

Learning through making
Digital fabrication of 1:1 experimental
constructions within an educational context

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Design-Build projects is nothing new in architectural education, they date as back as the famous BAUHAUS School (Germany, 1919-1933) or even more. However the use of new technologies has boosted this educational practice to a great extent, and as a result during the last decade we see several examples of experimental pavilions generated in architecture schools across Europe. This new trend, has been initially introduced by a few avant-garde architecture schools and has been propagated at lightspeed across the globe. There are numerous reasons that facilitated this surprisingly fast diffusion of ideas and practices, among which we can undoubtedly identify the sharing of information through the web, the introduction of new media in the architectural practice and the culture of open source code across disciplines.

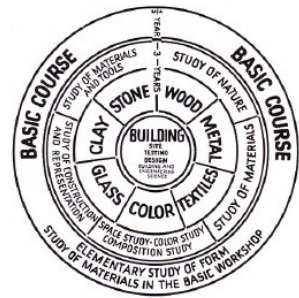


Fig. 1
The BAUHAUS workshop in Dessau (1919-1933) and the BAUHAUS curriculum. Bauhaus archive Berlin ©.

The research presented is looking at experimental 1:1 constructions that were built as part of an educational agenda; it examines the changes that are induced by the use of parametric design and digital fabrication and it discusses their educational value.

Pavilions as architectural experiments

The teaching of construction and architectural technology very often involves the fabrication of models or prototypes. This offers a hands-on approach and leads to an empirical understanding why a certain architecture fulfills the requirements of the design brief. A prototype addresses the issue of materiality, as well as assembly sequence which very often is overshadowed by the morphological characteristics. Very often a 1:1 construction is part of a big series of functional prototypes. In most of the cases encountered in this study, the outcome of design-build projects are pavilions, which due to their temporary character, small scale, loose programmatic requirements and relatively low budget, offer increased opportunities for experimentation. Their reduced temporal impact, both in environment as well as in society, allows architects, and in this case students, to take risks, experiment and innovate. In the teaching of science, an experiment has a very decisive role, it represents an orderly procedure carried out with the goal of verifying, refuting, or establishing the validity of a hypothesis. Although scientific experiments are of a different nature, as they mainly involve the analysis of quantitative data, architecture and engineering have adopted certain techniques and methodologies that can address construction problems. Beukers & Van Hinte affirm that *'Testing prototypes and models is the only way to see if theories really work'* (Beukers & Van Hinte 2005). In that sense, the construction of 1:1 pavilions can be considered as the equivalent of an experiment for architecture. Such an "architectural experiment" can also address qualitative data, aesthetics and materiality. Throughout the history of architecture, pavilions have always provided a fertile field for formal exploration and material innovation pushing the boundaries of known design and construction methods.

Architectural innovation and research by design

Our generation is witnessing a shift in architectural research and practice. The ongoing discourse is focusing more on technology related to design and construction than to theoretical issues in architecture. It is widely accepted that new technologies have accelerated innovation in architecture, which is inevitably reflected in architectural education. Pierluigi Serraino has written that "Form Follows Software"; in his homonymous lecture at ACADIA 2003 he discusses several case studies where the software used had a direct impact on the design outcome (Serraino 2003). Paraphrasing the above, considering the design-to-fabrication workflow as a File to Factory continuum (f2f), we could claim that "Form Follows Tools", referring to both design and fabrication tools and the reciprocal relationship between these two processes. Obviously the available

digital fabrication equipment as well as the software used has largely influenced the repertoire of forms, in digitally produced artifacts. This is in line with the famous phrase by William Mitchell, that “architects tend to draw what they can build and build what they can draw”(Mitchell 2001). More specifically, when referring to the pavilions produced within an educational context, the constructed works relate also to the sizes, material availability, and possibilities of material processing (CNC, robots) available at the school lab as well as to the close connection to faculties and scientists from different disciplines, such as engineering, mathematics and biology. In most of the cases studied in this research, an interdisciplinary approach has been of great importance, as it has facilitated decision making by looking at the same problem from different perspectives. It is commonly understood, that such interdisciplinarity both within the academia, as well as in design practice, is one of the main accelerators of architectural innovation. We can observe that during the last decades, such innovation has mainly happened in four different levels:

- 1) At material level with the use of plastic, fiber and polymer composites
- 2) At material-processing level, with the use of CNC machines and other digital fabrication tools for the scoring, cutting, folding, bending and thermoforming of raw material
- 3) At assembly level with the use of conventional material like wood or bricks processed with computer driven tools and robots
- 4) At design level, with the use of parametric software and computer simulations of the environmental, structural and material performance that encourage the growth of performative designs.

Each of the pavilions studied addresses one or more of the above, showcasing that innovation is happening at multiple hierarchical levels. The Institute of Computational Design (ICD) of the university of Stuttgart has effectively named these construction experiments “*Research Pavilions*”, as such practice brings up the very *hot subject* of Research by Design.

As it is constantly discussed in architecture conferences, architectural research still searches for an identity and content. Groat and Wang, in their book *Architectural Research Methods*, tackle several of the issues regarding tools and methodologies for researches, however traditional structures of research do not prove effective any longer and new technologies have also brought new paradigms in Research by Design. Henk Borgdorff in the Debate on Research in the Arts claims that “*Art practice qualifies as research if its purpose is to broaden our knowledge and understanding by conducting an original investigation in and through art objects and creative processes*” and that “*Research processes and outcomes are documented and disseminated in a appropriate manner to the research community and to the wider public*” (Borgdorff 2007). In that sense, there is no better research output than built examples to disseminate the results and

findings of design research within the academia as well as the industrial partners and local community.

It is important to see these educational construction experiments within a context of innovation, not only at the aforementioned levels from material to design, but also addressing innovative thinking processes and aesthetics. Due to their scale, the pavilions oscillate somewhere between art and architecture, between the size of a furniture piece and a building. Observing the whole body of work undertaken and academic institutions in Europe, it is easy to identify current trends, both as aesthetic paradigms as well as technological achievements.

A critical point on design processes

We are the generation of architects that commenced their architectural education with hand-drawn plans of all scales and ended up in their advanced studies or professional praxis adopting almost exclusively digital design methods. Inevitably these unique circumstances of this transition era have led to both positive and negative effects with regards to architectural research. Overwhelmed by the enormous capabilities of design tools architects have commenced to produce buildings of the most hysterical shapes, just because they have the capacity and know-how to do it. So are we really searching for the limitations of a tool? Are we prioritizing this requirement more than programmatic or aesthetic criteria? Or is it that the entire “fashion” in the architecture industry has been influenced by the advancements of technology. Patrick Schumacher claims that “there is a global convergence in recent avant-garde architecture that justifies the enunciation of a new style: *Parametricism*” (Schumacher 2009). This is a trend that has been going on for over 15 years in architectural creations of different scales, however, the development of digital design tools and scripts has accelerated a cumulative build up of virtuosity, resolution and refinement. Schumacher explains that aesthetically speaking the hallmark of this new style is “*the elegance of ordered complexity and the sense of seamless fluidity, akin to natural systems*”. As it is expected, most of the experimental pavilions examined in this research display the so-called “continuous differentiation”, versioning, iteration and mass customization.

The architecture of dipoles has shifted towards the display gradients between the two extreme conditions and very often architects look at nature for inspiration and innovation. While biomimetics is not a new concept in architecture, we can definitely distinguish between early years, where architects would copy an efficient form from nature, and current design research that focuses in understanding and emulating processes of natural growth. This affects not only the generation of forms, but also the generation of ideas; we are no longer designing an object, we are rather designing a process. This is probably the main difference in the designer’s role introduced by the use of new media in design and fabrication. As Parthenios explains in his paper for the Critical Digital Conference at the Graduate School of Design at Harvard “*conceptual design is not a linear process, it consists of sub-processes which are individual but interact with each*

other" (Parthenios 2008). Likewise for the design and construction of a research pavilion, the design process unfolds in several stages altering fabrication of prototypes, analysis, and ideation. Thus there are several critical points of change, among media, ideas, processes, that require that the designers very often re-address certain issues, go back and update the design, generating a kind of feedback loop. In most of the case studies the students design the process rather than the end result. However within the process itself there is not a centralised control, but a bottom-up strategy of information processing, where different design decisions and requirements negotiate with mixed media and diverse interdisciplinary input in quest for an equilibrium of the process and the design itself.

Despite the huge palette of media and processes at hand, we can paradoxically observe that the excessive use of the fashionable design processes and tools very often leads to projects that are particularly similar to one another. Thus many would claim that the use of digital design tools is limiting the creativity of students. Unfortunately there is a certain portion of truth in the above; as students become familiar with computational tools and scripting, they tend to produce algorithmically grown structures that in most cases are impressive and very positively accepted as innovative. Thus the main focus falls on the technical difficulty and the effect of "eye candy" that an algorithmic digital design creates, rather than functionality, aesthetics, adaptation to the surroundings, constructibility. However, the potential of new technologies in architectural praxis and education, goes far more than just creating a beautifully looking picture. In this sense, the integration of design-built projects within the curriculum aims to maintain the designer's awareness about materiality and real architectural construction.

Observations and conclusions

The research presented here has been conducted during the last 5 years, cataloguing and categorizing educational pavilions while studying in depth a given number of case studies. By evaluating a big number of student projects we understand that construction experiments are of incredibly high educational value as the *"explicit knowledge that is only achievable through physical making is made communicable and reproducible through a process of reflection"* (Geissbühler 2014). The software used and the digital fabrication strategies have a direct repercussion on the constructed object. However, after the initial fascination with the medium, the students tend to seek methods to twist and tweak the established methods, thus producing new knowledge. In turn, the additive or subtractive methods of manufacturing play a crucial role in the design process, defining the necessary steps for a file to factory continuum.

In their great majority, pavilions are comprised of modular elements which are usually differentiated to respond to design requirements, while being in line with the global fashion in architecture. There is a certain level of prefabrication before the final assembly. This happens for practical reasons, mainly relating to the size of available CNC machines as well as the weight of components and commodity of transportation and



Fig. 2
CNC cutting of the components and assembly of EmTech Canopy 2009 at the Architectural Association in London.

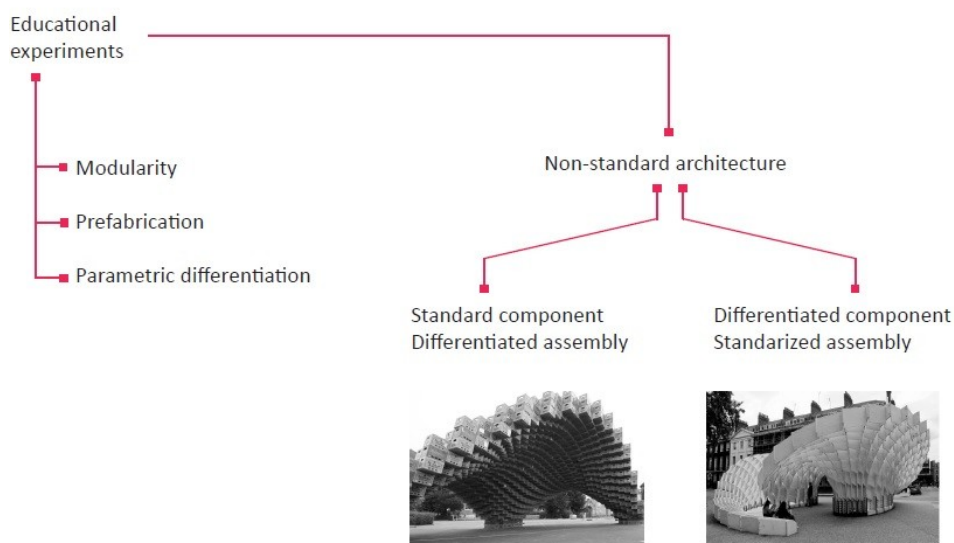


Fig. 3
Main trends in educational construction experiments.

assembly by students. In these non-standard constructions we can easily identify two main trends: a) Differentiated components, displaying mass customization at component level, which have a standard method of assembly, b) Standardised components that explore new assembly methods, ie non standard placement of the material with the use of robots. Both approaches obviously relate to the parametric processes of initial form generation and the possible differentiation induced in different scales, at component or assembly level.

Within the collaborative design processes that are employed for the design and fabrication of research pavilions, models and prototypes are both design and presentation tools. They are media for presenting an idea, but also experiments for material performance or assembly sequence. They investigate tangible and qualitative characteristics that cannot be evaluated on the computer screen. While digital models prove effective with handling numbers, forces, physical simulations and other quantitative data, built prototypes offer themselves as means for evaluating qualitative data. Materiality and tactility can only be experienced by constructing an artifact. Thus the combination and convergence of analogue and digital media supports the school of thought of Learning by making. Having understood the *modus operandi* of *Research by Design*, if such praxis could be combined with the use of new technologies and the accessibility to a fab lab, we might go a step further, considering *Research by Making* as a method of architectural inquiry.

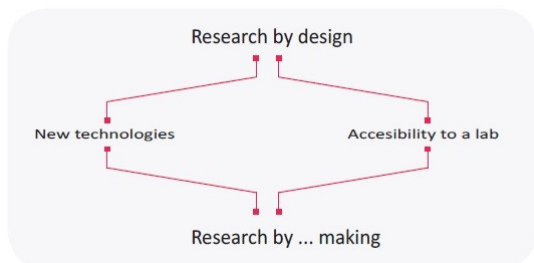


Fig. 4
Moving from “Research by Design”
towards “Research by making”.

The design and construction of research pavilions provides a very fertile ground for teaching construction, innovation and inventiveness. As most of the structures are modular, the nodes that connect the components play a decisive role. It is no exaggeration to say the solution of an efficient node is a project by itself. Inspiration is very often found in Japanese joinery and traditional wood techniques enriched with customised details, that are easy to fabricate in-house with the available technology. The immediacy of gaining feedback from fabricated prototypes through assembly and testing of both components and nodes, is a great asset. Students are able to assess the structural performance of the artefact locally and globally, and thus pinpoint optimized node solutions, both with regards to functionality and material resistance, as well as considering construction logics and assembly sequence.

Jason Griffiths in his paper for the EAAE-ARCC Conference in 2008 suggests that “*digital fabrication in architecture can be roughly categorized in two ways: Those that we can use today and those that we cannot*” (Griffiths 2008). Educational construction experiments prove to alimnt both categories, as they are driven by the desire to innovate and educate. With design-built projects students gain an experiential understanding of architectural structures, they train their intuition to understand material limits, as for example the breaking limit of a wooden component. This knowledge implicitly or explicitly is fed into their future designs. At the same time, there are pedagogies that encourage

a hands-on approach to precede the teaching of theory, as this sequence aids the students to construct by themselves the questions to be answered by theory. Thus the educator designs a pedagogical process, where the student will have questions arising from the experiential phase and will be answered by theory and experimentation in a feedback loop. Clifford Geertz explains the learning outcomes of a hands-on approach through an operationalist point of view *"If you want to understand what a science is [...] you should look at what practitioners do"* (Geertz 1973).

In addition to the above, the notion of time and project management becomes of crucial importance. As most of the design studios do not require so sophisticated logistics, students face for the first time the responsibility about material orders, processing methods and time required for fabrication and assembly. In most of the case studies students proved to be almost ignorant of methods of time-management and exceed the agreed deadlines. Construction experiments being the closest experience to a real construction site introduce students to the actual process from design to production. Very often this has a feedback on the design. For example cutting times with a CNC machine can be calculated within a Grasshopper definition, and if they exceed the desired limits, this can inform the initial design to produce bigger components with less cuts.

Last but not least, among the learning outcomes is the collaboration among student groups as well as between students and external consultants or industrial partners.



Fig. 5
Student pavilions from the Architectural Association London, ETH Zurich, Detmold University, University of St. Joseph, University of Southern California, Lodz University, Porto University, Washington University, Tonji University, ICD and ITKE Stuttgart.

This requires a clear distribution of tasks in the form of construction-management which emerges naturally within the group. At the same time, as these activities are rather intensive within a small amount of time, it has been very often highlighted by the educators, that construction experiments have been a good team building exercise and have helped students to develop the capacity to work under stress in a team environment. Moreover, these projects are characterised by high motivation in students, as there is tangible feedback of their work and satisfaction with the constructed result.

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