Build-up to the Waste House: The Development of Building Projects to Explore the Use of Recycled Materials and the Enhanced Engagement of Student Builders

Glenn Longden-Thurgood, University of Brighton, United Kingdom

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Abstract
The Waste House was completed in 2014 - built almost entirely by the collaborative work of some 300 young people including school children and students studying construction trades, architecture and design. "The building was Europe's first permanent public building made almost entirely from material thrown away or not wanted. It is also an Energy Performance Certificate 'A' rated low energy building." (Baker-Brown[1] 2017). Parallel to the production of this pioneering building, students from the architecture courses at the University of Brighton built a number of developmental pavilion structures. These pavilions, used to exhibit the work of students at the annual Graduate Show, helped build the knowledge and experience that supported and enabled a proposal to have the Waste House constructed largely by an "unskilled" workforce of students. Three key Graduate Show pavilions built between 2011 and 2013 were large enough in terms of scale and complexity to simulate the ambitions of the Waste House. These pavilions were developed following material searches that revealed an abundance of waste and locally sourced materials and as a result explored the use of unconventional construction processes such as rammed chalk, structural straw bales, tensioned birch and reciprocating structures. This paper describes the School of Architecture and Design's (SoAD) approach to these pavilions and how they helped inform an emerging attitude towards the (re)integration of technology and design in architectural education with a view to producing graduates who are in a position to direct more sustainable attitudes to construction in the future.

Keywords: Integrated teaching, integrated design and technology, waste house

[1] Duncan Baker-Brown is an expert in contemporary methods of ecology-friendly building design, architect and Senior Lecturer at the University of Brighton, UK.

Introduction

The first section of this paper is a brief summary of the opinions and observations of a number of academics since 1984 relating to the evolving relationship between design and technologies in architectural education. The second section describes the approach developed by the BA(Hons) Interior Architecture course team in SoAD at the University of Brighton for dealing with problems identified by External Examiners in the integration of technology in design portfolio submissions. This section includes a brief description of the pedagogy that was used and the projects that were developed as a vehicle for testing and implementing change. This work ultimately led to the construction of the Graduate Show pavilions, which are described and illustrated. Sections three and four are outcomes and conclusions respectively.

Literature Review

There has been a cyclical debate about the relationship between design and technology in architectural education over at least a 30-year period with numerous academics and professionals lamenting the dissection of architectural curricula into easily digestible subject areas suitable for modularisation: design, humanities, technology and professional practice being the most commonly used subject areas. In addition, the trend has been for architectural philosophies to replace the historical survey of architecture (i.e. students no longer learn from precedent studies), and for new digital or virtual technologies to replace construction technology courses.

Barbara Allen[2] (1984) made the point that architecture schools have become preoccupied with theory and philosophy and its influence on design in favour of a conversation relating to construction, materials and environment.

David Lee Smith[3] (1984) discussed the issue of reintegrating technology into architectural education in response to gaps in the curriculum he had identified as a result of the ever-increasing range of topics with which academics were concerned.

Professor G. Goetz Schierle[4] (1984) illustrated the importance of technology to the architectural designer, warning that sound technological knowledge allows the architect to retain the position of leader in the construction process, with the alternative being relegation to the roll of ‘aesthetic consultant’.

Several academics regard construction technology as an area that is learned through experience. William Carpenter[5] (1997) proposed that hands-on experience was vital to the education of an architect. Maurice Mitchell[6] (1998) explored the role of technology in architectural education in terms of experiential learning, social responsibility and the sustainable use of materials. He supports a ‘culture of making’ with a view to establishing technological principles, transferable knowledge and the attainment of skills through participating in the design and construction of buildings or large-scale models.

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[2] Barbara Allen, University of Southwestern Louisiana, USA.
[3] David Lee Smith, Professor of Architecture at the University of Cincinnati, USA.
[4] G. Goetz Schierle, Professor of Architecture at the University of South California, USA.
[5] William Carpenter, PhD, Fellow of the American Institute of Architects.
[6] Maurice Mitchell, Professor of Architecture of Rapid Change and Scarce Resources, London Metropolitan University, UK.

In the introduction to his selected essays 'Rethinking Technology' (2007), William Braham[7] asserts that technology relevant to the field of architecture has evolved to such an extent that 'the tools of design and construction have become a matter of systems'. Structural systems, computational systems, nervous systems: 'technology has become autonomous, not part of a design discourse, but a discourse in its own right.' As a counter point, in his foreword to 'Introduction to Architectural Technology' (McLean and Silver 2008) structural engineer and experienced teacher Hanif Kara[8] points out that an architecture based on systems and computational tools is an extreme. The contemporary student of architecture requires a middle ground where basic structural principles are enhanced by the new possibilities offered by the computer. Input from experts in new technologies, combined with a sound knowledge of historical precedent, offers the student 'a better chance of designing with originality and novelty without becoming an engineer or computer scientist'.

Pedagogy

From this brief sample of opinions spread across the last 30 years it is clear that there has been an ever-increasing level of concern about the evolution of construction technology in architectural curricula and its integration into the design process. The evolution of architectural curricula is inevitable and indeed desirable, however the problems that have arisen from the distillation of design from the rich influences of technology, building and construction still need to be addressed, or at the very least recalibrated. Solutions range from identifying specific project briefs that, out of necessity, require an element of design, theory and technology, to the introduction of specific approaches to teaching and learning that align the delivery of design and technology. So far it seems that none of the explorations or discussions have been conclusive in finding an approach or attitude that successfully brings together the issues of design and technology that recognises the interdependent nature of the two while retaining two distinct subject areas.

Antony Radford[9] and Susan Shannon[10] (2010) identify the difficulties students have applying knowledge of environment, building performance, structure, construction and building services from precedents to their own projects. They discuss the introduction of specific and intensive technology projects as part of an iterative process that deals with design through technology. Their strategy was to use iterations of the same project with different foci. The first was a technology-centric design project run over a relatively long period with regular technological discussions and quizzes before and after the sessions testing the students on what they had learned. The second much shorter iteration repeated the project in a slightly different context, substituting the technology-centric theme with 'design for delight' and the experience of space as drivers for the students' explorations. Both projects incorporated increasing levels of complexity and were taught through iterations and elements of peer learning[11]. They deployed three tactics in relation to their studio experiment: spiral curriculum[12], scaffolding[13] and peer learning. Radford and Shannon's

[7] William Braham, Associate Professor of Architecture at the University of Pennsylvania, USA.
[8] Hanif Kara, Professor in Practice of Architectural Technology at Harvard Graduate School of Design, USA; design director and co-founder of London-based structural engineering practice AKT II.
[9] Antony Radford, School of Architecture, Landscape Architecture and Urban Design at the University of Adelaide (Australia).
[10] Susan Shannon, School of Architecture, Landscape Architecture and Urban Design at the University of Adelaide (Australia).
[11] Peer learning is a pedagogical tool where students work with and learn from each other to achieve their educational goals.
[12] A spiral curriculum deploys the tactic of revisiting a topic or theme over a project, academic year or course, with complexity increasing with each revisit.

conclusions, however, do not relate to the success or failure of the project in relation to students' ability to understand architectural technology. In fact, they argue that in the context of architectural education it is almost impossible to quantify the pedagogic effect of one particular module over three or five years of education.

The Integrated Approach

The evolution of the technology curriculum for the architecture courses in SoAD at the University of Brighton began in 2010 when we too began to explore the benefits of an integrated approach. Specifically, combining design and technology into an integrated curriculum that recognises the interdependent nature of the two subject areas, acknowledging that there is no design without technology. In support of an integrated curriculum we developed studio-based design and technology projects for Interior Architecture students, a course in SoAD that had manageable student numbers and was complex enough in its technological ambitions to be comparable to architecture courses generally. Through the incorporation of a variety of pedagogic strategies, we introduced a series of briefs that described increasingly complex and ambitious attitudes towards technology supported by the incorporation of making projects (scale models, artefacts, installations and exhibitions) that required students to deal with both design and technology simultaneously.

The use of a spiral curriculum allowed us to revisit issues and build up complexity through a series of iterations (Bruner 1960). Students moved quickly through the initial stages of projects as they drew and physically modelled initial design ideas. Building on early simple ideas, complexity increased as the scale of the investigations zoomed in and moved from general principles to detailed proposals describing material, structure and how elements work together.

Scaffolding (Wood 1976) was used to support students through projects that were far too ambitious for them to deal with individually. Teaching staff supported students through the more ambitious aspects of a project, explaining how to proceed and providing raw material and data, offering a complex framework within which the students worked. Often producing work in groups, students had the opportunity to learn a wide variety of skills by participating in scaffolded making or building projects linked to their design ideas.

Peer learning, linked to scaffolding, problem solving, seminars and critiques, was used to encourage students to interact with and learn from each other within a directed educational framework (Boud et al 2001).

Iterations (Radford and Shannon 2010) were used to deliver associated modules at the same time. We encouraged students to make the connection between different modules and subject areas. For example, technology lectures, week-long 'sign-up' workshops and a series of 1:1 tutorials with technologists were related to a design project. This allowed staff to deploy a range of teaching tactics to help students develop a design project and encourage them to address the issues raised by the design question from a number of points of view.

[13] Scaffolding refers to a process where teachers demonstrate how to solve a problem and then let the students take over, offering support when required.

The increasing complexity and ambition of the making elements of these projects led, in time, to the inclusion of a construction project in the curriculum for second year Interior Architecture students. As a vehicle for these projects the course team proposed to build pavilions for the SoAD Architecture and Interiors Graduate Show. In 2011 second year Interior Architecture students were asked to build the first of a series of Graduate Show pavilions and keep a record of their experiences.

How do we build a shelter large enough to house our Graduate Show, relying mainly on the abilities of our students, on an extremely limited budget?

In parallel to the discussion about the (re)integration of technology into design projects, Duncan Baker-Brown from SoAD was in negotiations with the University of Brighton to build the Waste House on their Grand Parade site. Recycled materials were an obvious resource to investigate for both projects. By 2010 research in this area was not new, in fact, enthused by the ethos of recycling, reusing, and remaking, championed by pioneers such as Samuel Mockbee, staff and students from SoAD had already made a series of experiments with waste materials in their exhibition entitled 'The Given, the Twisted and the Broken' in 2004.

Mockbee's view was that architectural education should "expand its curriculum from paper architecture to the creation of real buildings" (Dean and Hursley 2002). This led to his formation of Rural Studio, in collaboration with Auburn University in the early 1990s. Rural Studio was a design and build programme for second and fifth year architecture students who took up residency in Hale County and worked on domestic and public buildings in this underprivileged community in the American South. Students experienced the whole development process from inception to completion. Their activities included consultation with the local community, applying for and gaining planning consent, design and ultimately the construction of the buildings they had conceived. As budgets were extremely limited, students were also expected to be creative in the collection and use of materials. These financial restrictions led to remarkable innovations. The creative reuse of materials such as car windscreens and licence plates as cladding, and carpet tubes and bailed cardboard as structure, became the signature aesthetic of many of the early projects.

'The Given, the Twisted and the Broken' (figure 1) was an installation project carried out by second year architecture students in SoAD, looking at the reuse of materials in building. Working with plastic sheet from furniture stores, food cans, drink bottles and, of course, cardboard, students and staff applied what they knew about architectural construction to the materials they had gathered. Plastic sheet, plastic bottles and thin insulation were abundant – one student looked at using drink bottles to secure a plastic waterproof membrane to a structural surface by slitting the bottom of the bottle to make fixings and using the top to secure the plastic and insulation. Another used the bailed plastic as structural material held within a timber frame, a detail we would use later with hay bales. Yet another flattened hundreds of drink cans to create a tile hanging – nothing much new here, but we explored the principle again and again in later projects where we tried DVD boxes, CDs and office paper trays, until eventually the Waste House was clad in repurposed carpet tiles.

Although these early attempts at building with recycled materials were thought provoking, and often innovative, the images (figure 1) reveal that the experiments were largely intellectual ideas that really only explored the aesthetics of the installation and not the practical application of recycled material in the construction of shelters with specific performance criteria such as protection from the elements.

Figure 1. The Given, the Twisted and the Broken.[14]
Image courtesy of Duncan Baker-Brown.

Ultimately both the Waste House and the Graduate Show pavilions were made primarily from waste material. The Waste House used recycled plywood and OSB as its main structure, it was insulated with material that include denim off-cuts, video or audio tapes, and even tooth brushes. The building uses plastic publicity hoardings as a vapour barrier.

The Pavilions: How do we enhance students learning through participation in live built projects?

To contextualise the Graduate Show pavilion projects, there were between 140 and 180 graduating students in SoAD who needed a wall space on which to mount drawings and a horizontal surface for models and artefacts. Each exhibiting student needed roughly 4sqm or 720sqm in total for the largest of the pavilions. The second year Interior Architecture students who were charged with carrying out the construction were presented with a comprehensive description of the pavilion. This included general arrangement drawings, a plan of works, construction details, risk assessments and health and safety plans. Students were expected to work for five days on the building site but were encouraged to come back over the period of the build and complete their individual document evaluating the construction process.

The construction site was set up formally in compliance with UK Construction, Design and Management (CDM) regulations, was cordoned off with security fencing and students were provided with protective gear: boots, high-viz jackets, gloves and hard hats. A foreman ran the site in collaboration with several members of staff. When construction started students were expected to read the drawings and to participate in all aspects of the building process. Throughout the process students were given instruction in the use of various tools and processes. Alongside our

[14] Figure 1 clockwise from top left: 1. Plastic bale wall; 2. Drink bottles used to hold an insulated rainscreen off a sub structure; 3. Food tin tile hanging.

activities industrial demonstrations where provided where possible. These projects provided the students with hands-on experience on a real construction site.

Pavilion 1 - Chalk Wall

In 2011 the intention was to build three key structural elements to support a large flat roof: a rammed chalk wall, a straw bale wall, and recycled plywood wall, demonstrating different structural principles. We accepted almost everything we could get our hands on in an attempt to revive our experiments from 2004. Our first external pavilion used 22 tonnes of chalk, 100 sheets of plywood, 54 water damaged timber I-beams, 64 hay bales, an abundance of wooden pallets that were available locally and a lot of cheap plastic sheeting.

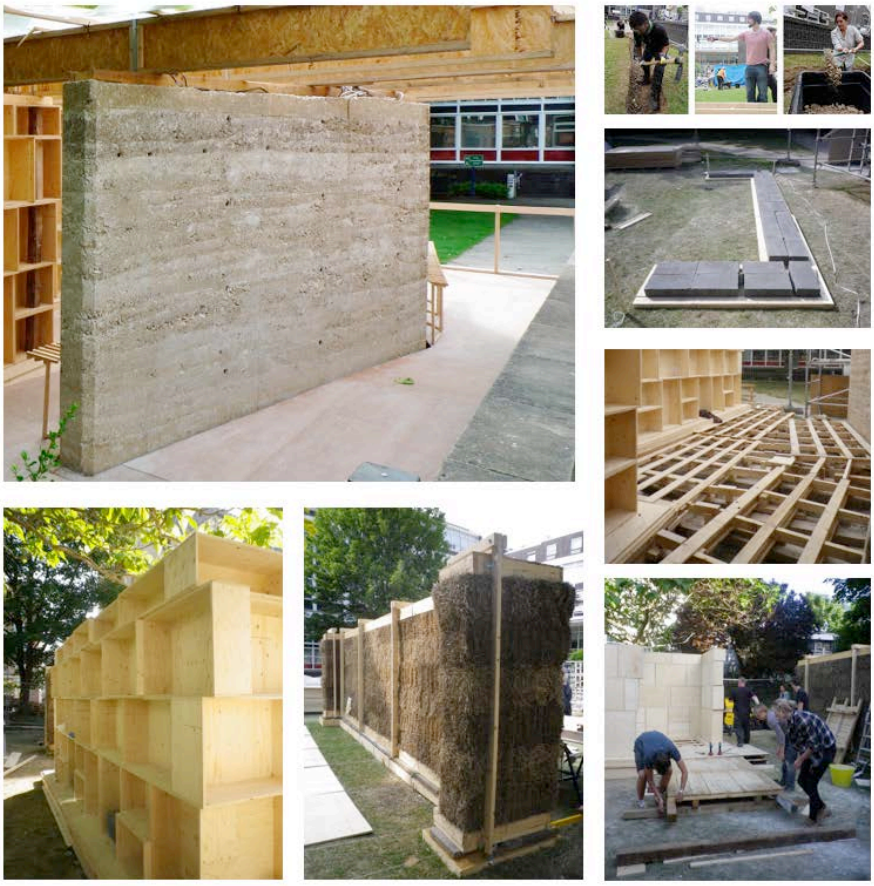

Figure 2. Chalk Wall Pavilion.[15]
Images courtesy of Glenn Longden-Thurgood.

Chalk and straw bales came from a University building site and a local farm respectively. We had external help to run two workshops - Rowland Keable, expert in rammed earth construction oversaw the rammed chalk wall, and instructors from Amazonails, specialists in straw bale housing, helped us manage the straw bale build. We had to buy the plywood as we were let down by the contractor who had promised 200 recycled sheets, but altered the details to minimise the amount of material and

[15] Figure 2. clockwise from top left: 1. Rammed chalk wall; 2, 3 and 4. Chalk wall foundations; 5. Straw bale wall footing; 6. Pallet floor substructure; 7. Floor construction of recycled timber; 8. Straw bale wall; 9. Plywood wall.

ensure that we could reuse it later. With the three main wall structures up, the site foreman for the nearby building site started to deliver a continuous stream of rejected timber and pallets for the floor.

We fitted the roof structure of rain damaged timber I-beams to span between the main structural elements. Larger than usual timbers were used as counter battens from which to hang plastic sheet in a catenary to allow for drainage.

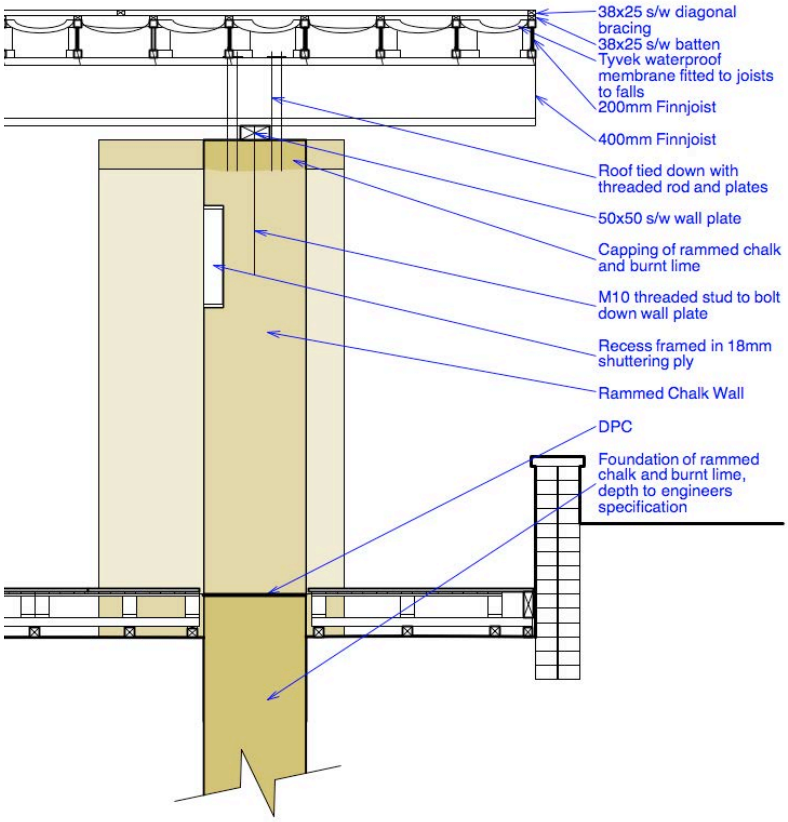

Figure 3. Section through chalk wall.

The two key lessons learned from pavilion 1:

1. Manage the number of students/volunteers. Too many and you spend your time inventing things for them to do, too few and progress is slow and the students are overworked.

2. Use techniques that students can pick up and achieve quickly. Contrary to expectations, the students built almost all of the chalk and straw bale and plywood walls following the instructions of the experts. The floor, however, was built almost entirely by staff. The relatively imprecise and unusual processes of building the main walls were popular and held students' attention - the complexity of building a level floor structure with multiple odd components was less successful in terms of engaging students or providing them with any meaningful learning experience.

Pavilion 2 - Birch Pole Pavilion

In 2012, based on our experiences the previous year, we started early and took students to local woods to carry out a series of experiments with David Saunders from Woodland Enterprises Ltd in East Sussex.

We explored how we might use tree species that were in abundance locally, but in unconventional ways through the use of contemporary materials and techniques. We felled 100 seven metre tall birch trees that were crowding slower growing oak. We learned to fell, debark, bend and join green timbers. Once we had concluded our experiments we were confident we knew enough about the material to build a curved timber structure. As the birch was felled late in the season, pre-bending was unnecessary. We found we could hold it in tension to create a desired curve as it was dry enough to spring back but was rigid enough to resist bending forces, allowing us to control the curve. See figure 3.

Figure 3. Birch pole test rig.
Image courtesy of Kate Cheyne.

For pavilion 2 we used the timber I-beams to create the floor – this quickly gave us a safe flat work surface. We use recycled plywood saved from the previous year to build a spine wall that would act as a pivot over which we bent the birch poles. The opposite wall was lightweight and was used to tie the birch poles down to the deck. The weights used to create the curve were one tonne troughs of rainwater, the thick end of the pole was stabilised in laser cut plywood bearers.

Figure 4. Birch Pole Pavilion.[16]

Main image courtesy of Jim Stevenson, details Glenn Longden-Thurgood.
Thinner birch poles were used as roofing battens that were tied to the main poles with cable ties. The roof was once again clad in plastic – this time much heavier scaffold sheeting (Monarflex) tied down in tension with elastic tarpaulin ties. The intention here was that the ties would break if we had winds over 35 mph, and the sheeting would lift off safely.

[16] Figure 3. clockwise from top left: 1. Completed pavilion looking at the lighter of the two walls, the heavy water troughs can be seen in the right of the image; 2. Wall head beam and laser cut bearers used to locate the thick end of the timbers; 3. Cable ties used to fix the birch roof battens to the bent birch roof structure; 4. Wooden pegs and elastic tarpaulin ties used to hold down the roof covering.

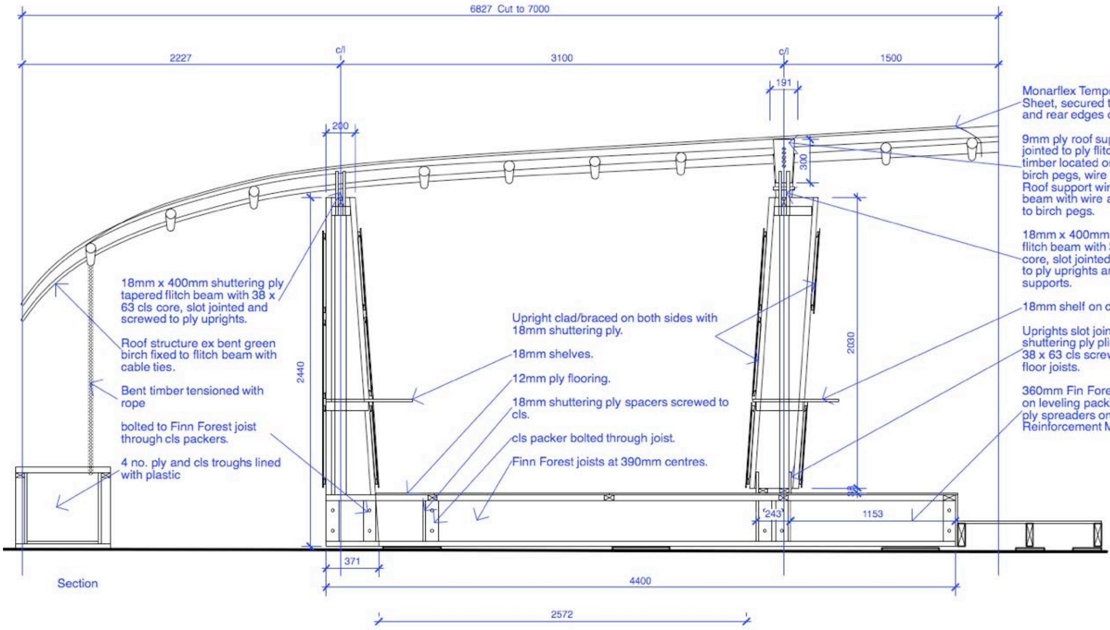

Figure 5. Cross section through the Birch Pole Pavilion

Pavilion 3 - Reciprocating Lamella Roof

While working on the Birch Pole Pavilion in 2012 I saw a simple reciprocating structure that David Saunders had built to bridge a stream in his woods at Framfield, East Sussex. This was of particular interest to me as I had developed a curved version of this structure in my postgraduate thesis project. As part of the strategy for this project I developed a proposal for a lamella roof - a technology that would allow relatively short pieces of material to be combined into structures that could bridge relatively wide spans. This was a response to a project located in a poor area of Mumbai in an environment that had limited timber resources. I didn't completely understand how this worked at the time. I look back on the drawings I made to describe this structure, and they are relatively convincing, but it wasn't until we built pavilion 3 in 2013 that I really understood the potential of this structural system. (figure 6; 4.)

In 2013 we spent the Easter break building models at increasing scales that explored reciprocating lamella structures. These are vaulted structures made of crisscrossing elements, in this case, using small reciprocating sections in a square grid pattern. Following the modelling process we made a 1:1 version to be tested by a consultant structural engineer. An underlying challenge was that we intended to use recycled plywood for the roof structure to demonstrate that it could be built cheaply from recycled materials, be built using hand tools by our students and be strong enough to support a roof covering. Once the engineer had watched us put several hundred kilograms of weight on it without deflection, he agreed to the principle and we went into production.

Figure 6. Reciprocating Lamella Roof.[17]
Images Courtesy of Glenn Longden-Thurgood.

The major difficulties for this build were to source 100 sheets of 18mm plywood and how to set up equipment, jigs and working processes that would help the students to cut each roof components precisely. We used all our reserve stock of plywood from previous shows, begged and borrowed what we could from local recycling companies, then fortunately came across a haul of plywood that had been water damaged in transit. We took possession of two pallets of this which was more than enough to complete the roof.

The roof consisted of 200 curved components and 200 parallel components, each with a tongue at each end, a square hole in the centre to receive two tongues and corresponding circular holes through which to peg the components together. We made several sets of templates so students could mark out, jigsaw and drill each component, getting as many out of one sheet as possible.

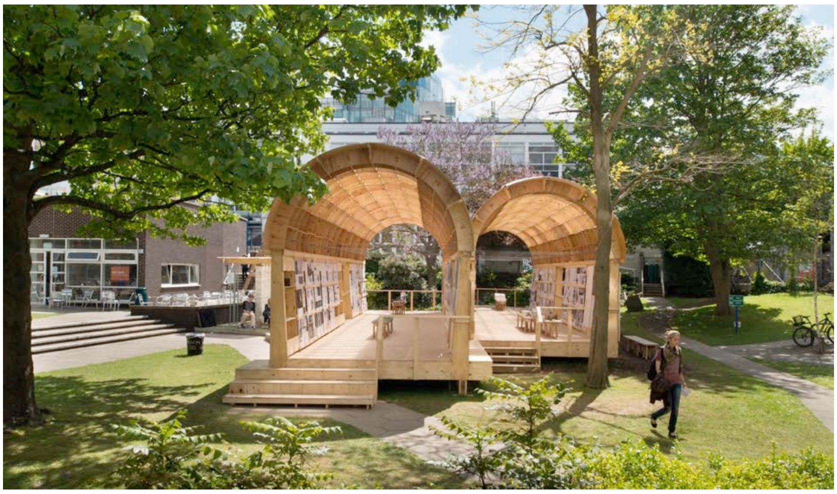

Figure 7. Reciprocating Lamella Roof pavilion.
Image courtesy of Jim Stevenson.

[17] Figure 6. clockwise from top left: 1. Full scale model; 2. 1:50 laser cut model; 3. 1:20 laser cut model; 4. Digital model from the author's postgraduate thesis project.

Once all the components were ready we started the long job of building the roof. This required two passers, sending the right component up at the right time, a director, telling us which way each component had to face relative to the previous one, two fitters, two lifters and two peg fitters. We fitted thin plywood panels to the external sides and to the open arches at the front and back, stabilised the whole structure and gave us a clear bearing surface for the plastic roof covering.

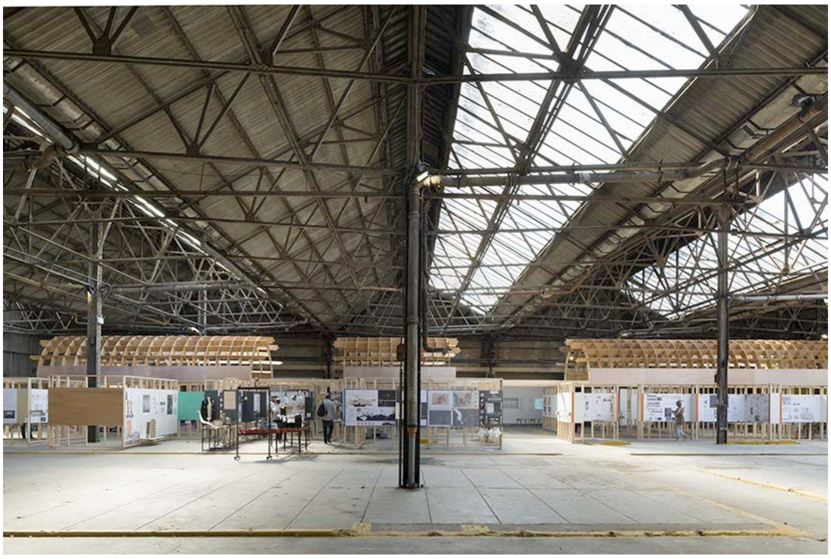

Figure 8. Reciprocating Lamella Roof pavilion rebuilt in 2014.
Image courtesy of Jim Stevenson.

The reciprocating lamella roof pavilion was the most successfully reusable of the three structures. It was rebuilt by SoAD in 2014 in a new venue for their Graduate Show, and was subsequently sold to become the entrance to a garden centre.

Outcomes

1. Measuring the success of the projects and approaches described is difficult over the time period they were carried out, this reflects the comments of Radford and Shannon (2010). We carried out numerous surveys, held focus group discussions and made analysis of the students' marks relating to technology. This analysis indicated some improvement, however, perhaps the best way to illustrate our successes is to quote Elizabeth Adams, who at the end of her five year period as external examiner for Interior Architecture wrote:

"With the technology component of the course now embedded in the design studio there was more evidence of the architectural section being used to properly and intelligently explore the relationship between technical precision and invention and spatial/material proposals."

This indicates some movement in the right direction in terms of the integration of design and technology teaching.

2. Following a recent Curriculum Design Review where we looked in detail at all our courses, technology and design are now integrated in all three UG courses in SoAD. Each course now embeds technology teaching into the design studio. Interior Architecture no longer separates technology teaching and delivers it under the broad subtitle 'systems' as part of the design modules. In 2017 the course started the academic year with the assertion that 'technology is everywhere!' and built on this throughout the year.

Conclusion

For most architectural students the integration of design and technology currently happens in practice after graduation. In industry, young designers have the opportunity to watch buildings grow and to discuss projects with experts from different disciplines. Perhaps more importantly, the constant requirement from building contractors for detailed and precise drawing packages drives home the interdependent relationship between design and construction technology.

In the 'Re-Use Atlas', Duncan Baker-Brown, (2017) relates that in the UK approximately 20% of all material arriving on building sites ends up incinerated or going to landfill; 30% of this is new material that was never used. Finding ways to reduce or eliminate waste from the construction process could help reduce environmental destruction from mining, as well as add value to material resources currently defined as waste.

While we have architectural courses that struggle to maintain the interdependency of design and technology, and where the larger proportion of technical expertise is learned in industry, we have a stalemate as the need for innovation and forward thinking is often stifled by the constraints of a construction industry that is slow or even unwilling to change. Our graduates need to be equipped with the tools that will enable them to go into industry and revolutionise the way we think about building.

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Contact email: gl@brighton.ac.uk