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HORIZONTAL AND VERTICAL KNOWLEDGE MANAGEMENT IN MULTIDISCIPLINARY RESEARCH AND DESIGN-BUILD TEACHING: A TIMBER-ONLY TRAIL

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ABSTRACT: "The Kouvola Trail" is part of our timber-only research project and consists of 2 realized parts, (i) the prefabricated, "Modular Trail" and the customized "Plaza" modules. On the example of the trail project, this paper describes its combined systemic horizontal and vertical processes, network, knowledge management and multidisciplinary collaboration. Based on systemic knowledge management and the concept of the vertical design studio, we have simultaneously implemented and exposed our research in timber-only structures and architecture to teaching, real world application and manufacturing to enable both, horizontal and vertical alignments. We provide insights into how our academic research on using locally salvaged timber and wooden nail connections vertically links both, disciplines within Aalto, to the Kouvola region vocational college and to industrial partners and manufacturers. This vertical alignment and collaboration not only facilitated academic and practice-oriented knowledge transfer but also increased project-complexity by exchanging ways of thinking. Consequently, we recognized a significant increase of students´ technical expertise, functional development of knowledge, skills, and also motivation, as demonstrated by the "Street Furniture" prototype. Additionally, horizontal learning and collaboration as an inter-organizational system-relationship was fostered by setting up multidisciplinary design teams including the disciplines of civil engineering, architecture, arts and design, plus practical approaches to construction by the vocational school. Expanding this approach e.g. to business schools may open new perspectives and opportunities for industrial partners in future.

KEYWORDS: knowledge management, horizontal and vertical teaching, vertical studio, timber-only structure, wooden nails, architecture, timber engineering, multidisciplinarity.

1 SYSTEMIC KNOWLEDGE MANAGEMENT

Today, we can increasingly recognize the importance of knowledge and expertise as the basis for successful products and services. Not only companies have to adapt to this change, but also organizations of all kinds with respect to the transformation to a knowledge society [1]. In addressing the specific question of systemic knowledge management, according to [1], the task is to consider "knowledge management as an element of a context of social, organizational, technological and individual factors". However, one essential aspect of knowledge management is differentiating personal knowledge from organizational knowledge. In the context of knowledge-based societies and organizations, "knowledge work" has become a crucial factor for success, and in distinction from purely scientific work it involves the application of knowledge to practical tasks [2]. The interplay between individuals and organizations is essential in knowledge work, with an emphasis on how the expertise of the individual is continuously revised and refined in this context. Expertise has become a control element in knowledge-based societies, and this highlights the significance of personal and organizational knowledge. One of the critical insights in knowledge management is the need to organize both personal and organizational knowledge effectively including a departure from an exclusive focus on the individual. The challenge of managing increasing amounts of knowledge is often seen as a threat rather than an opportunity. Systemic knowledge management offers valuable and effective support wherever increasing amounts of knowledge have to be managed or the intention is to generate this increase [3]. In this regard various disciplines and branches from the supply chain management of companies to the curriculum planning of universities take into consideration both, vertical and horizontal alignments, when it comes to achieving specific strategic goals [3].

2 HORIZONTAL AND VERTICAL TEACHING, LEARNING AND COLLABORATION

The UNESCO International Bureau of Education (IBE) describes the organization of contents according to the sequence and continuity of learning within a given knowledge domain or subject over time as vertical articulation to improve coherence, and the scope and integration of curricular contents from different knowledge domains within a particular grade level as

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horizontal articulation or balance to develop integration between subjects, disciplines or knowledge domains [4]. In other words, alignment in teaching can be vertical when a specific subject or topic is taught to various grades, or horizontal when those in the same grade level teach different subjects. The steps that can be taken to make sure every student is receiving the same level of quality instruction is curriculum alignment that brings teams of teachers together to plan instructions. Therefore, vertical alignment is when teachers who teach the same content area meet across grade level bands, while horizontal alignment is when teachers at the same grade level meet to coordinate learning activities. Educators who use vertical alignment to support cohesive instruction find it helps them save instructional minutes by reducing repetition. On the other hand, horizontal alignment provides a higher probability that the majority students will be brought to a certain level, which can consequently be built upon.

Some architecture, design and arts schools have introduced for example so-called "vertical design studios", where students from multiple cohorts are taught together to provide holistic and contextual thinking skills essential to architectural design education [5–8]. Basically, [8] describes the vertical studio as a single-class combination of students at different levels in a given program of study, and [9] argues that the “Vertical Studio” system challenges traditional, sequenced design studio organization by allowing students of various developmental and skill levels to interact and compete with one another in a topical, thesis–based studio. To [10] the key feature of a vertical studio model is the collaboration of students across all years to address specific themes without overriding the traditional curriculum, but to both add, as well as, amplify design skills, and to create peer-to-peer learning opportunities.

In the context of systems design, [11] identifies three learning approaches that can be applied to vertical studio learning; learning through confusion, single versus double loop learning, and social learning through the "Master-Apprenticeship" model. The process of learning often involves confusion and uncertainty, and learning through this experience can help students develop a deeper understanding of the subject matter. Single versus double loop learning involves taking for granted versus questioning the assumptions and frameworks that inform goals and strategies. Social learning through the "Master-Apprenticeship" model involves project-based learning and critiques, allowing students to learn from experienced designers and develop the social competence and personal experience needed for collaborative design projects. The motivation behind most of these approaches is not only to train students to solve complex design problems or even research questions [12], but also to familiarize them with teamwork in which individual group members depend on each other's performance.

From the students´ perspective horizontal learning is about developing competencies such as communication, active listening skills, and responding effectively and constructively to conflict [13]. In addition to these general aspects, they also expand their technical and artistic knowledge and skills through collaboration with other disciplines [14]. They also gain expertise and an awareness of the potential and practical challenges that arise from interactions. So, the main focus of horizontal learning is the functional development of knowledge, skills, and behaviours that strengthen key competencies. Vertical learning from the students´ perspective, is about changing the way they think [15], feel, and make sense of the world; it is about increasing the complexity of how one sees and relates to the world and what one knows.

The authors of this paper conducted a review of literature pertaining to systems approaches, teaching and learning in vertical and horizontal articulation. The majority of the literature reviewed, which is related to vertical and horizontal articulation, highlights approaches and case studies from the design and arts disciplines, with a particular focus on architecture, industrial design, and the arts.

While the International Bureau of Education (IBE) describes horizontal and vertical curricular contents from various knowledge domains, it appears that even in architecture or design schools, these approaches are not systematically or explicitly implemented in the curricula. While we found single course descriptions that explain the contents and methodology to students, it is not reflected or incorporated into the overall curriculum. Interestingly, it appears that these approaches are not commonly followed or even known in engineering and business disciplines, as the authors could not find indication of vertical studio practices in those curricula or related publications. And even though we found extensive literature about multi- and transdisciplinary teaching and learning, to the authors knowledge there is marginal to no literature on combined multidisciplinary vertical teaching and learning articulations. In addition to our observations, we found that also only few companies and organizations seem to use an organizational development process that acknowledges the power of vertical learning conflict [13, 16].

3 VERTICAL AND HORIZONTAL, MULTIDISCIPLINARY RESEARCH AND DESIGN-BUILD TEACHING OF TIMBER-ONLY STRUCTURES AND ARCHITECTURE

In the context of the co-author´s research on timber-only structures and architecture, we investigate the topic both, from an engineering [17–19] as well as from an architectural and artistic point of view [20–22].

On the example of “The Kouvola Trail”, a timber-only trail project [17], this paper describes its systemic

horizontal and vertical processes, network, knowledge management and multidisciplinary collaboration.

Kouvola is a city and municipality in southeastern Finland. It is located along the Kymijoki River in the region of Kymenlaakso. “The Kouvola Trail” is part of a development initiative by the city of Kouvola and Kouvola Innovation Oy (Kinno) a business development company, which supports local companies and boosts the overall business environment.

Figure 1 provides an overview of the network of involved entities. As mentioned the PhD project “Timber-only Structures and Architecture” is located at the threshold of architecture and structural timber engineering, at the Department of Architecture, School of Arts, Design and Architecture and the Department of Civil Engineering, School of Engineering, Aalto University, Finland.

dimensions, orientations, and arrangements to determine their performance in timber-to-timber connections. Results showed that inclined wooden nails exposed to shear and tensile forces had a higher shear resistance due to their activated tensile capacity, with failure predominantly observed in nails loaded in tension rather than at the interface with the timber. An analytical model, later validated with experimental test, was developed using the results from shear tests to predict the load bearing capacity of timber-to-timber connections exposed to bending stresses.

At Aalto University, both of the above studies were presented to an almost equally distributed numbers of Master´s students from architecture and from civil engineering, whereas roughly 30-40% of students had international background including Spain, Belgium Austria, Italy and Latvia (Figure 1). All students took part

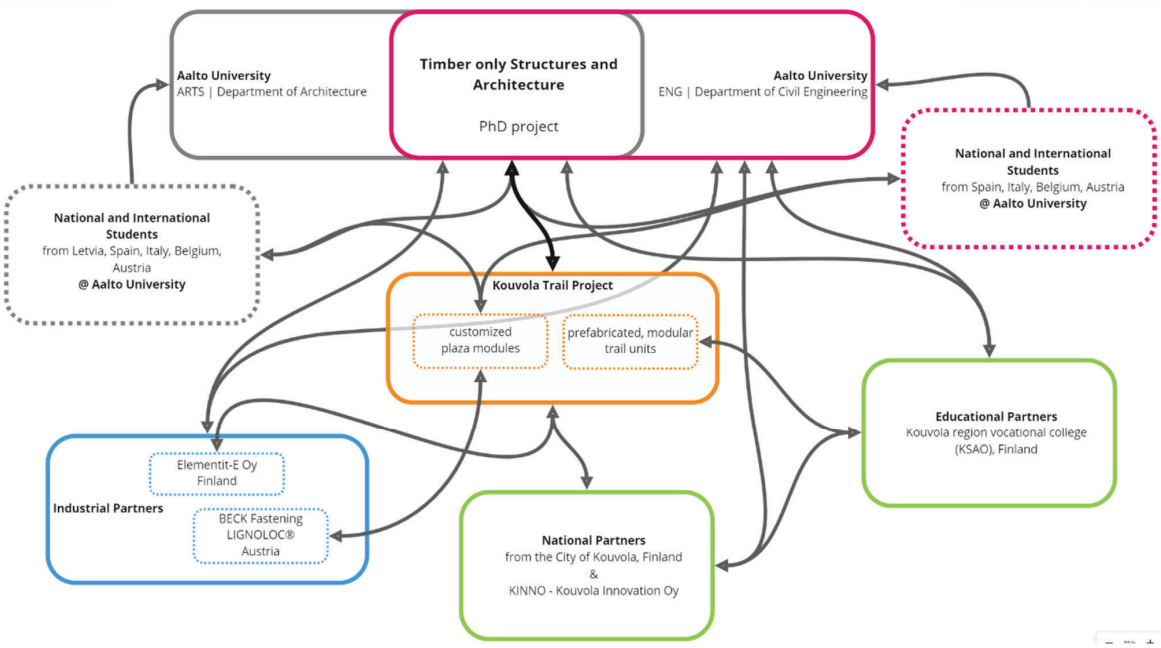

Figure 1: *Network of entities involved in the research and design-build teaching of the Kouvola trail with an emphasize on its systemic horizontal and vertical processes, network, knowledge management and multidisciplinary collaboration.*

The study [17] introduces a new low-tech design concept for short span structures using salvaged timber products and hardwood nails. Different design proposals for batches of salvaged materials with varying dimensions are guided by three aspects: timber board patterns, assembly process, and nail arrangement. The design concept is first conceptually applied short span bridges on a natural trail path in Finland. As a follow-up, in [18] we report about a series of 90 shear tests to explore the shear capacity and slip modulus of timber-to-timber connections with wooden nails. As densified wooden nails might become an alternative to metallic fasteners, this study examined different specimens of wooden nails in varying

in the same courses and classes. Leaving the exclusive focus on the individual the shared knowledge and expertise formed the basis for multidisciplinary groupwork, initially in pairs of architects and engineers and later as a larger group. After an introduction to the technological aspects and full-scale testing, the students rapidly got into the subject and were then challenged to creatively design structures and spaces based on the knowledge they had previously gained. From a course-of-study perspective, the approach may seem horizontal, but in reality, it is a more vertical articulation, as the level of knowledge about each other's disciplines put all participants on both an expert and novice level at the same time. The disadvantage of this approach is sometimes the slower development speed of projects, as the "expert input" is sometimes perceived as a limitation, but in the authors' experience, this delay is later more than made up for and the results are comparatively superior in quality.

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However, the horizontal teaching and learning component could be most recognized by the increased technical expertise, functional development of knowledge, material understanding [23] and skills for all involved parties by disciplinary exchange between the individuals and groups. Additionally, an underestimated horizontal learning and collaboration effect as an interorganizational system relationship was fostered by the fact that the participating students came from different nationalities and (design) cultures.

Our academic research at Aalto University on using locally salvaged timber and wooden nail connections only vertically linked with the Kouvola region vocational college (KSAO), now Eduko (Kouvola Vocational Institute Ltd.) and industrial partners and manufacturers. Compared to academic research, teaching and learning, Eduko follows other principles. Eduko, an Erasmus+ accredited organization, is a vocational training institute involving annually approximately 6500 students in various training activities, and employs more than 300 experts on education, counselling, administration and other services. Training programmes focus on enhancing skills and expertise that are essential in the working life, including basic, advanced, or specialized qualification. On-the-job learning is a vital part of the learning process.

Similar to the previous experience within multidisciplinary courses at Aalto, the vertical alignment and vertical collaboration between Eduko and Aalto not only facilitated academic and practice-oriented knowledge transfer [20] but also an increase of complexity by exchanging ways of thinking [24]. The horizontal collaboration of same level or stage but different studies allowed greater ease of work and cooperation towards achieving common objectives, while emerging additional design and manufacturing options.

4 THE SIMPLEXITY OF A MODULAR TIMBER-ONLY TRAIL

"The Kouvola Trail" is part of above-mentioned timber-only research project and consists of 2 parts, (i) the prefabricated, "Modular Trail" units and (ii) the customized "Plaza" modules. Not least because of its low-tech [25, 26] and low processing approach, the Kouvola trail project can also be seen as a case of simplexity [27, 28], an emerging theory that proposes a possible complementary relationship between complexity and simplicity. Presently, both types of physical outputs have been realized, the more industrialized modular set of prefabricated trail units realized by Eduko, and a set of customized, bespoke but also modular elements for a plaza area of the trail by Aalto University.

4.1 PREFABRICATED "MODULAR TRAIL"

Due to practicality reasons, the fabrication of the "Modular Trail" was organized as a workshop at the facilities of Eduko in Kouvola. The expectations were to communicate the design intend and the approach to fabrication of modules from salvaged wood and wooden nails, with the aim to assembly a few prototypes.

6 Eduko-students were involved (3 female and 3 male), all of them vocational school students in construction. At the time of the workshop, their age was in the range of 25 to 60 years. The supervising team was formed by the co-author and one teacher from Eduko.

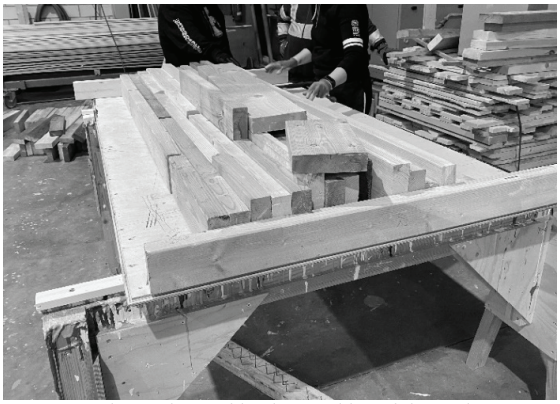

Figure 2: *The working table, designed by Eduko students to ease and expedite the precise fabrication of the modular trail elements*

Figure 3: *First finished modular elements*

Based on previously gained knowledge and expertise in the assembly of specimen for testing purposes, the supervisor provided an input lecture regarding the trail project, which covered the design concept, the intended salvaged material, and the connection details. Following this, a 5-day hands-on workshop was conducted, during which the first two elements were constructed under the guidance of the supervisor, serving as examples for the students to comprehend the process and the nailing gun with wooden nails. Due to their practical education and backgrounds, which provided them with a strong foundation in construction techniques and materials, the students were trained to act and improvise within specific boundaries and restrictions. They brainstormed ideas to streamline and simplify the work process, including considerations for working height, ergonomics, and efficiency. Consequently, they designed specific tools

such as the working table and nailing marker, to expedite the process. This practical approach enabled them to maximize their efficiency and fabricate an unexpected additional number of 10 elements, a total of more than 30m of trail, during the workshop days.

4.2 CUSTOMIZED "PLAZA" MODULES

In the context of the "Plaza" within the design build phase of "The Kouvola Trail", 7 university students were involved (5 female and 2 male), 6 of them Master students (3 in Engineering, 2 in Architecture and 1 in Architectural Engineering) plus 1 bachelor student in Engineering. Their age is in the range of 19 to 25 years. The supervising team was formed by the authors.

Figure 4: *Working process using templates and guides for precise fabrication of bespoke plaza elements*

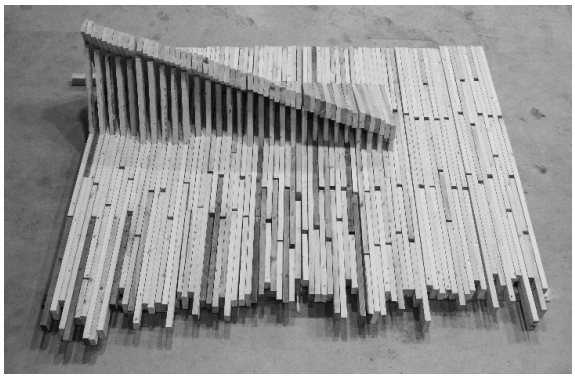

Figure 5: *Finished plaza part as exhibited at the exhibition SALVAƎƎ – sustainable use of salvaged wood [29]*

The fabrication of the "Plaza" clearly took advantage from the experience with Eduko students and their processes. Additionally, the fabrication process followed the above-mentioned course, its theoretical inputs and students´ work on their design proposals. Again a 5-day workshop was organized, but Aalto students prepared both digital drawings and working tools such as the working platform and nailing marker, based on the lessons learned from the fabrication of modular elements. During the first of a 5-day workshop, the students received instruction on the use of the tools and the arrangement of the timber boards from the supervisors, resulting in the completion of one element as a showcase on the first day. Then, the students were assigned different roles, such as nailing, arranging the timber boards and marking nailing locations, and cutting, in order to finalize the remaining elements. Interestingly, the role assignment was perceived in a very positive way by the students, since they were equally informed and updated on the processes, aims and results. As a consequence of this collaborative effort, seven elements were successfully completed over the course of the following four workshop-days.

5 STREET FURNITURE: A FOLOW-UP PROJECT

As a follow-up two students, one Master student in Engineering and one Master student in Architecture, who continuously followed the design as well as the design-build course and the workshop, gained experience on many levels. Besides expanding their skills and knowledge in each other´s discipline, they familiarized themselves with sustainability aspects such as the use of salvaged timber, with structural testing and architectural design or with using nailing guns.

Figure 6: *Preassembled units for a novel slide-in connected, planar reciprocal frame structure. The units are assembled from salvaged wood by the use of wooden nails.*

Figure 7: *Students on the assembled Street Furniture on campus of Aalto University, Finland [19]*

Consequently, they applied for involvement in the design of reciprocal frame structures from salvaged timber, another project within the research in timber-only structures and architecture. Based on our investigations in this field and their collected skills, the students successfully built and assembled a small-scale prototype of "Street Furniture" in just one day.

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6 DISCUSSION AND CONCLUSIONS

Even though vertical studio practices are known and used in architecture, design and arts education, they are not reflected or incorporated into many curricula, and it appears that these approaches are not commonly followed or even known in the engineering and business disciplines. Combined multidisciplinary vertical teaching and learning articulations seem almost non-existent.

The attempt of combined multidisciplinary vertical teaching and learning articulations in the presented approaches and setting took advantage from involving at least one discipline, architecture, that is more familiar with the concept. Architectural students are also more used to problem-framing [14] and learning through confusion as described by [11]. Combined with problem-solving [14] skills and analytical work style, as they are very much taught at engineering schools, as well as practical down-to-earth and even improvising approaches, can significantly enhance the final quality of a project.

Obviously, the student groups of 15 in earlier design courses and 6 to 7 in the design-build phase have been of small size. With larger groups the risk of losing overview drastically increases for both sides, the students and teachers. In earlier courses with up to 290 students we perused similar vertical studio and multidisciplinary approaches. Although we could prove a significantly positive effect on students' creativity through creativity tests, such as Alternate Uses Tests (AUT) and ShapeStorm (SS) Exercises [30, 31] but together with challenging pedagogical and logistic tasks a relatively high number of students complained about lack of clarity and meaningfulness.

However, any system that allows free choice does so at the expense of rigorous control. The vertical studio provides considerable freedom of choice but with this freedom come some distinct limitations and new responsibilities for both faculty and students. For the success of the presented workshops and the project consequently, it was crucial to be well organized, with clear milestones and a very clearly communicated aim. In best case, the vertical studio advances the idea of collaborative design pedagogies. Not only does it promote and encourages a close working relationship between students of all years, across disciplines and the teaching staff but demonstrates an overall improvement of student's general development and self-responsibility as they identify their individual roles and contribution to the project. The confidence in decision-making is a side-effect of what [11] describes as social learning through the "Master-Apprenticeship" model. The follow-up project of the "Street Furniture" is an excellent example for the empowerment of students by this approach. The "Master" is both peer-to-peer learning and learning from teachers, that serve as a backup in case.

Accordingly, we have simultaneously implemented and exposed our research in timber-only structures and architecture to teaching, learning, manufacturing and real-world application by utilizing both, horizontal and vertical approaches, offering unparalleled opportunities for teaching, learning research and potential projects.

As the business value is hidden, only few companies and organizations seem to use an organizational development process that acknowledges the power of vertical learning [10, 12]. The collaboration with Eduko may be seen as a step in this direction and may open new perspectives and opportunities for companies but also academic partners from business schools in future.

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