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The ITECH approach: Building(s) to learn

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Abstract

The Integrative Technology and Architectural Design Research (ITECH) Programme at the University of Stuttgart provides an international educational environment open to students from a variety of disciplines, such as architecture, engineering, biology and computer science. Together they envision, design and build novel material and fabrication systems for the creation of structures, giving a glimpse of what tomorrow's built environment could be i.e. as seen in the recent research pavilion [1]. This paper describes the teaching of the program and draws out aspects that the tutors consider to be most relevant in the training of students for future careers in the architecture, engineering and construction (AEC) industry. ITECH has a strong focus on interdisciplinary skills and offers an integrative approach by merging the fields of architecture, design, engineering, construction, natural sciences and biology in a research-led teaching environment.

Keywords: education, integrative design, interdisciplinary design, collaboration, flexible study, pavilion

1. Introduction

The ongoing digitalization of the architecture, engineering and construction (AEC) industry is changing how industry practitioners work, a topic discussed by Forbes [2] in relation to current technical practice and Carpo [3] in his discussion of the shifting design culture. The move from paper drawings to digital models and fabrication data (initially created by humans but increasingly generated using machine-driven computational design logic), in combination with new methods of digital communication, requires a rethink of design methods, internal processes, contracts, business models and forms of interaction amongst disciplines within a highly fragmented industry.

Technology may enable this change, but people are required to champion the new possibilities and drive them onwards. Mutual understanding, cross-disciplinary skills and a robust understanding of software, data handling and digital fabrication form the backbone of the professional skill set required for a transformed construction industry. The Master of Science program "Integrative Technologies and Architectural Design Research (ITECH)", offered at the University of Stuttgart, was created to provide an educational environment focusing on these exact requirements. ITECH is taught by the Institute of Building Structures and Structural Design (ITKE) and the Institute for Computational Design and Construction (ICD).

Students in the ITECH Programme are encouraged to utilize cutting-edge computational techniques and advanced digital fabrication technologies. The students also take advantage of the extensive research collaborations among the doctoral students, researchers and professors of the ITKE and the ICD, as well as other institutes at the University of Stuttgart and partners within the wider AEC industry.

The students entering the master's program come from diverse backgrounds (both culturally and professionally) and hold degrees in architecture, engineering or other relevant disciplines. During the two-year program, the students work together as a group on a collaborative design and build project and are again encouraged to work in smaller groups for the one-year master thesis project, in both cases reinforcing the benefits of collaborative working.

The program was first offered in 2013. Since then, 79 students have graduated from the ITECH Programme with a Master of Science degree and three research pavilions have been built through the collaborative efforts of students and researchers (two additional pavilions are currently in construction). The career trajectories of ITECH graduates are very diverse. For the ITECH Class of 2017 25% of the students started the program with an engineering degree and 69% with an architecture degree. From a partially-complete current survey, 17% are working in research roles (both architecture and engineering) and 53% in offices (13% in engineering and 40% in architecture).

Figure 1: ITECH Class of 2017 [images from ITECH Social Media Accounts - @itechstuttgart]

The next deadline for ITECH applications will be February 15th 2019 and the course brochure [4] may be found on ITKE and ICD websites.

2. Education strategies for architecture, engineering and construction

Pedagogical approaches and educational strategies are continuously evolving in response to broad societal and political discourse. Additionally, within the bounds of specific industries the education of future professionals is constantly reviewed and discussed by the incumbent practitioners.

The AEC industry has multiple associations and societies covering education (i.e. the European Association for Architectural Education and European Society for Engineering Education) and in the last 10 years there has been increasing focus on the need for interdisciplinary teaching (as discussed by Irizarry et al. [5] and IASS 2017 Session #52 "Education at the Intersection of Architecture and Structural Engineering"). Out of these discussions, a range of collaborative courses with names such as Architectural Engineering, Civil Engineering and Architecture, Architecture and Engineering have emerged. These programs typically sit alongside the single-discipline courses, drawing together content from both faculties in a teaching-based educational environment, yet retaining a clear division between the two disciplines. These courses represent a significant step forward in educating students for practice in the AEC industry, where collaboration between disciplines is a necessity, yet further educational strategies remain open for exploration.

In recent years, there has been an ongoing discussion about the possible impacts of thematic teaching [6], flexible study [7] and learning through research [8] on the future of education. The work of C. Ortiz and the team at Station1 [9] is one example of a proposed combination of these concepts. This sort of flexible model offers the possibility to provide specific skills while exploring novel research possibilities and simultaneously preparing students for a future in an industry where technology is having a profound impact, the full bounds of which remain under discovery.

ITECH lies within these education concepts, coupling a highly flexible, self-tailored, research-driven and experiment-based educational framework within a truly trans-disciplinary environment, in order to investigate "integrative technological advancements as novel potentials in architecture and construction" [4] and to challenge and re-examine current techniques, methods and theories.

3. The ITECH M.Sc. Programme

The program aims to prepare students for a future model of architectural and engineering practice with an intellectual as well as technical approach to computational design, simulation and fabrication. It is based on the German semester system and is structured as a two-year program.

3.1. 1st year - Integrative technologies and architectural design research project

The 1st year of the ITECH Programme is structured around a 2-semester-long Integrative Design Research Studio Project, which is a collaborative undertaking between the students under the supervision of ICD/ITKE researchers and Prof. J. Knippers and Prof. A. Menges. The pedagogical framework has been developed over the course of 8 years, initially through the design studio within the University of Stuttgart architecture diploma program that led to the creation of ITECH. The supporting technical and design curriculum of the ITECH Programme, as well as the increased knowledge and skill sets of students and researchers has enabled the technical scope of the research pavilions to increase over time. The design and development process of each project involves working with experts from several other fields (such as aerospace engineering, biology, geodesy and textile technologies) to provide technical knowledge and feedback. The underlying research questions of the Integrative Design Research Studio Project are often connected to an institute research project, giving the studio access to corresponding funds.

The first phase of the pavilion studio is a phase of intense ideation and concept development, tightly coupled with a biomimetics seminar co-taught with the department of Evolutionary Biology of Invertebrates and the department of Palaeontology of Invertebrates at the University of Tübingen. While this initial research phase is prescriptive in the material technology and research framework, the concept for the fabrication and building system is unforeseen and biological models are mined for possible transfer into morphological or process concepts for the pavilion.

In the second semester, the program focus shifts towards technical development. In this phase, several smaller teams are formed to solve key technical aspects of the pavilion and to assess the relative feasibility of the current global design concept.

The pavilions are finalized and built between the 2nd and 3rd semester, enabling the students to collectively apply their prototypical designs through technical development to construction of a full-scale prototype.

Ultimately, the pavilion studio model exemplifies the potentials of learning-through-research and applied making, as well as being a successful combination of research and education. This unique model forces the students to step out of their comfort zone and forces them to rethink existing methods and theories. Students start to develop a high level of responsibility and self-organization, yet also develop individual skills within the context of the studio project and seminars. This ideally results in a group of experts in various fields, sharing and deploying their knowledge and expertise through their collective work on the studio project and also extending this collaboration into their thesis year.

3.2. 2nd year - Integrative technologies and architectural design research thesis project

The second year is structured around the preparation and development of the individual or group Master Thesis Dissertation. In the 3rd semester, students conceptualize their research topic and develop their proposal from both theoretical and technical perspectives, using a critical and analytical approach. They then consolidate this thesis argument in the 4th semester through the development of their project.

The thesis students are supported in this phase through close collaboration and supervision with researchers and professors from both institutes. A thesis preparation seminar instructs them in how to properly structure their thesis proposal, develop their thesis project in a scientific manner, critically engage with their chosen topic and build up a cohesive argument that demonstrates the student`s proposed contribution within the research field.

The students can choose from a range of specialized topics and research fields within the research areas of the institutes, but are also encouraged and supported to develop their own interests. Many students build upon skills and initial studies that have emerged from their contributions to the integrative design

project or seminars. This often results in highly refined and relevant thesis projects, which contribute significantly to the larger research agendas of the institutes.

The ITECH Programme currently provides 3 research directions for Master Thesis Projects:

- Track A - Research Project: This is a scientific and highly methodical approach on current methodologies and systems. Students conclude with a comprehensive research document.
- Track B - Design/ Research Project: Students engage in an architectural system or process by expanding both its technical development and its design application to develop a spatial or structural study or prototype as well as a related research document.
- Track C - Design Studio Project: This incorporates a Design Studio (in ITECH or elsewhere at the faculty of architecture at the University of Stuttgart) as well as a research extension (a short version of Track A or B).

Similar to the Studio Project, the thesis year has a strong focus on an integrative and interdisciplinary approach, in which research topics do not require specific placement within a discipline but can combine multiple overlapping subjects. Additional seminars and workshops during this year focus on deepening the already-acquired skills with a particular focus on advancing the individual thesis research topics.

3.3. Seminar Modules

In alignment with the integrative research project in the 1st year and thesis project in the 2nd year, a range of skill-building seminars introduce students to topics in computational design and simulation, engineering and construction. These provide the technical and conceptual foundation necessary for the successful development of the projects, while still allowing the students to explore individual interests within the curriculum. The seminars do not aim for a pre-defined outcome but are shaped around the student's individual research questions, whether addressing a certain topic of their studio research or a specific question within their envisioned thesis topic.

The expert colloquia modules bring experts from various fields within the AEC industry to Stuttgart to give lectures or workshops that support the overarching research question of the studio and thesis and expose students to emerging research from other research institutes or companies.

4. Collaboration between disciplines within the program

Traditional graduate-level engineering programs are generally structured with a strong technical approach and skill-building focus. Compared to these programs, the ITECH Programme requires students to apply their skills directly to a specific research project and to contribute their individual knowledge by working collaboratively in a group research project. Throughout the program, students work in teams with state of the art technology and explore and develop novel structural design concepts and fabrication strategies.

The design and construction of a building or structure (whether it is a bridge, a high-rise building or a temporary pavilion) always requires the combined skill set of multiple disciplines. The ITECH Programme seeks to bring these disciplines together from the start in an integrative and collaborative approach. The students are not only expected to work on one project as a group, but also to take on individual responsibility and collectively make critical decisions to successfully complete their design project.

Throughout the program, seminar modules enable the students to acquire the general core skill set needed for a successful career in the construction industry. The structure and organization of studio and later on the thesis project teaches them - similar to a real industry environment - to work with people from different backgrounds and fields. Students also start to take on self-responsibility and develop an advanced individual skill-set, which they bring into the group project and share with their peers.

Students graduate from the program with a general technical skill set, as well as high social skills and an advanced individual skill set they tailor towards the future career they envision for themselves. ITECH graduates typically cannot be categorized within a specific discipline anymore; alumni with a pre-ITECH engineering background now work in traditionally design-oriented positions (e.g. design and

research departments in the automotive or sportswear industry) and some with a background in architecture continue their careers in engineering offices.

5. Examples of specific program elements

The following sections provide examples of elements within the ITECH Programme and some of the student work that has been produced through these.

5.1 Seminars

5.1.1 Form and Structure

The seminar focuses on the interplay between geometry and behavior in different structural types, categorized with respect to the load bearing system. In particular lightweight structures (i.e. form-active, bending-active and surface-active structures) are introduced to the students along with their relevant design processes. The seminar covers historic and current structures, digital modelling, mathematical background, detailing and realization/construction. The goal of the course is to design, optimize and analyze a lightweight structure in teams of two to three students, allowing the taught material to be investigated and experienced within a project context.

The seminar has led to several interesting research outcomes, such as the seminar project of Pedro Giachini and Bahar Al Bahar on irregular cable nets that was developed further into a full paper presented at IASS 2017 [10] and the seminar project by Ramon Weber, Ayuna Mitupova and Tiago Silva de Carvalho that won the Frei Otto Förderpreis (competition) “Flexible Space” through a novel combination of lightweight typologies [11] (see Fig. 2).

Figure 2: Irregular Cable Net by Giachini and Al Bahar (left) and Flexible Space by Weber, Mitupova and Silva de Carvalho (right)

5.1.2. Materials and Structure

The seminar teaches students how to fabricate new architectural systems by thinking three-dimensionally through material, design and production. Applying a learning-by-doing concept gives students the opportunity to experience working with materials and to understand their structural limits and advantages. As an example, students were asked in this course to design and fabricate a chair, manufactured from one or more given materials, e.g. composites, wood, steel, concrete or others. The materials and their structural capacities were first introduced to the students in form of theoretical lectures. In a second phase, the students started to conduct further research on the chosen materials and then worked experimentally with them to fabricate physical prototypes. At the end of the course, students built the prototypes with the selected materials, applying reinforcement based on the loading conditions and internal forces. The weight of a human body was a good example for a typical loading condition and allowed the students to practice thinking about optimization of form, material development, fabrication constraints and the creation of innovative solutions. Figure 3 illustrates three examples of chair prototypes developed during the summer semester 2016.

Figure 3: (left to right) Biocomposite chair by Sachin Gupta and André Kauffman, Wood chair by Leonard Balas and Juan Patricio Lara Ditzel, Carbon fiber composite chair by Tania Araujo and Masih Imani

5.2 Integrative technologies and architectural design research project (pavilion studio)

The ITECH studio is a unique pedagogical model in which a large team of students and researchers work together to build an experimental pavilion based on an underlying research question. The outcome is not preconceived, but emerges through iterative investigations and experiments. Three pavilions have been developed as part of ITECH Programme since its inception. For each pavilion, technological implementation has necessitated custom mechanical tooling and hardware, customizable computation and communication workflows for design and fabrication, as well as advanced methods for structural prediction, analysis and modeling.

One of the core unique possibilities of the ITECH Programme is the option for students to select their group based on interest as opposed to background, allowing them to gain specialized expertise through practical development of the project. For example, in the research pavilion 2016/ 2017, the technological teams included structures, computation, global design, mechanical/hardware, drone development, materials and project management/logistics. During this phase, development is goal oriented: the students develop critical aspects of the required technology under the guidance of tutors while forming an understanding of how their deliverables of relate and impact on the design and development of other groups.

Figure 4: (left to right) ICD/ITKE Research Pavilion (RP) 2014/2015: An FRP-reinforced pneumatic. ICD/ITKE RP 2015/2016: A robotically-sewn wooden-veneer double layered shell. ICD/ITKE RP 2016/2017: A robotically woven FRP cantilever.

This educational setup necessitates iterative communication, weekly demonstrations of research and development and a collective assessment of progress and challenges. A key criterion which enables the pavilion studio to succeed is effective communication between groups, particularly when one group depends on the outcome of another (much as required as an AEC practitioner). For example, in 2016/2017 the mechanical development team was responsible for developing an effector that would minimize fiber friction when the drone was actively flying, while the drone group was responsible for developing a drone that could still fly given a fluctuating tension force on the line. A tight coupling was also necessary between the global design team and the structural team: where fiber layout had to negotiate between geometrically-achievable fiber paths and suitable fiber to fiber interaction, while achieving the required structural performance. Additionally, a less technical requirement was the interaction between design teams and the material team that negotiated sponsorship and the logistics of material supply, a critical input to achieving the final demonstrator.

5.3 Thesis project - "Tailoring Self Formation"

The master thesis "Tailoring Self-Formation – fabrication and simulation of membrane actuated stiffness gradient composites" by Lotte Aldinger and Georgia Margariti [12] can been seen as an exemplary outcome of the interdisciplinary environment. The two authors, with previous degrees in structural engineering, were supervised by two researchers with architectural backgrounds to work on the development of a design to fabrication framework for moldless construction of doubly-curved surfaces, based on inherent material behavior driving a self-formation process. Glass and carbon fiber strands are stitched onto a prestressed high-strain membrane with the use of tailored fiber placement technology. After releasing the prestress, the stored elastic energy in the membrane is used to drive the self-formation process. The master thesis is situated within ongoing research trajectories at the ITKE, namely elastic material deformation for bending active structures and compliant mechanisms, novel fabrication processes for fiber composites, and combined physical and digital form-finding within a computational design process. The thesis integrated the findings into one coherent design-to-fabrication tool that calculates a specific fiber layout on a specifically prestressed membrane, based on an input that requests certain areas of synclastic and anticlastic curvature in the self-formed geometry.

Thus, a strong analytical investigation of all parameters that drive the formation process culminated in the development of a design tool that integrates cutting edge technological developments in the fields of structural engineering, fiber composite fabrication and computational design (Figure 5).

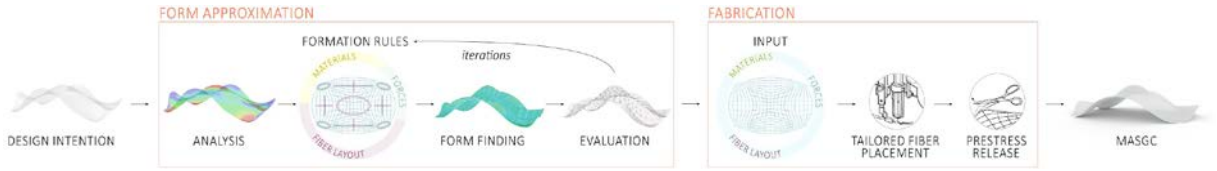

Figure 5: Workflow of the computational design to fabrication tool proposed in Aldinger et al. [12]

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