses regular soil material. Both, the cladding/roofing and the ground are overgrown by local species. In the underground hexagonal grid, there are left unbuilt spaces for rainwater infiltration.

- **Current ecological characteristic**

Origin vegetation type: *Molinio arundinaceae - Quercetum*

Current vegetation type: *Carpinion* as. *Carici pilosae-Carpinetum betuli* (Neuhäuslová, Moravec, & et. al., 1997)

Vegetation gradient: 3rd vegetation gradient (Culek, 2005)

Climate character: T 2 - warm climate (Quitt, 1971)

Natural forest area: Polabí (Forest Management Institute Brandýs nad Labem, 2012)

The area is located on flat area of bordering of urban area and urban forest. Ecotone between these biotopes is consisted of nitrofile species such as *Sambuscus nigra,* and *Rosa canina.* Nitric and ruderal character of both eco-systems also indicates *Impatiens parviflora* and *Urtica dioica* in the ground. Ruderal species are characteristic for the urban area but can be also found in the forest. Some parts of the forest eco-system are close to original vegetation type. Both species *Quercus petraea* and *robur* with *Carpinus betulus* dominate there.

- **Species selection**

Figure 114: Selected Species; form left to right: Raspberries (photo: Motl n.d.; with the courtesy of Motl); Calluna vulgaris (photo: Motl n.d.; with the courtesy of Motl); Alchemilla (photo: Zímová n.d.); Grasses Poaceae (photo: Zímová n.d.)

The main motive for the selection of species (see Figure 114) is forest environment, formed to generate natural like biotopes, which ease and please human presence. Such polyfunctional biotopes are usually used for example in ecological restoration in damaged areas (Aradottir & Hagen, 2013). For this reason, only the species growing in Czech forests that can survive design's geotope are used. The overall greenery has more functions: a) water retention; b) biotope for pollinators, c) food for people using area, d) aesthetical landscape scene. To reach this, these species were selected for these locations: a) ground: *Bryophyta* in as species variability as is possible. Dominate species are *Polytrichum.* The other ground species are *Poaceae* with domination of *Nardus* and also *Juncus* in more wet sites, b) west and east orientation and ground: Ground with *Sphagnum* and fruits hedges of *Blueberries (Vaccinium myrtillus), Cranberries (Vaccinium vitis – idaea, Vaccinium oxycoccos* and Raspberries *(Rubus ideaeus).* These species generate bushes areas anf offer fruits, serving as food for animals and people. Robotic harvest will be used during season; c) South side: Moor with *Calluna vulgaris* and Birch tree *(Betula pendula).* Heath generates natural year-long blossoming carpet that collects well water and solidifies slopes. For better solidity stunted birch is also used. The moor need permanent trampling and disturbance of the top layer, which will be performed by robotic cells; d) north side: The main task of northern side will be water retention. Species such as *Alchemilla* or *Plantago*, which actively collect horizontal precipitation, are used. To this *Juncus*, a long term collector of rain and underground water will be added.

For the pollination of fruit bushes bumble bee hives will be built. All the greenery system provides food for pollinators during the entire vegetation season. Selected species diversify blossoming seasons, which is suitable for allergic people. Vegetation accessible by people will be enriched by spices Melisse (Melissa officinalis), Sage (Salvia officinalis) and Rosemary (Rosmarinus officinalis), suitable for food and drinks.

9.2.3.5 The Underground

The underground and green surface (see Figure 109 and Figure 111) insulates the occasionally used spaces. Therefore, the energy usage for keeping their climate is lowered to minimum. The climate is operated by ventilation shafts, cooling from an underground pool and heating from an underground forest waste bio-mass incinerator. Both above- and under-ground the shafts can be opened and closed in reference to its climatic needs. The hot air can leave through the fans that also serve as skylights and visual connection to landscape with greenery. The infiltration pool on the lowest level of the build-up area is a reservoir for fire security as well as a source of its water.

9.2.4 Structural and Mechanical Performance

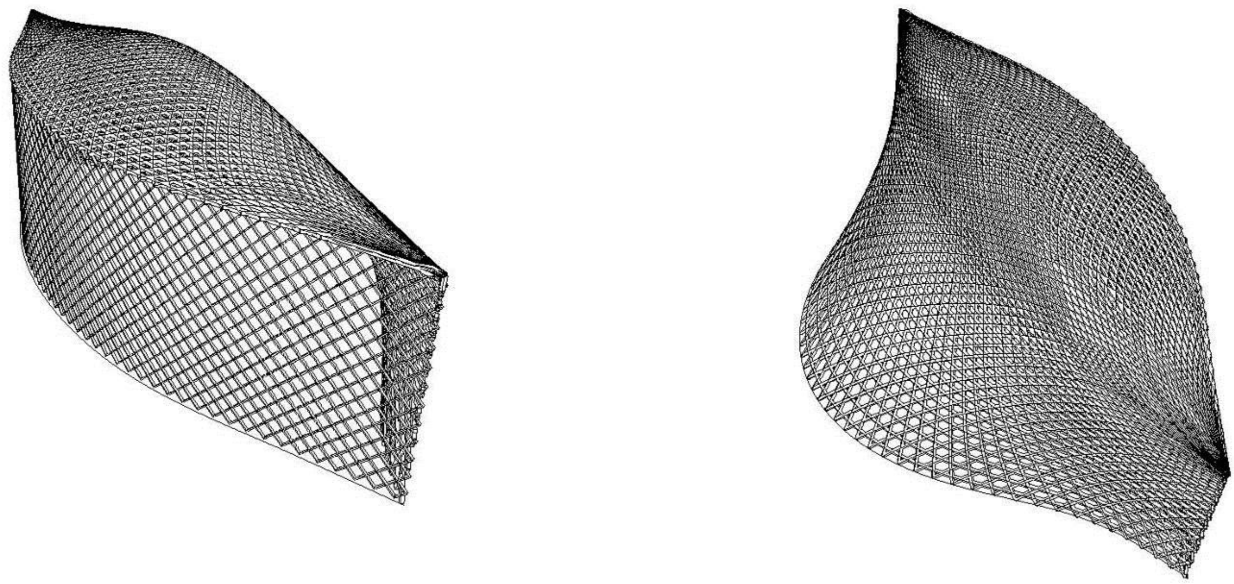

Figure 115: Wooden Shell Structure of the Cell (Collaborative Collective 2016)

The structure itself is divided in two parts: surface and underground. The underground part of the structure consists of hexagonal grid of reinforced concrete cells, with different purposes and roles in the structure. Some cells in the grid are accessible from the surface while others are only accessible from neighbouring underground cell. The cells themselves vary in the number of individual levels, as some are only one level deep while others can reach deeper underground levels. The cells are placed in position in an open excavation pit and assembled together. The entire structure can also be broken into individual cells when necessary, their positions can be modified and their quantity can be changed in both ways, increased or decreased as necessary.

The surface structure is not an actual structure in traditional terms, but rather a set of moveable interlockable elements. Elements above the underground cells with surface connection can rotate in position like a turntable. Other elements can crawl on the ground and form different arrangements and shapes. The elements when locked open their doorways and create larger structure accessible through the docking ports. Utilities are connected through these ports with units connected with underground acting as distribution hubs.

The structure of the elements themselves is a curved wooden shell (see Figure 115) with horizontal framework forming the floor of the structure. The structure is supported by retractable supports and pivot wheels. When the wheels are lowered the structure can crawl to a new position, and when the supports are lowered the structure is locked in place. The wheels allow for translation and rotation of the structure, as they can be rotated in tangential direction relative to the axis of rotation or set parallel for translational movement. The unit itself, while not settled in the locked position with neighbouring hub unit uses batteries as power supply for the actuator motors, with the possibility of external power source when the battery runs low. Under operational condition of the building, these batteries are used as power banks for solar generated energy to compensate for the power surges.

9.2.5 Discussion and Conclusions

The project was the fusion of architectural performance, environmental science and mechanical and structural engineering field where *'transdisciplinarity'* was secured by equal roles of either participants' research's aim as defined by Hensel (Hensel, 2013). Therefore, the project entry result does appear to be 'weird', when looked upon from a traditional architect centred perspective. From our experience, this approach brings new insights to the complexity of human settlements in relation to the overall eco-system, where the designed system has no clear boundaries. The system boundaries here are understood as a platform for exchange of the *'inner'* and *'outer'* system (Hensel, 2012e; Hensel & Turko, 2015) and always engaged in real-time adaptation on multiple levels with the use of biology itself, material-biological responsiveness and physical computing. Living in more climatic layers with other species seems to be natural and basis for humans and others, though rejected by today western building laws. It occurs to be possible to design non-human centred, or *'non-anthropocentric'* (Hensel, 2013, 2015c) eco-system, where humans play an equal role next to the other species within abiotic environment and therefore we suppose it is less likely to collapse and therefore sustainable. There is of course clear lack of prototyping in the work as it is purely concept design speculation, gathered together from several partial researches and fare more investigations would have to be done to bring this to practice. In addition, it has been argued by Koffka that the whole does not perform as sum of its parts in Gestalt Psychology (Kurt Koffka), followed by Systems Theory. This has been also elaborated by the first author with Sevaldson in relation to her experience with full scale prototyping (Davidová, 2016m; Davidová & Sevaldson, 2016a). However, it has been argued for by Sevaldson for open-ended design process through and after it's so called realisation in his upcoming publication on Systems Oriented Design (Sevaldson, 2017b). We believe, that this project is a clear step forward to such design processes, handling synergy of humans with their surroundings, where architect is not playing central role, but by the proposed adaptability is opened endless space for *'co-design'* (Szebeko & Tan, 2010).

10 Summary, Discussions and Conclusions of the Thesis

The thesis is to my knowledge the first research exemplifying the field of *'responsive'* (Hookway & Perry, 2006) wood on project practice application and the first to examine this study on solid wood. It is done in the sense of arguing for the option of learning from traditional knowledge through the use of solid wood and architectural *'types'*, researched through GIGA-map as a new *'typological*[55] *diagram'*[56] exploration of *'non-discrete spaces'* (Hensel, 2013; Hensel & Turko, 2015) and human settlements. In contrast to impenetrably insulated enclosed spaces that are propagated today (Davidová, 2009) even by building laws of many countries, the research proposes different layers with various fields (S. Allen, 2009; Hensel & Menges, 2009) of boundaries, serving as active zones of mediation between them (Addington & Schodek, 2005; Hensel, 2012d, 2012e; Hensel & Menges, 2009). It covers important findings in **wood material research**, methodology development in the field of **Systems Oriented Design** (Sevaldson, 2013b, 2013c, 2017b), **Time Based Design** (Sevaldson, 2004, 2005, 2017b), **co-design with biotic as well as abiotic agents** and **full scale prototyping**, majorly through fusion of these for **Performance Oriented Architecture**. It is a transdisciplinary research involving various levels of institutions and social groups suggesting not only different approach to ***'architectures'*** but also to design **process**, its **methodologies** and **management of such**. This fusion lead at the end into major conclusion – ratification of new design field: **Systemic Approach to Architectural Performance**.

One more PhD project: 'Bio-Climatic Layers in Built Environment: Exploring Environmental Dimensions' in currently undertaken by the author at the Faculty of Art and Architecture at the Technical University of Liberec in art field, bringing this case study project into larger complexity of dwellings and settlements.

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[55] 'Typology is the comparative study of physical or other characteristics of the built environment into distinct types.' (Güney, 2007)

[56] Jacoby proposed to overcome the existing historiographical separation between a typological or diagrammatic discussion by 'typological diagram', meaning a diagram that is specific to the discipline of architecture in its production of form and knowledge, and is framed in both typal and typological terms. This typological diagram should be an abstraction arising from a set of related conceptual, descriptive and design problems (Jacoby, 2015).

10.1 Major Acquisitions to Research Fields Summary

By practising **Research by Design** and **Systems Oriented Design**, the work needed to be **more complex approach than just looking at one focus area**. Though I tried to keep this this thesis **thematically focused**, it had to address **more than one field** for the reason that **neither any method** for the research, **nor the material science** was **advanced enough** or applicable for the project, its **local** as well **as team members' parameters** settings. For this reason, a new **design field**, fusing all the areas discussed within the holistic perspective of real life, was founded. This field is called **Systemic Approach to Architectural Performance.**

10.1.1 Methodology Research Acquisitions

The following acquisitions in this section are gained through design, fabrication and prototypes testing practice, employing intuition, observations and reflections upon it. These investigations are grounded in research's area and stakeholders' complexity and relations and time basis within it. Within this project, the process and the never ending *'result'* are seen as one within its evolution.

- ***MINI-maps*:** The research involved MINI-maps and combined them with concept sketch models as a kick start in design-research process.
- ***Processing Performance of the Whole:*** The research positions tacit and subliminal knowledge as relevant design-research parameter, equal, or often superior to hard data and proposes the strategies for its application from registering through GIGA-mapping to prototyping and its further performance observations, followed by next applications. This is for the reason, that hard data can never cover the complexity of the overall performance of the whole.
- ***Performance of the Whole:*** The research claims the necessity of full scale prototyping, showing that partial simulations and prototypes often perform other way than the whole, following similar discussion in Gestalt Theory.
- ***Rich Design Research Public Space:*** The research progresses the synergy of transdisciplinary GIGA-mapping and full scale prototyping, while exposing the work to different performers and public in public space for its co-design, thus generating one more step forward in Rich Design Research Space. This is only possible thanks to the strategy of involving NGO into Research by Design as a key partner.
- ***Feedback Looping of Final Prototypes:*** The research exhibits practical examples of Time-Based Design, when the final architectures that are already in use are in the same time research's full scale prototypes.
- ***Time Based Eco-Systemic Co-Design:*** The research exhibits a practical example of Time Based Design through prototypical built environment, that is co-designed and re-designed by its users, including all biotic and abiotic factors in eco-system, over time.
- ***Practice Generated Theory:*** The work claims to generate theory through practice.
- ***Systemic Approach to Architectural Performance:*** Through the fusion of Performance Oriented Architecture and Systems Oriented Design with time based ever evolving eco-systemic co-design perspective that involves all biotic and abiotic agents, the research ratified new design field.

10.1.2 Material Research Acquisitions

The following acquisitions in this section are gained through samples and environment hard data observations and rating these to forestry, microscopic wood material science research and craftsmanship. Spoken knowledge had to be collected for the reason that not enough has been published in the field. This could be also claimed as one of the acquisitions, as this knowledge is seriously disappearing.

- ***Life Cycle Based Eco-Systemic Material Selection:*** Pine wood seems to be most suitable for discussed design properties in researched location, considering local pine species and local eco-system.
- ***Force-Hygroscopicity Relations:*** It seems that the stresses within the material, followed by its growth material distribution have direct relation to wood's hygroscopic behaviour, namely its warping. This was largely observed on samples of tension wood of false acacia and in smaller extent on narrow samples of pine wood.
- ***Time-Based Force-Hygroscopicity Relations:*** About 10% of the samples warps other direction for certain time after the wood is cut (about three months) on observed samples. This might be for the reason that the stresses of the overall tree stays in the material.
- ***Angle Cut-Fibre Direction Hygroscopicity Performance:*** Not only the thickness and density of the material, but also the angle of plane cut in reference to fibre direction affects its cup warping of the observed samples.
- ***Sugar and Amyl Free:*** The material can be protected against biological decay by soaking to salt water before it is applied. For better data within the researched location it would need testing periods that widely extend the scope of this research project. Related evidence of this protection is from Norway on its traditional panelling, even from very humid locations. However, it is impossible to claim same performance in the research area with its clime and biotic specificity and different morphology of the proposed design itself, therefore its interaction with the environment. It seems to be the most sustainable treatment for such wood protection. Therefore, more investigations in this field sound reasonable.
- ***Biological De-Re-Sorption Relation:*** Algae habitation has decent effect on material's moisture content, while it distributes along the fibre orientation and the morphologically defined moistest locations of the samples.
- ***MC-Cut Hygroscopicity Relation:*** The material's performance can be partly pre-programmed by setting certain moisture content when it is cut.
- ***Responsive Material-Design Life Cycle:*** At least in researched location (Czechia), the solid wood has currently more sustainable life cycle than the ply-wood within the field of proposed design.
- ***Introduction of Solid Wood Responsivity to POA:*** Solid wood can be applied in Performance Oriented Architecture as clime-responsive material.

10.1.3 Architectural and Urban Design Research Acquisitions

The following acquisitions in this section are gained through design-research speculative practice and traditional architectures' and prototypes' observations and hard data collection. Those were elaborated by its reflective analysing through GIGA-mapping or tacit and subliminal experiences. The speculative practice concepts part is generated through observational, registering and mapping experience for building new theory.

- ***Responsive Solid Wood's Application:*** The research suggests two practical applications of responsive wood for non-discrete architectures: a) Semi-interior spaces of dwellings exemplified on two competitions entries by my practice platform Collaborative Collective where the designed screen is applied. This design solved major practice application questions of the basic research done by the other researches. b) Urban design of clime-active pavilions that were built and observed in the city of Prague, serving as micro-clime modulator, public life activator, as well as i.e. repose object for birds in dense city centre. In all these cases I was the project leader and manager, as well as a key design team member.
- ***Performance Based Beauty – Beauty's Performance:*** While i.e. Hensel or Zumthor claim that beauty is coming out of the performance (Hensel, 2008; Zumthor, 2006b), the research is adding a claim, that beauty also performs, such as we know it from biology. And that it can serve as a critical design-research tool or architectures' *'protection'.*
- ***Embodied Architectural Performance:*** The research integrates environmental and bodily performance of architectures.
- ***Boundary Conditions Crossing:*** The research maps and claims climatic performance of semi-interior spaces of traditional architectures in Norway arguing for its biotic and social aspect.
- ***Onion Principle:*** The research concludes on need of different understanding of build environment – not as a strict differentiation of exterior and interior, but as an onion principle of different fields of exchange among its layers.
- ***Eco-Systemic Environmental Interaction Principle:*** The research maps biotic and/with abiotic interactions through different levels of enclosures of architectures claiming better human and social performance when more environmental factors and their larger variety is employed. This argues for the route of non-anthropocentric architecture which in fact gains largest benefits for humans and is in that way human-centred in the same time. In the same time, it argues for the multiple approach of this thesis.
- ***Trans-Co-Design:*** The research proposes and exemplifies different understanding of architectural practice as it is common in discussed location. It is rejecting the role of master architect or mastering architects' teams and her/his/their design ruling the game but suggesting transdisciplinary over evolving process of co-designing overall eco-system with both, biotic and abiotic agents, including humans.
- ***Local Climatic Adaptation:*** By doing all mentioned, the research suggests a route to architecture adapted to climatic changes in researched location.
- ***Systemic Approach to Architectural Performance:*** Through the fusion of Performance Oriented Architecture and Systems Oriented Design with time based ever evolving eco-systemic co-design perspective that involves all biotic and abiotic agents, the research ratified new design field.

10.2 Consequences to Architectural and Urban Design Practice and Research

This **transdisciplinary work urges** for more balanced view on **eco-system of co-generation and co-living of design** that plays its **active role**. Such strategies have been common throughout **vernacular history**, as design has been used, made, developed and lived as a ***'Time Based Design'*** (Sevaldson, 2004, 2017b) by its **biotic** as well as **abiotic users and communities** within **feedback loops**. While architects seam to truly believe in their **elitist state**, it has and never will, be accepted by the rest of the environment. This strong fight for their **professional status** has rather **imprisoned** them in enclosed, non-responsive cycles and alienated them from the rest of the world. Similar can be stated on humanity, acting within it from **anthropo-centric perspective**, such as there could be **privileged agents of biosphere**.

10.2.1 To Architectural Profession and Its 'Result'

The research integrates disciplines, institutions, practices and individuals, biotic and abiotic factors of eco-system and biosphere, digital and analogue design processes into design process merged with design result through participation and co-design to reach its *'complexity'* (Sevaldson, 2009)[57] of ever evolving *'Time Based Design'* (Sevaldson, 2004, 2005, 2017b). It is thus extending *'Rich Design Research Space'* (Sevaldson, 2008, 2012c, 2017b) into overall life cycle with all its consequences, such as *'entropic'*[58] disintegration or becoming, in the means of *'autopoiesis'*[59] discussed by Maturana and Varela (Maturana & Varela, 1980). It is discussing such through practice application examples, not letting fields for misinterpretations. It is thus questioning architectural practice as we know it: interdisciplinary work operated by architectural profession where it is everlastingly controlled by the master architect through authorship (Picon, 2016). Instead, it is proposing equality of professions fields within everlasting co-design process by *'active agency'* (Hensel, 2012c). Sprecher and Ahrens stated that the boundaries between humans and the environment are increasingly blurred by the mechanical character of information that can be found across many scales in nature, thus questioning major authorship status of architectural profession in human transdisciplinary team (Sprecher & Ahrens, 2016). This research is

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[57] 'Complex World: The world is becoming an increasingly complicated place to relate to. This applies to many fields: politics, economics, culture and information. And design is no exception. There are ever higher demands for more knowledge, following trends and the capacity for interdisciplinary collaboration. The context designers operate in is becoming increasingly composite. Rules and regulations are one manifestation of globalisation, along with the increasing focus on the consequences manufacturing and consumption have for the environment, economic systems, users and our ecological footprint. The Fair Trade movement is also gaining influence. The increasing complexity of the actual process of producing a product is the result of the fact that a growing network of stakeholders has to be consulted – both within the customer's organisation and also through regulations, customer surveys, focus groups and user involvement. The stakeholders constitute a field of intentions that are at times contradictory.' (Sevaldson, 2009)

[58] 'Entropy: This is the amount of disorder or randomness present in the system. All non-living systems tend towards disorder; left alone they will eventually lose all motion and degenerate into an inert mass. When this permanent stage is reached and no events occur, maximum entropy is attained. A living system can, for a finite time, avert the unalterable process by importin energy from its environment. It is then said to create negentropy, something which is characteristic to all kind of life.' (Skyttner, 2005).

[59] 'The word autopoiesis: 'If indeed the circular organisation is sufficient to characterise living systems as unities, then one should be able to put it in normal terms' (Varela), I agreed, but said that a formalisation could only come after a complete linguistic description, and we immediately began to work on the complete description. Yet we were unhappy with the expression 'circular organisation', and we wanted the word that would by itself convey the central feature of organisation of the living, which is autonomy. It was in these circumstances of one day, while talking with a friend (Jose Bulnes) about an essay of his about Don Quixote de la Mancha, in which he analysed Don Quixote's dilemma of whether to follow the path of arms (praxis, action) or the path of letters (poiesis, creation, production), and his eventual choice of the path of praxis deferring any attempt of the poiesis, I understood for the first time the power of the word 'poiesis' and invented the word that we needed 'autopoiesis'. This was a word without a history, a word that could directly mean what takes place in dynamics of the autonomy proper to living systems.' (Maturana & Varela, 1980).

questioning this through authorship of overall eco-system.

Though not truly admitting it, Midgley is in his *'boundary critique'* (Midgley, 2015) discussing the transition layers from social systems perspective as same, as we know it from biology (Cavalier-Smith, 2000; Soll & Schleiff, 2004), physics (Addington & Schodek, 2005; Bischoff & Rehren, 2016; Frensley, 1990), climatology (Fan, Li, Wang, & Catalano, 2016; Oke, 2002) or actually, architecture (Hensel, 2012c; Hensel & Turko, 2015; Teerds, 2013). When the Ray project (Davidová, 2016f), exhibiting that the architectural surface can have a performance (Leatherbarrow & Mostafavi, 2002). When the Ray project (Davidová, 2016f), exhibiting that the architectural surface can have a performance (Leatherbarrow & Mostafavi, 2002), was submitted for funding to InovaCentrum whose mission was to connect science and commerce (CTU in Prague, 2014), the reviewers' largest reason for rejection was that the system is penetrable for birds to nest in, air-flow, not presenting insulating features, habitable for flora, etc. This, among other penetrations through the material as well as architecture, has been and helped to strengthen the project's agenda to create an active screen, or *'breathing wall'* as discussed by Leatherbarrow (Leatherbarrow, 2009) brought to its literacy, that orchestrates spaces for exchange among various agents for truly habitable eco-system.

While Leatherbarrow exemplifies such on modernist examples (Leatherbarrow, 2009), I must claim that such architectures are just enlightened exceptions. According to Addington, these authors were even using word *'hermetic'* for envelope's new role description (Addington, 2009). The field is rather developed in vernacular cultures around the world (Addington, 2009; Hensel, 2008) by its builders and users in one person, over generations, the more climatic extremes in the region, the more developed (Davidová, 2016i, 2016m; Davidová & Uygan, 2017). This fact is registerd by my personal mappings (see Figure 116) and mappings of authors such as Rudofsky, Fathy, Fakouch et al., May, Hensel, Vegas et. al. and others (Fakouch et al., 2004; Fathy, 1986; Hensel, 2012c; Rudofsky, 1964; Vegas et al., 2014) discussed on weaved screens even by Semper (Semper, 2010).

Figure 116: 'Breathing Walls' in Vernacular Architecture; from left to right: a) Norwegian Svalgang Screen of Loft from 1797, Oslo Open Air Museum, Norway (photo: Davidová 2016); b) Moroccan Mashrabīya from around 15th Century, Houston Museum of Fine Art, USA (photo: Davidová 2016); c) Traditional South Portugal Screen Wall in Fishermen's Village Salema, Portugal (photo: Davidová 2016); d) Çavuşin Monastery from 964/5, Cappadocia, Turkey (photo: Davidová 2016)

This seems to argue for *'Time Based Design'*, or lets better say Time Based Co-Design, of architecture being in constant development with its users, discussed in upcoming publication by Sevaldson (Sevaldson, 2017b). The fact, that at the moment, there are discussed four Ray screen commercial tasks for buildings' add-on applications, or *'auxiliary architectures'* (Hensel, 2012c, 2012g, 2013, 2015a; Hensel & Sunguroğlu Hensel, 2010), two as claddings for the walls suffering with extreme humidity environment, two for semi-interior spaces, commissioned by the current users of the houses, talks for the claim, as the lack of performance can be confirmed by user experience. On the contrary, todays' building market and building law is not yet ready for such inquiries. As exactly, those are generated by user experience, not when the dwellings are offered for selling with the rates of climatised square meters.

Throughout all the history, dwellings were mainly rebuilt or recycled for different socio-environmental reasons (Davidová, 2016i; Davidová & Uygan, 2017; Davidová et al., 2017), not turned down and built again from new, different material. The discussed competition entry task (Davidová et al., 2017) was to be built on site where the previous administrative centre buildings lost their use only thirty years after being built, being unreuseable and unrecyclable due to its low quality of material and future development speculations. It has been standard to turn down and built again since after the second world war in discussed location. However, Czechia has got an incredible amount of long life span abandoned buildings and brown fields from the times preceding to it (anti, 2016; Opustené budovy SK/CZ, 2016; Opuštěné Stavby, 2016; Prázdné Domy, 2016) (see Figure 117) that due to mainly political reasons lost the continuation of its users, not being adapted to current needs. Within the time of fast climatic, social and technological changes, adaptation of existing is a necessity (Davidová et al., 2017). This is especially alarming if we consider the decrease of natural resources and increase of need of habitation in our location[60]. In 2006 *'Transformation Design'* was introduced as a new co-design field by British Design Council (Burns, Cottam, Vanstone, & Winhall, 2006), addressing mainly the field of Service Design. Such approach can address i.e. homelessness and other social needs in our country in contrast to current brown fields 'retransformations' into luxury apartments, stores and administrations, that largely cover way more new, added material than the former one that ends up in dumps. Zeithaml et al. describe Service Design as *'a form of architecture that involves processes rather than bricks and mortar'* (Zeithaml, Parasuraman, & Berry, 1990). It seems that new current task to architecture is to adopt these strategies next to our traditional skills, merely not to build but to keep rebuilding over time in the same way as we know it from architectures created by its users (Davidová, 2016i; Davidová & Uygan, 2017), biotic as well as abiotic, who, next to all the other related fields, need to be fully included to reach the performance.

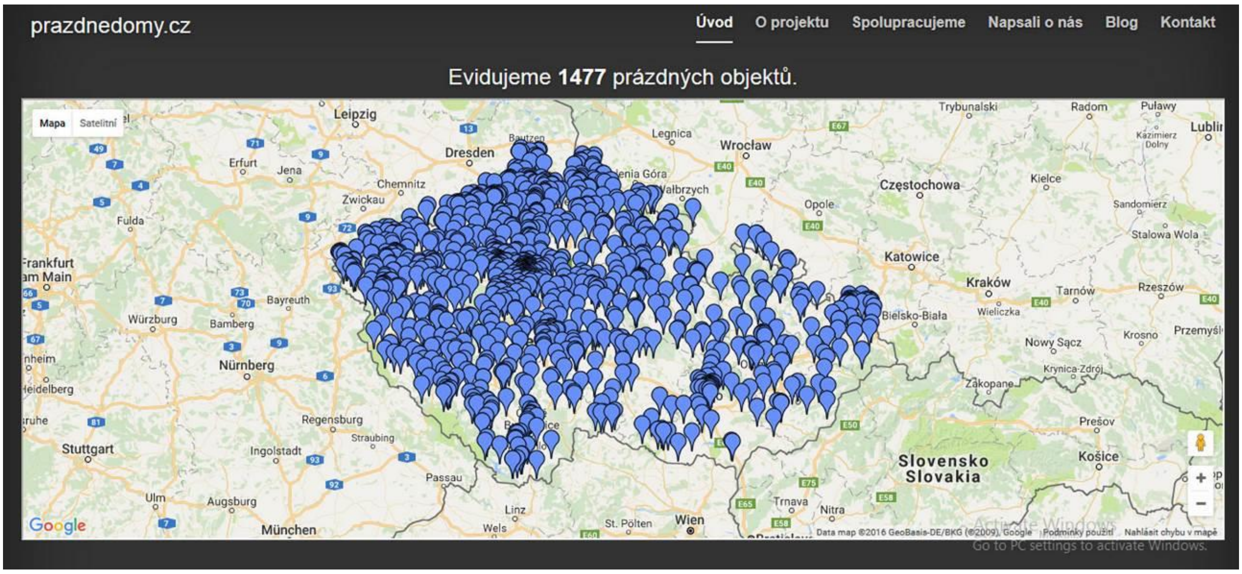

Figure 117: Map of Registered 1477 Abandoned Building Objects in Czechia by the Website Users of Prázdné Domy / Empty Houses Site (from anti, 2016; with the courtesy of anti)

We have successfully tested approach oriented in this way by intervention of releasing transdisciplinary practical user manual for public to grow greenery in their local public space (Sidorová et al., 2013) instead of fighting for the case from the point of professional practice, thus reaching larger, ongoing effect. Similar approach from seemingly human-centred perspective is called for in Unfinished Manifesto (García-Germán, 2016). In the same mode, the process is discussed by Mostafavi and Leatherbarrow on

[60] Czechia registers 187 thousands people without home (Iniciativa mít svůj domov, 2017). This is quite high number if we consider that the country has about 10 million citizens.

weathering, that is on the contrary excluding humans (Mostafavi & Leatherbarrow, 1993). Non-anthropocentric with human inclusion view on our time-base observed world slowly starts to access our society. This is apparent for example from movie industry, producing films such as Les Saisons discussing Earth's history from this perspective (Pathé Distribution, 2015). My research seeks for fusion of overall eco-system in its performance.

10.2.2 To Architectural Research and Practice

As also discussed in *'Architecture Oriented Otherwise'* publication by Leatherbarrow in relation to spirituality, performance and atmospheres (Leatherbarrow, 2009), it seems that the user experience of performance appears to be crucial, therefore so must be the holistic tacit knowledge discussed i.e. by Böhme or Pallasma (Böhme, 2006; Pallasmaa, 2005) of performance gained through her/his *'embodiment'* (Böhme, 2006; Merleau-Ponty, 2002) or generally *'enactment'* (Leatherbarrow, 2009; Merleau-Ponty, 2002). Thus kinesthetic sense is discussed as provision of information on the whole repertory of our motor actions in relation to embodiment (Farnel & Varela, 2008). This is close to what Farahi describes on the model of Iranian architecture:

> *'The architecture of these classical periods is rooted in a theory distinguished by its belief in the existence of an independent imaginary world that intervenes between the rational and the sensory world. On one hand, this 'in between' realm takes sensory forms out of the material world, gives them an abstract and virtual determination, and 'de-materialises' them. On the other hand, it gives shape, dimension and direction to the intellect and, at this level, unifies the spirit and the body.'* (Farahi, 2012)

From the interaction design perspective focused on developing digital technologies, in order to inform design and design practice, Hansen and Morrison decided to approach movement as a design material. They focused on the dynamic, moving body as a material and a mode. In other words, to understand how movement data may be read, interpreted, shaped, presented, and applied in order to design from it, with it, and for it. They also state, that this feature is crucial to design's performance (Hansen & Morrison, 2014).

This all can be studied as something similar of what is discussed by Havel as *'Introspection Plus'* researched particularly on short metaphysical experiences that he exemplifies on phantasms or micro-dreams (Havel, 2015) as an *'uncontrolled experience trough responsivity'*[61] (Hookway & Perry, 2006). Such phenomena are the first of what is met by all stakeholders, designers included, thanks to what further research is initiated, as no work is ever done without personal motivation. In this way, this takes and receives the role as/of an intuition gained through practice and practise of observation elaborated in detail i.e. by Schön, Sevaldson, Zumthor and others (Sevaldson, 2005; Schön, 1983; Zumthor, 2006b).

The integration of spirituality and science has been reported as a society move of new millennium by Institute of Noetic Sciences in 2007, exemplifying the intuition prior to research based on evidence (Institute of Noetic Sciences, 2007). The same has been discussed by Talbot and others from diverse research fields, integrating knowledge and skills from i.e. shamanism, psychiatry, neuro-science and neuro-psychology with that time physics discoveries and/or theories, over two decades earlier (Bohm, 1994, 2002; Bohm & Nichol, 1998; Bohm & Peat, 2000; Grof & Bennett, 1993; Talbot, 1981, 1992). Such theories seem to be getting evidenced by today scientific hands on experiments, i.e. the question of non-linearity of time on photon experiment (Ringbauer et al., 2014). As Nelson and Stolterman put it:

[61] 'responsive suggests mutual reaction and exchange, with adjustments occurring continually on both sides of the use equation' (Hookway & Perry, 2006)

'The metaphysics arises as a consequence of the interaction of the foundations and fundamentals of the design tradition, with one another and with the larger domains of human existence…..

…. Every designer must also reflect on the substantial metaphysical issues that arise from a design approach to life.' (Nelson & Stolterman, 2012)

Therefore, it has to be subject to performance oriented design-research that should be lived.

Such traits are hard to be accepted by academy and practice even in established sciences, though already showing their evidence. They are than even harder to admit in the fields that fight for their research or practice acknowledgement, such as architecture, urban design, or generally, built environment. One of the move in this field could be counted to AD Special Issue: Collective Intelligence in Design, September/October 2006 (Hight & Perry, 2006), that could be ferly related to application of the theories of interconnectivity of the mentioned authors from 80/90ties. The strategy for such, to found an NGO, was later on concluded by, in this issue discussed network OCEAN (Hensel, 2006), who founded not-for-profit association in 2008 for similar reason: to conduct unconventional transdisciplinary practice-research (Davidová & Sevaldson, 2016b; Hensel & Sunguroğlu Hensel, 2016). The NGOs takes the role which academy or practice are either refusing or at least neglecting for their existential, traditional, conservative or other reasons. The message to practice is than clear: it is not enough to either produce knowledge on its own, neither to only cooperate with academy within its current state. The NGO has higher competence in its light-weightiness and activisation of related stakeholders, while delivering less over-framed interpretations to the audience that better corresponds to the world as we perceive it or might perceive. Thus NGO, next to the enabling of more radical research and organisational and funding *'Design Management'*[62], plays also a crucial *'Interaction Design'*[63] role towards all related stakeholders for *'co-creation'* (Sanders & Stappers, 2008).

10.2.3 To Architectural Theory

The above discussed is not meant in the way that either theoretical research or practice should be neglected. On the contrary, this research calls for an integration of theory, practice and activism. Coming from the side of *'projective design-research'*[64] , the work generates and seeks for theory and skills through ongoing adaptive design process and prototypical applications in the sense of *'reflective practitioner'* (Sevaldson, 2005). In 2009 Christopher Hight discusses in the context of announced end Critical Theory what are we going to do after the end of theory (Hight, 2009a). I think his real discussion was, what are we going to do after the end of architecture or better, the architects. He refers to opportunities of the profession to explore overall eco-systems. But then we cannot talk on architects as we know them, but rather on Systems Oriented Designers or generally, Systemic Designers (Jones, 2014a, 2014b; Systemic Design Research Network, 2016) that would have to accept non-human centred perspective, employing more than in architectural practice well established interdisciplinary cooperation

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[62] 'Design management encompasses the ongoing processes, business decisions, and strategies that enable innovation and create effectively-designed products, services, communications, environments, and brands that enhance our quality of life and provide organizational success.' (Design Management Institute, 2016)

[63] 'Interaction design can be understood in simple (but not *simplified*) terms: it is the design of the interaction between users and products.' (Interaction Design Foundation, 2016)

[64] In 2000 at the conference: *'Things in the Making: Contemporary Architecture and the Pragmatist Imagination'* Robert Somol urges for a new alliance, *'reconfiguration of projects'* of *'American formalism'* and *'Dutch functionalism'* and *'move from critical architecture that is reflexive, representational and narrative, towards projective architecture … that respects and reorganizes multiplicity of economy and ecology*.' Somol discussed creativity and imagination as a place of experiment, as a design laboratory and proposed an understanding of an architect as a practitioner of design as research. (Mitášová, 2011) This can be followed by Leatherbarrow's statement: 'Design practice can be seen as a form of scientific research when both are seen as projective activities' (Leatherbarrow, 2012)

with master architect, structural engineer, electrical engineer and other technicians. Sanders and Stappers clearly discuss the shift within the design fields from *'designing products'* towards the '*designing for peoples' purposes'*:

> *'visual communication design > design for experiencing; interior space design > design for emotion; product design > design for interacting; information design > design for sustainability; architecture > design for serving; planning > design for transforming'* (Sanders & Stappers, 2008).

I would better call this designing that is performance oriented. While I cannot agree on the stated shift from architecture to design for serving, it is important to notice that they seem to have already clearly agreed on the end of the profession. On the contrary to that, I would better discuss design that is living and that is lived. Though I would argue that architectural theory hasn't lost its meaning, it obviously seems to have lost its specialized subject research field, while it even hasn't made it to answer the question on what it really was. As same as this work is questioning master architects or teams of them, it also questions the master architectural theorist. It is no longer possible to discuss architecture in itself, neither only in relation to its 'architectural' context. In new transdisciplinary design-research teams we need to generate, discuss and reflect *'prototypical interventions'* (Davidová, 2004; Doherty, 2005) as *'auxiliary architectures'* (Hensel, 2015a; Hensel & Sunguroğlu Hensel, 2010) to co-design and/or co-evolve and/or co-exist with its eco-systems. Similar collaboration was introduced by Bratton and Diaz-Alonzo as *'general reconfiguration of design as research, aimed very much at privileging the projective act of innovation and novelty, as opposed to the more traditional, reflective form of research as retrospective criticism'* on their '*interinstitutional Design Research'* between design studio and theory seminar lead by architect and sociologist (Bratton & Diaz-Alonso, 2006).

Has architecture become something else as Puglisi states it? (Puglisi, 2009). My from the research discussed in this thesis it seems is that it just seeks to be integrated into the world where it is located and lived, thus losing its elitist state and message within a further step within *'design intelligence'*[65] to reach fully *'adaptive synthesis'*[66] co-designed within eco-system.

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[65] Design Intelligence design evolution through co-design and co-learning through the use of electronic network (Mitášová, 2011; Speaks, 2011).

[66] Adaptive Synthesis is performance co-designed by its users and by itself in real life of architecture (Somol & Whiting, 2011).

10.3 Discussions and Conclusions of Closing Chapter

It is no wonder that UN agenda for 2030 sustainable development that is by the way titled ***'Transforming our World'*** is calling for **collaborative partnership of all stakeholders** and **fight of poverty**. Further on, this document is determined to ensure that economic, social and technological progress occurs in **harmony with nature** to reach prosperity (United Nations, 2015). However, as it itself states, this document is *'people-centred'* (United Nations, 2015). Its goals are so anthropocentric, that *'Cities and Communities'* are discussed in separated goal (United Nations, 2015, 2016a) from bio-diversity, discussed in *'Life on Land'* goal. The later one is in return not addressing the first mentioned (United Nations, 2015, 2016b). This work aims to demonstrate, that only when we **stop placing human kind into our main focus**, we can move closer to the achievement of the ***'sustainable development in its three dimensions – economic, social and environmental – in a balanced and integrated manner'*** targeted by this declaration (United Nations, 2015). The declaration has one important point that is also crucial to this work: it is calling for ***'adaptation'***[67] through ***'transformation'***[68] (United Nations, 2015), not through *'change'* or *'revolution'*[69].

In 2008 a special issue of Architectural Design called *'Neoplasmatic Design: Design Experimentation with Bio-Architectural Composites'* was released, where in introduction paper Cruz and Pike states:

> *'Neoplasmatic Design does not purport to put forward a complete vision of the future wherein architecture is fully replaced by neo-biological conditions, but rather an evolving scenario in which pre-existent, more traditional surroundings will be infiltrated by it, creating new hybrids and composite living environments.'* (Cruz & Pike, 2008)

In 2009 Petra Blaisse asked:

> *'If our interest in the procedures and methods of nature resettles, then why not introduce biology into our work and into architecture literally?'* (Blaisse, 2009)

I would ask: Why not to **be inside of processes** of its **eco-systems** as ***'living environments'*** **in itself** which we would call ***'our work and architecture'***? I would like to strictly stress out the distinction from the term ***'engineering ecologies'*** (Trummer, 2008) for the reason that ecologies, or eco-systems, cannot ever be engineered but lived. And thus the life becomes the design process.

The presented project **'*Wood as a Primary Medium to Eco-Systemic Performance: A Case Study in Systemic Approach to Architectural Performance*' is** to my belief, taking a step in such, though rather small one as being a particular case study. However, it is ferly targeting the direction through **10.1.1**

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[67] The Principle of Adaptation: For continued system cohesion, the mean rate of system adaptation must equal to or exceed the mean rate of change of environment (Hitchins, 1992).

[68] Transformation: '1. the act or process of transforming. 2. the state of being transformed; 3. change in form, appearance, nature, or character; 4. Theatre: a seemingly miraculous change in the appearance of scenery or actors in view of the audience; 5. Logic: Also called transform. one of a set of algebraic formulas used to express the relations between elements, sets, etc., that form parts of a given system; 6. Mathematics: the act, process, or result of transforming or mapping. function (def 4a); 7. Linguistics: transformational rule. the process by which deep structures are converted into surface structures using transformational rules; 8. Genetics: the transfer of genetic material from one cell to another resulting in a genetic change in the recipient cell; 9. a wig or hairpiece for a woman.' (Dictionary.com, 2017)

[69] 'This word is commonly used to refer to a sudden overthrow of the status quo and its replacement by an entirely different state of affairs. That the word is also used for the turning of a wheel conveys this sense of social arrangements being turned upside-down. Many believe in the necessity of revolution for a fundamental reformation of society. The argument is that existing political and social institutions must be swept away if better ones are to emerge. Democratic SOCIALISTS and the reformist left prefer the idea of change achieved gradually by an incremental transformation of society, mirrored by changes in individual consciousness and behaviour. Finally, a revolution may be conceived not as a deliberate strategy so much as the emergent effect of other social, political and economic changes, as in the industrial revolution.' (Parker & Fournier, 2007)

methodology, 10.1.2 material research and its eco-system and their acquisitions to **10.1.3 architectural and urban design research**, that as a field is in the end questioned by the theory it itself generated **10.2**. Though architecture and urban design are being referred to as the most complex professions, my work concludes, that it is still not enough. Therefore, we also cannot consider reductionist perspective in its design-research profession. This work fuses 10.1.1 methodology, 10.1.2 material and 10.1.3 architectural and urban design into one **Performative Eco-System** and is giving birth to new design field: **Systemic Approach to Architectural Performance.** As stated, it is not engineering project where the interaction would be 100% pre-programmed as the material and its environment is far too complex for this and it even hasn't been the project's aim. It is rather focused on prototypical environment modulating interventions to generate responsiveness and thus performance within given eco-systems.

11 My Bio

Figure 118: Me in front of the LOOP pavilion at the Press Conference (photo: Exner 2014, with the courtesy of City Council of Prague)

Marie Davidová, MArch. (see Figure 118) is a founding member and chair of **Collaborative Collective**[70] practice design-research network and NGO, PhD research fellow at the **Faculty of Art and Architecture at the Technical University in Liberec** in the visual arts field; and in the architecture and built environment field at the **Czech Technical University in Prague, the Faculty of Architecture**, studio **FLO|W**, MOLAB department, where she is also scientific consultant in studios FLO|W and PET-MAT. She gained her master's degree in architecture at the **Oslo School of Architecture and Design** under the supervision of Birger Sevaldson and Per Kartvedt. Marie had been working as an architect in practice studios **Snøhetta** and **Expology** in Oslo and researching and teaching as a university lecturer at the **Faculty of Architecture and Fine Art at the University of Science and Technology in Trondheim**. She has been the visiting transdisciplinary studio course leader at the **Architectural Institute in Prague** and at the **Faculty of Art and Architecture at the Technical University in Liberec**, both in cooperation with the **Faculty of Forestry and Wood Sciences at the Czech University of Life Sciences in Prague**.

Marie has founded the **Systemic Approach to Architectural Performance** field that joins in the fields of **Performance Oriented Design** and **Systems Oriented Design**. She has held guest lectures and workshops in this field across **Europe**, **North America** and **Asia**, where she is also widely published.

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[70] Collaborative Collective is a collective of architects, designers and friends, first conceived in 2008 as an open platform for sharing ideas and pursuing personal agendas. After this first formation broke up, the team without its establishing founder got rise to different platform called EDIT!. This platform also, deservedly, refers to the former Collaborative Collective's work. In 2011 Kryštof Hanzlík, the former founder of the previous platform, and me ratified a design-research network practice with this name under the agreement of the former platform members. This network already started with its own physical office, while outsourcing external transdisciplinary collaborators. In 2012, me, Kryštof Hanzlík and Martin Gaberle founded and registered an NGO with the same title as a civic association for science, research and development within the architectural field.

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