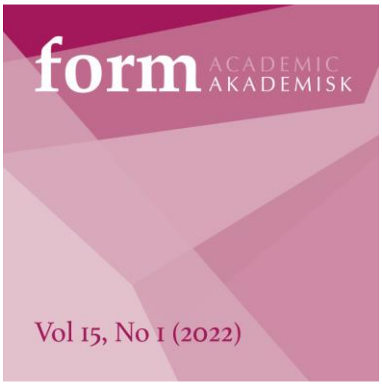

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**Barak Pelman**
PhD candidate
The Hebrew University of Jerusalem
Barak.Pelman@mail.huji.ac.il

**Amit Raphael Zoran**
Associate professor (PhD)
The Hebrew University of Jerusalem
zoran@cs.huji.ac.il

# Material-Driven Architectural Pedagogy

## A sociomaterial perspective

*ABSTRACT*
*Most contemporary architecture programmes use a pedagogical model in which students construct their design knowledge by engaging in an architectural project. Due to the size and complexities of the physical environments they study, students develop their design knowledge primarily by using representations of the material world. The learning opportunities afforded by the experience of materials hence are often overlooked. In this study, we seek evidence that material experiences have an agency on architectural teaching and learning. Using sociomaterial perspectives, we followed two architecture designbuild courses, analysed their students' learning diaries, and contextualised them with the teacher's pedagogical reflections. We found correlations between specific materials and specific knowledge, skills, and technological competencies and demonstrated how materials could be used as 'learning agents' in architectural education. The paper's findings contribute to the development of a material-driven pedagogy in which materials are used as 'learning agents' in architectural education.*

*Keywords:*
designbuild, architectural education, material experiences, sociomateriality, architectural prototyping

## INTRODUCTION

The etymology of the word 'architect' – from the Greek *arkhi* ('master') and *takton* ('builder') – provides an insight into the original nature of the practice. In ancient times, architects were masons, carpenters, and members of other trades who moved into the practice of building while working on various building sites and experimenting with materials (Carpenter, 1997, p. 5). At that time, the creative process of 'building' included both practical and theoretical knowledge (Ingold, 2013, p. 56). Throughout the Enlightenment period, however, as well as during the industrial and digital revolutions, architectural processes became split between the 'design stage', performed by architect-designers in offices, and the 'construction stage', done by builders on construction sites. As a result, most formal educational processes related to architecture became divorced from building sites and moved into academia. Real projects were replaced by theoretical ones, and first-hand experiences with materials were replaced by interactions with their representations (Carpenter, 1997, p. 6).

Over the last few decades, some prominent architecture writers and practitioners have addressed the role of practical knowledge, materiality, and workmanship in architecture practice (Pelman, 2022). Pallasmaa notes that 'spaces, places, and buildings are undoubtedly encountered as multisensory lived experiences' (2011, pp. 579–598) and that in order to design for multisensory experiences, architects must understand their practice as workmanship, experience their materials, and 'think through the senses' (Pallasmaa, 2009, pp. 64, 114). Garg (2019) and Spence (2020) have suggested that designing for the multisensory experience of space enhances the creation of more immersive, engaging, and memorable spaces. Other thinkers base their arguments on technological advances, specifically on digitally based mechanics that allow designers and architects to engage again in construction and fabrication processes (e.g. Aish et al., 2017); still others focus on the human, social, and environmental aspects of the separation between designing and making (e.g. Ingold, 2011, 2013).

One of the most significant manifestations of this discourse in the realm of architectural education is the growing number of designbuild courses in architectural academic programmes, especially from the 1990s onwards (Kraus, 2017, p. 5). The designbuild pedagogical model implies that students are engaged not only with design processes but also with the fabrication and realisation processes of their design proposals. The model is based on the belief that architects' learning processes are significantly enhanced through hands-on engagement with materials and fabrication processes.

This belief has gained new support from contemporary orientations in educational research over the last few decades; during that time, researchers have called attention to the importance of materiality in learning processes. Drawing on actor-network theory (ANT), spatiality theories, complexity science, and others, these orientations share an epistemological and ontological stand that assumes no prior distinction between the social and the material and therefore can be viewed as sociomaterial orientations (Fenwick, 2015; Fenwick et al., 2011).

A growing number of studies have adopted sociomaterial orientations in recent years to demonstrate how materials, objects, and technologies have agency on learning processes (Burnett & Merchant, 2020; Fenwick & Edwards, 2013; Hawley, 2021). But although a substantial body of knowledge exists on the effect of materiality and material experiences on design processes (Fernandez, 2012; Groth, 2017; Karana et al., 2015; Thomas, 2007; Menges, 2012; Nimkulrat, 2010; Oxman, 2010; Vega et al., 2021), few studies appear to have focused on material agency in architectural learning processes.

Focusing on two designbuild courses instructed by the first author, in this study we adopt a sociomaterial perspective to look for evidence that material experiences (Karana, 2009) have an agency on architectural teaching and learning. To advance a deeper understanding of these case studies, we juxtapose two voices in this paper: that of the scholar, who analyses the data, and another of the practitioner (the teacher), who adds to the scholar's analysis a complementary pedagogical reflection. The paper thus contains a technical report on the methods and analysis alongside a detailed account of the course design and process. Topics addressed include the design brief, the considerations we made when choosing the materials, the course structure, the nature of group work, the design and fabrication processes, and the tools we used. We hope the paper will contribute to the development of a material-driven pedagogy in which materials are used as 'learning agents' in architectural education.

## METHODS

The course used in this study was a designbuild studio course, held once in the summer of 2017 and again in 2018. During these two instances, students received the same design brief, which was to design an entrance pavilion for the courtyard of an architecture department. The design brief indicated the need for a meeting place and a passage that would offer a multisensorial experience. The course structure was similar each summer and was divided into three stages: 1) capacity building, where students acquired the basic workmanship skills and knowledge required for the rest of the course; 2) schematic design, where students drafted their initial design ideas; and 3) design development and fabrication, where students developed their design ideas through actual building and full-scale prototyping. In all stages, students worked in groups of 3–4, although the composition of the groups changed many times throughout the course. The main differences between the two instances were the students themselves and the predominant materials used for the construction.

## Materials

In choosing the predominant construction materials for each course, we wanted to ensure that they would hold social and environmental meanings that the students could explore. Building materials are social and cultural constructs that are produced through the complex relationship of legislation, regulations, production techniques, language, and use. In return, they create possibilities and limitations, ways of working, and specific experiential conditions (Thomas, 2007, p. 8). From a pedagogical point of view, however, we wanted to avoid using standard building materials (represented in our case by standard Israeli industrial products). We believed this decision would encourage innovative thinking in solving various architectural and structural problems.

Another way to look at the social values of materials is through their commercial value. Appadurai (1988) suggests that objects and materials have ‘social lives’ and that their value can be described as they change shape, place, and hands, from their natural state through extraction processing, manufacturing, distribution, use, exchange, repair, and then disposal or recycling. The manner in which materials are processed will also have different environmental impacts for each phase of their social ‘lives’. By adding social values to material without adding a significant environmental impact, we can achieve greater efficiency in terms of a material’s social values versus its environmental impact.

With these considerations in mind, we chose non-standard construction materials that were either at the end of their ‘life’ (e.g. by reusing material from dump yards) or were in an ‘idle’ phase of their ‘life’, such as time spent sitting in a store, waiting to be sold. For the first runs of the course, which took place in the summer of 2017, we thus contacted a bamboo vendor and asked to borrow 200 bamboo poles to use in the temporary construction. For the second run, which took place in the summer of 2018, we contacted Jerusalem’s parks department and asked them to give us branches from their tree-pruning activities. Cities in Israel generate approximately 380K tons of pruned branches each year, which usually are chipped and used either for compost production or soil cover in an expensive downcycling process (Israeli Central Bureau of Statistics, 2020 n.d.). Using these branches in our course would potentially return these trees back to the city, where they could provide shade again and thereby regain social and cultural meaning. We collected some 100 branches from multiple species with various shapes and properties. Figure 1 shows the final pile of tree branches and the commercial bamboo we used.

**FIGURE 1.** Our raw materials for the first and second courses: trimmed branches and commercial bamboo. Images: Barak Pelman.

## Data

The first data source for this study was students' personal learning diaries, which they were asked to maintain during the course. These diaries contained written self-reflections on their individual learning trajectories and achievements, accompanied by images, diagrams, and drawings. A total of 25 students participated in both course instances (15 students in 2017 and 10 in 2018). The diaries were written in Hebrew, and the quotations in this paper were translated into English by the authors.

Apart from serving as an empirical data source for this study, the learning diaries also had a pedagogical role in mitigating assessment difficulties in group work and encouraging 'self-directed learning' (Moallem et al., 2019, p. 15). Group dynamics and outcomes often hide individual achievements in group-work settings, which can challenge formative and summative assessments of individual students and potentially harm their motivation to learn. Students thus were asked to maintain a personal learning diary, which they shared digitally with their teacher during the course and handed in as a final learning report at the end of the course. Students were then assessed and marked only according to their own learning choices and achievements, regardless of the design qualities achieved by the group.

The second data source consisted of the teacher's field notes, images, and videos taken on-site during both courses. This data reflected more than 250 hours of site visits and interaction with students and was used to contextualise the outcome of the analysis.

## Analysis

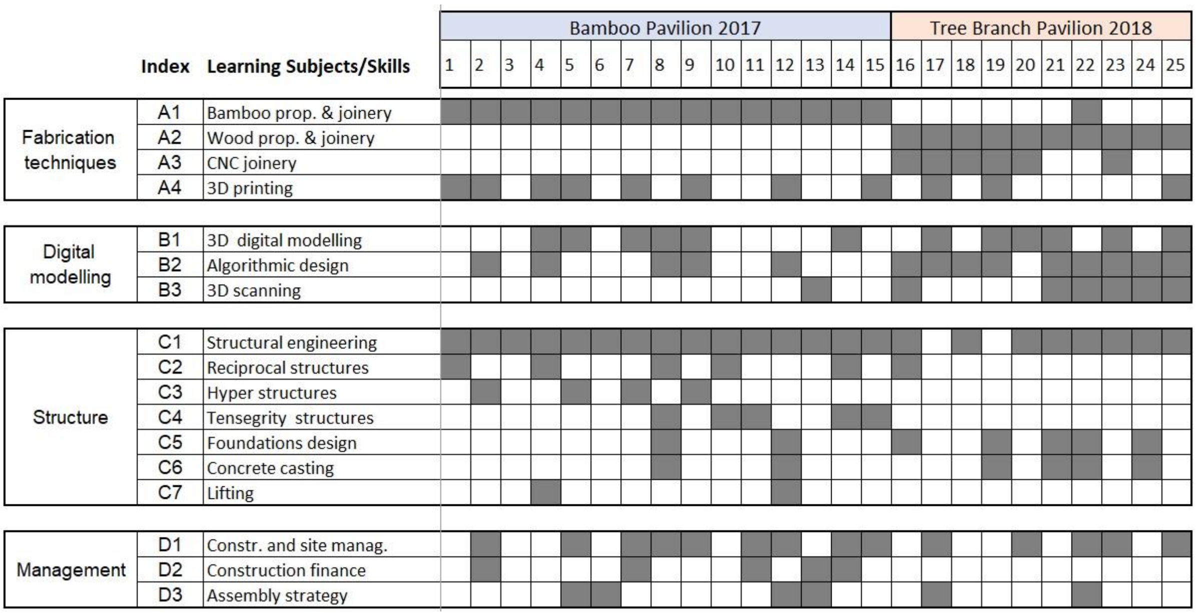
The analysis was undertaken in two stages. In the first stage, we wanted to find correlations between the primary materials used for the construction and specific learning subjects and skills (LSSs). We thus analysed the learning diaries to identify LSSs stated by the students. Table 1 shows coding examples of the textual and visual data.

TABLE 1. Learning subjects and skills (LSSs) coding examples of text and images in students' learning diaries.

| Textual / visual data | LSSs coding examples |
|---|---|
| *'The **understanding of the material led to the development of longitudinal joints**, and **I could understand the [structural] forces** that might work in different places in bamboo' (student no. 5)* | Bamboo joinery<br>Structural principles |
| *'We moved to **examine an idea to cut the joint using CNC** [computer numerical control], to cut a section that fit the round shape of the tree branches' (student no. 17)* | CNC joinery |
| <br>*Image: student no. 4* | Digital modelling<br>3D printing |

We then grouped and mapped each student's self-reported LSSs to associate them with the primary materials they had used for the construction. Table 2 shows the outcome of this process. Each student clearly had a unique learning path, as the table shows, although a deeper look shows specific patterns and commonalities in learning that cut across both runs of the course, and others that occurred only among students from the same period. For example, learning achievements in joinery techniques differed between students who worked on the bamboo pavilion and those who worked on the tree branch pavilion (indexes A1, A2). 3D scanning was more associated with the tree branches, while some structural schemes (indexes C2, C3, C4) were more associated with bamboo. Subjects such as structural engineering, construction management, foundation design, assembly strategy, and lifting were not associated with any of the primary materials. Sometimes they were associated with other material constructs such as physical models and the physical site, while at other times they were associated with the designbuild pedagogy model.

TABLE 2. Summary of students' self-reported LSSs. Each number in the first row represents a student in the course. The grey boxes indicate that this student reported learning the subjects or skills listed on the left.



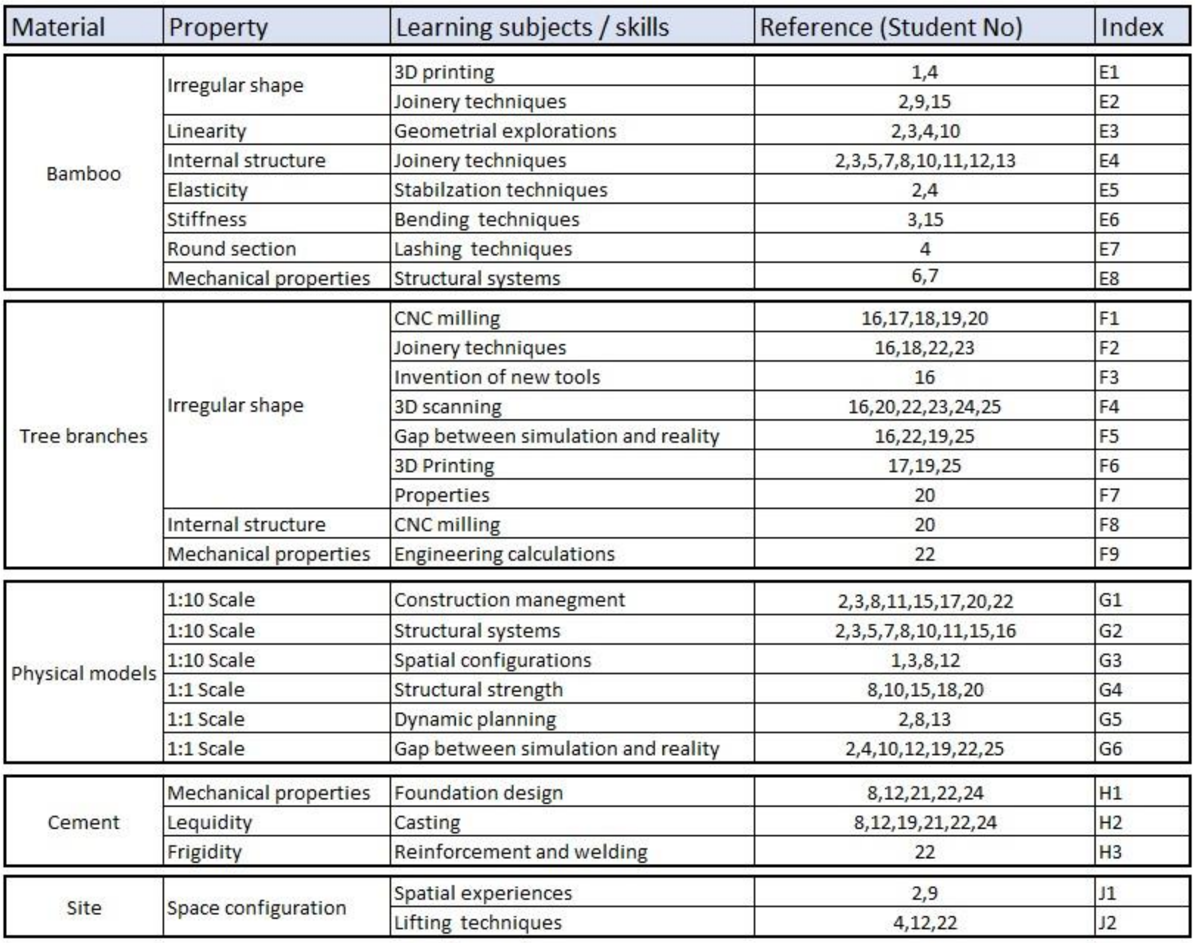
| | | | Bamboo Pavilion 2017 | | | | | | | | | | | | | | | Tree Branch Pavilion 2018 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Index** | **Learning Subjects/Skills** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| Fabrication techniques | A1 | Bamboo prop. & joinery | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | ■ | | | |
| | A2 | Wood prop. & joinery | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | A3 | CNC joinery | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | | | ■ | | |
| | A4 | 3D printing | ■ | ■ | | ■ | ■ | | ■ | | ■ | | | ■ | | | ■ | | ■ | | ■ | | | | | | ■ |
| Digital modelling | B1 | 3D digital modelling | | | | ■ | ■ | | ■ | ■ | ■ | | | | | ■ | | | ■ | | ■ | ■ | ■ | | ■ | | ■ |
| | B2 | Algorithmic design | | ■ | | ■ | | | | ■ | ■ | | | ■ | | | | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ |
| | B3 | 3D scanning | | | | | | | | | | | | | ■ | | | ■ | | | | | ■ | ■ | ■ | ■ | ■ |
| Structure | C1 | Structural engineering | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | ■ |
| | C2 | Reciprocal structures | ■ | | | ■ | | | | ■ | | ■ | | | | ■ | | ■ | | | | | | | | | |
| | C3 | Hyper structures | | ■ | | | ■ | | ■ | | ■ | | | | | | | | | | | | | | | | |
| | C4 | Tensegrity structures | | | | | | | | ■ | | ■ | ■ | | | ■ | ■ | | | | | | | | | | |
| | C5 | Foundations design | | | | | | | | ■ | | | | ■ | | | | ■ | | | ■ | | ■ | ■ | | ■ | |
| | C6 | Concrete casting | | | | | | | | ■ | | | | ■ | | | | | | | ■ | | ■ | ■ | | ■ | |
| | C7 | Lifting | | | | ■ | | | | | | | | ■ | | | | | | | | | | | | | |
| Management | D1 | Constr. and site manag. | | ■ | | | ■ | | ■ | ■ | ■ | | ■ | ■ | | ■ | ■ | | ■ | | | ■ | | ■ | ■ | | ■ |
| | D2 | Construction finance | | ■ | | | | | ■ | | | | ■ | | ■ | ■ | | | | | | | | | | | |
| | D3 | Assembly strategy | | | | | ■ | ■ | | | | | | ■ | ■ | | | | ■ | | | | | ■ | | | |

In the second stage, we thus broadened our analysis and included other materials and physical constructs mentioned in the diaries, which included cement, physical models, and physical sites. In this analysis, we wanted to understand *which* material properties led to which LSSs. We hoped this approach would explain the correlations found in Table 2 and open up new correlations between material experience and learning. Table 3 shows the outcome of this analysis.

Table 3 shows strong correlations between some of the materials' properties and LSSs (i.e. more students mentioned them in their diaries), including indexes E3, E4, F1, F2, F4, F5, G1, G2, G3, G4, G6, H1, and H2. These correlations can be explained by the availability of certain technologies (F1, F4), the course structure (E4, E3, F2, G1, G2, G3, G4: in these cases, the request to make joints and to develop structural and architectural solutions), and by the designbuild pedagogy, which includes real size (1:1 scale) construction (F5, G6, H1, H2). Other correlations between material properties and LSSs had fewer mentions in the diaries. The reasons for this variance are varied. Sometimes the small number of mentions could be explained by an individual interest of a student in a learning subject (e.g. F3, F9, H3, E7), at other times by a specific interest growing in a particular group (e.g. E6, G5, J2). A small number of mentions could also be explained by students' lack of awareness of materials agency, their ability to articulate that agency, or the relevance they thought it had to their diaries. The existence of a small number of references thus does not necessarily mean a lack of agency.

In addition to the agency that material experience had on LSSs, some students also described how material experience contributed to their *learning conditions* and *opportunitie*s. Student 7 related his direct experience with materials to curiosity and motivation. Students 2 and 17 mentioned classroom walls as elements that enabled the presentation of ideas and therefore acted as agents for inspiration. Students 3, 12, and 19 related material experience with looking for information within external building shops and experts. Other students described *learning journeys* affected by various materials' properties. For example, student 18 related her computer numerical control (CNC) milling study to the irregular shapes of the tree branches. The CNC software also helped her to understand 3D coordinate systems. Student 20 was also directed to CNC milling, but in his case, both the irregular shapes of the tree branches and their internal structure were what had led him to try CLC milling. Afterwards, encountering problems in anchoring the tree branches for milling led him to learn welding practices.

TABLE 3. Correlations between materials, physical structures, their properties, and LSSs found in the learning diaries.



| Material | Property | Learning subjects / skills | Reference (Student No) | Index |
|---|---|---|---|---|
| Bamboo | Irregular shape | 3D printing | 1,4 | E1 |
| | | Joinery techniques | 2,9,15 | E2 |
| | Linearity | Geometrial explorations | 2,3,4,10 | E3 |
| | Internal structure | Joinery techniques | 2,3,5,7,8,10,11,12,13 | E4 |
| | Elasticity | Stabilzation techniques | 2,4 | E5 |
| | Stiffness | Bending techniques | 3,15 | E6 |
| | Round section | Lashing techniques | 4 | E7 |
| | Mechanical properties | Structural systems | 6,7 | E8 |
| Tree branches | Irregular shape | CNC milling | 16,17,18,19,20 | F1 |
| | | Joinery techniques | 16,18,22,23 | F2 |
| | | Invention of new tools | 16 | F3 |
| | | 3D scanning | 16,20,22,23,24,25 | F4 |
| | | Gap between simulation and reality | 16,22,19,25 | F5 |
| | | 3D Printing | 17,19,25 | F6 |
| | | Properties | 20 | F7 |
| | Internal structure | CNC milling | 20 | F8 |
| | Mechanical properties | Engineering calculations | 22 | F9 |
| Physical models | 1:10 Scale | Construction manegment | 2,3,8,11,15,17,20,22 | G1 |
| | 1:10 Scale | Structural systems | 2,3,5,7,8,10,11,15,16 | G2 |
| | 1:10 Scale | Spatial configurations | 1,3,8,12 | G3 |
| | 1:1 Scale | Structural strength | 8,10,15,18,20 | G4 |
| | 1:1 Scale | Dynamic planning | 2,8,13 | G5 |
| | 1:1 Scale | Gap between simulation and reality | 2,4,10,12,19,22,25 | G6 |
| Cement | Mechanical properties | Foundation design | 8,12,21,22,24 | H1 |
| | Lequidity | Casting | 8,12,19,21,22,24 | H2 |
| | Frigidity | Reinforcement and welding | 22 | H3 |
| Site | Space configuration | Spatial experiences | 2,9 | J1 |
| | | Lifting techniques | 4,12,22 | J2 |

Students also described how materials triggered environmental considerations (students 14, 17, 19), improvisation and innovation (student 15), and problem-solving capabilities (student 25). For example, student 17 wrote that she 'wanted to create a recyclable joint that would fit *aesthetically and ethically* with the tree branches' (our italics). Student 15 noted the use of 'materials that are dedicated to one thing in other ways, understanding the advantage of some materials and taking them out of their context to serve different needs'. Student 25 wrote that 'the course contributed to my personal development and provided me with improvisational skills, spontaneous thinking, and innovative problem-solving capabilities'.

Apart from materials, it is worth mentioning that the students were also aware of *non-material agents* that affected their learning. These agents included regulations (student 4), financial considerations (students 13, 14), and institutional holidays (students 8, 20).

## THE TEACHER'S PERSPECTIVE

To better understand the correlations we found in the analysis, this section elaborates on the various pedagogical moves that characterise each stage of the courses and the multiple tasks, materials, technologies, and tools that the students interacted with.

### Stage 1: Capacity building

This first stage lasted 1–2 weeks and was devoted to acquiring fundamental knowledge of the chosen materials and the basic workmanship skills required to use them. The primary pedagogical approach was to learn through interacting and tinkering with the materials while reflecting on their affordance (Gibson, 1983) and experience (Karana, 2009).

During the 2017 session, each group looked for different structural concepts relevant to bamboo and investigated tensegrity structures, hyperboloid structures, three-dimensional grids, and reciprocal structures. In this process, each of these systems unfolded rich structural, geometrical, mathematical, and material issues for the students to study. At the same time, the students were asked to develop relevant joinery systems by referring to the literature and by testing ideas on real bamboo pieces (see Figure 2). The groups were attracted to different directions. Some looked to connect bamboo poles using strings, others explored the potential of 3D printing to join them, and still others tried to bend the poles into different shapes.

FIGURE 2. Experimenting with bamboo joints, properties, and structural systems. Images: Barak Pelman.

During the 2018 session, where the primary material was tree branches, students looked for joinery techniques based on wood carving. After being exposed to manual and digital tools, they developed interpretations of traditional wooden joints made with contemporary digital-based machinery such as 3D printing and CNC machines (see Figure 3). In both cases, the students merged various learning sources such as textbooks, tutors, and materials with technical experience to construct their own individual knowledge about natural materials, biological and structural properties, and social meaning.

FIGURE 3. Evolution of traditional Japanese joints using manual and digital fabrication techniques. Images: Barak Pelman.

**Stage 2: Design proposals**

During stage 2, between four and six groups of students were asked to develop proposals for the entrance pavilion. For the design-selection process, students were asked to build 1:10 scaled models, a 1:1 joint prototype, and a digital model. In addition, they were asked to present a structural scheme, a site analysis, a budget plan, and fabrication and assembly strategies.

The students worked parallel on both digital and physical models, where each model type acted as a different learning agent. The physical 1:1 scaled models were made of real branches or bamboo poles such as those allocated for the final construction. This decision allowed them to learn about the performance of the joints themselves. Building 1:10 physical models helped them *experience* the behaviour of the whole structure, including its ability to move and its shading and sunlight interactions. The digital models allowed for *simulating and visualising* potential structural and environmental behaviour. Digital simulations provided quantitative information driven by mathematical models (see Figure 4). Physical models, in contrast, could only produce qualitative information about structural and environmental behaviour. Combining the different types of models thus enabled the students to construct a fuller understanding of their designs.

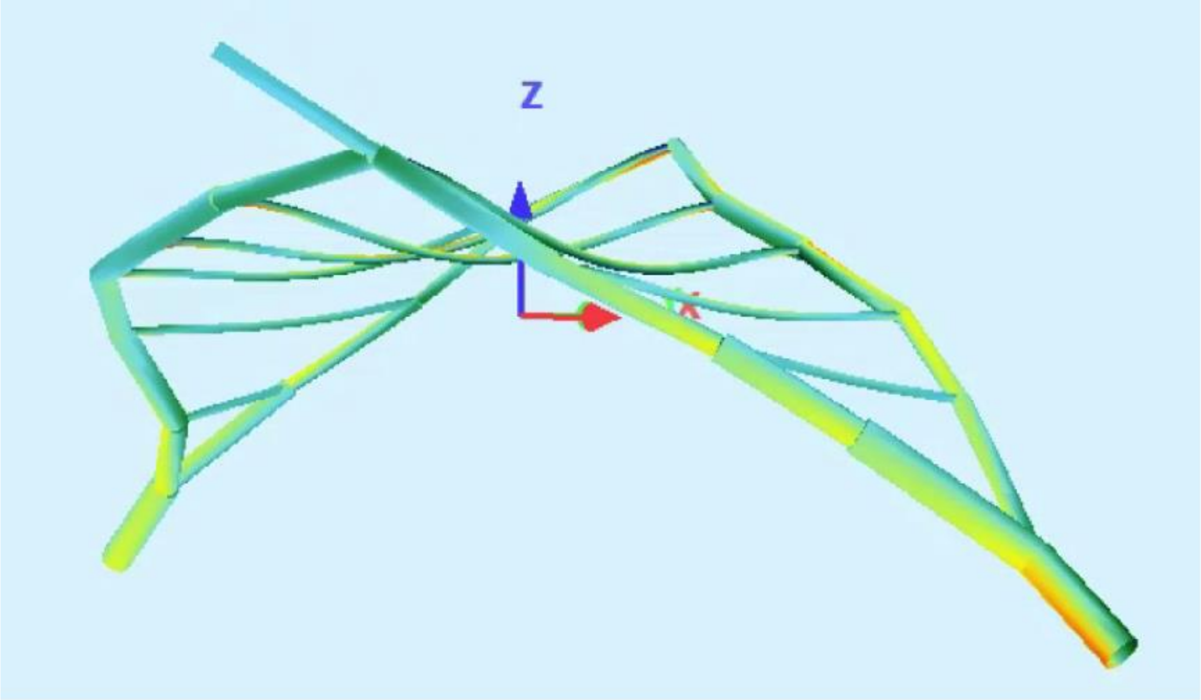


FIGURE 4. Structural simulation of the wind's effect. The colours represent internal and latent forces such as compression tension and moments. Prospective deformation is characterised by the material's distortion in shape. Simulation software: SofisTik. Image: screenshot taken by Barak Pelman.

The representation techniques were also affected by the materials' properties. While representing standard (or nearly standard) materials such as bamboo can be done simply by copying their dimensional characteristics into the software and rebuilding their shape digitally, representing materials with complex geometries, such as tree branches, is a more complicated task that requires advanced 3D-scanning techniques (see Figure 5).

The singularity of each tree branch led the students to develop a whole new design approach. As opposed to mainstream design techniques that rely on standard materials, this approach coupled the design with the specific materials at hand: each branch was indexed, its precise geometry was digitally scanned, its texture was mapped, its structural strength was estimated, and its biological deterioration was observed. The design proposals thus relied on specific branches that would be difficult to replace if they disappeared or broke.

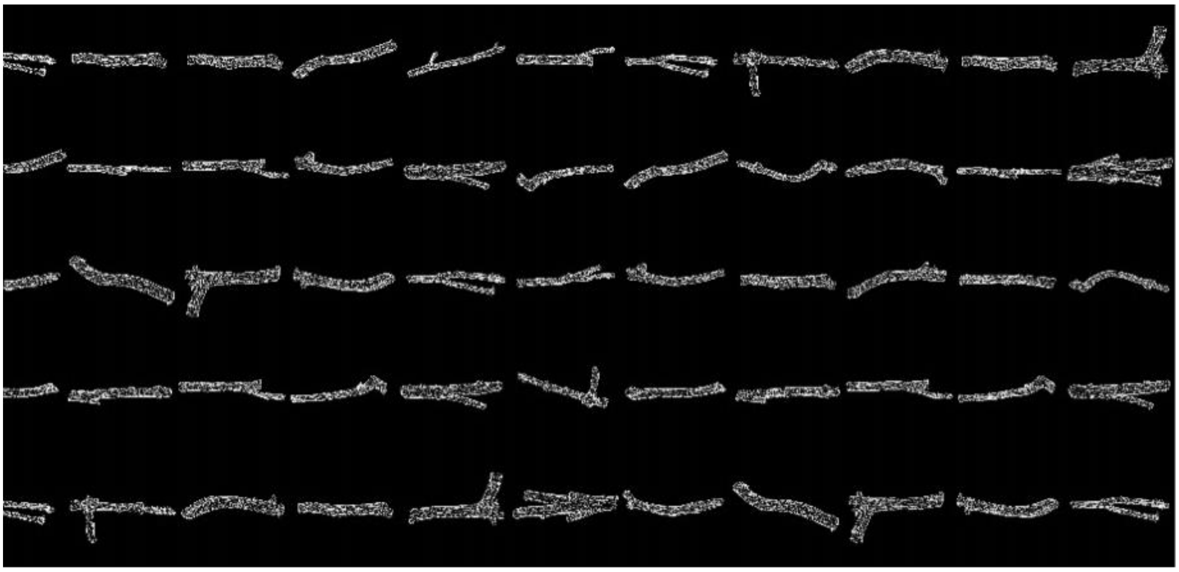


FIGURE 5. Digital representation of complex tree branch shapes using 3D scanning. Image: Barak Pelman.

### Stage 3: Design development and fabrication

In this stage, students developed joinery systems while building the final pavilion. In addition, they had to comply with safety regulations, develop assembly strategies, and manage the site, material flow, and construction finances. The process of developing the joints was reiterated through drafting, prototyping, testing, and drafting again, followed by the fabrication and assembly of the pavilion part by part. The incremental building process was conceived as yet another way to understand the contribution of each piece in relation to the overall design. During the design process, the students could compare both the performance of the pavilion with the results of the digital simulations they had conducted previously and their experience of the constructed pavilion with their expectations. This exercise enabled the students to reflect on any gaps between representation, simulation, and experience.

In the case of the bamboo pavilion, we needed to return the bamboo poles to the vendor in a commercially useable state once the pavilion had been disassembled. The students thus needed to develop joinery systems that would not harm or penetrate the bamboo, which they achieved by 1) designing ‘lashing joints’ (used for the grid-roof) and learning to use tensile ropes to brace the bamboo poles together, 2) developing moving joints that used ropes and Velcro-style tape to allow the hanging bamboo to move freely with the wind, and 3) developing clipping joints that joined four poles in such a way that they worked as one constructive column (see Figure 6). These joints were 3D-printed with the exact dimensions of the specific poles from each column. This design required an extensive investigation into 3D-printing techniques, the elasticity of printable materials, and the stability and strength of different printing patterns. This scenario helps to explain how the need to maintain the bamboo poles’ social value (i.e. their commercial state) affected the students’ learning processes and achievements.

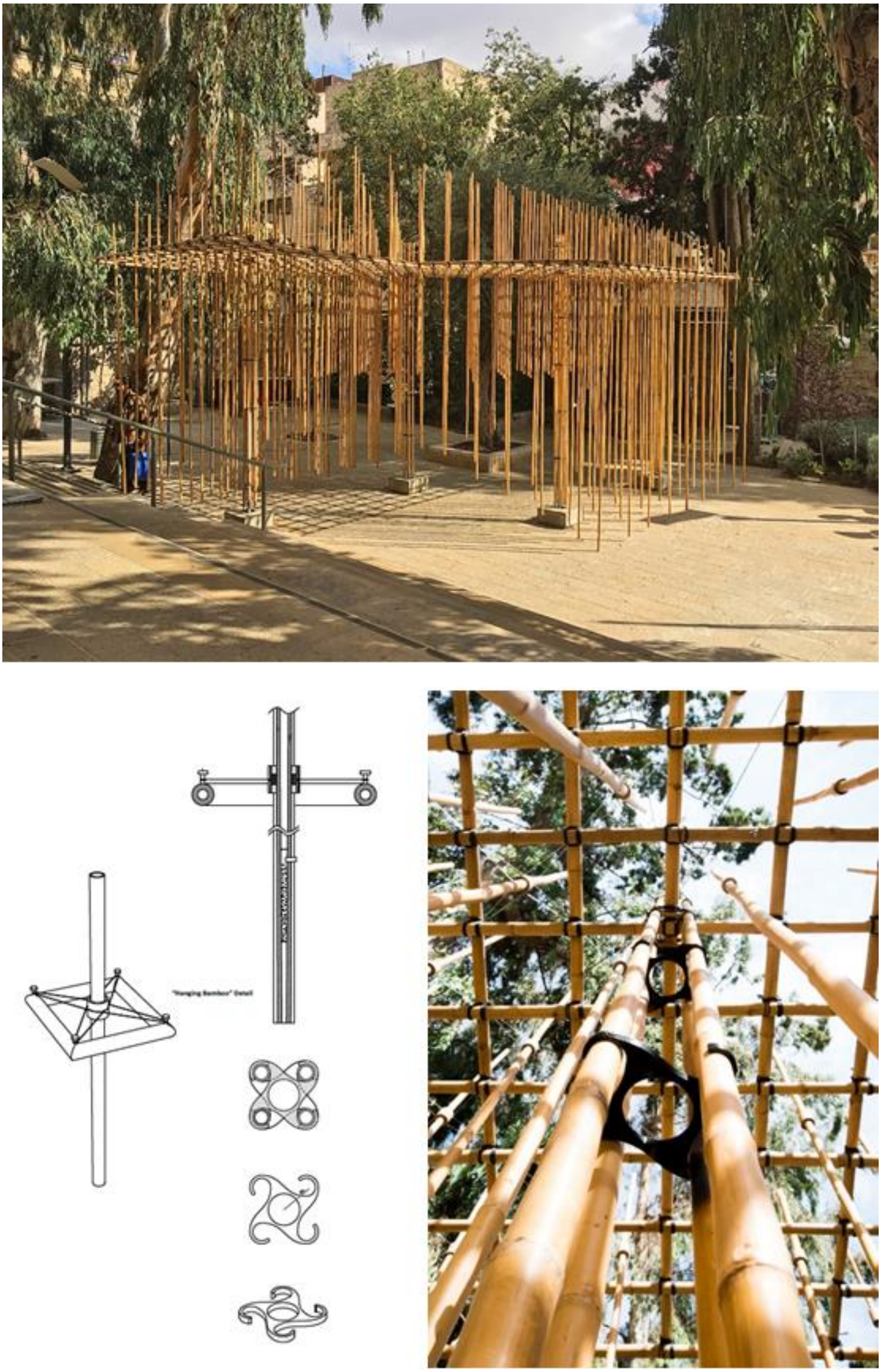


FIGURE 6. The final bamboo pavilion with joint details. Sources: top image: Barak Pelman; lower image: Yifat Zailer (reproduced with permission); drawings: course students.

In the case of the tree branches pavilion, the variations in the shapes of the tree branches did not allow for a design of a standard joint system. Since each branch was unique in terms of both shape and character, the students were directed to design a joint that could be automatically adjusted according to the unique shapes of the branches. Because it was very difficult (or even impossible) to carve each unique joint with its slight variations using simple hand tools, they included a seven-axis robotic arm in the process (see Figure 7).

The group designed a semi-automated fabrication process that involved multiple human and non-human agents. Each agent channelled, transformed, and exchanged information with other agents. Digital 3D scanners were used to sample geometrical information from the physical branches; computer codes were used to simplify the data and extract the diameters from three sections to adjust the joints' geometry. The updated geometry was then translated to a set of tool-paths that were uploaded to the robotic arm software. The robotic arm was used to carve the branches, leaving the marks of the designed tool-path. The students then evaluated the carved branches – now coded with specific information that allowed the branches to be placed only in their designated place on the pavilion – and joined them on-site. If necessary, the students adjusted the branches using simple hand tools. The resulting knowledge was thus the product of multiple translations of information within a complex network of human and non-human agents. Figure 8 shows the final pavilion.

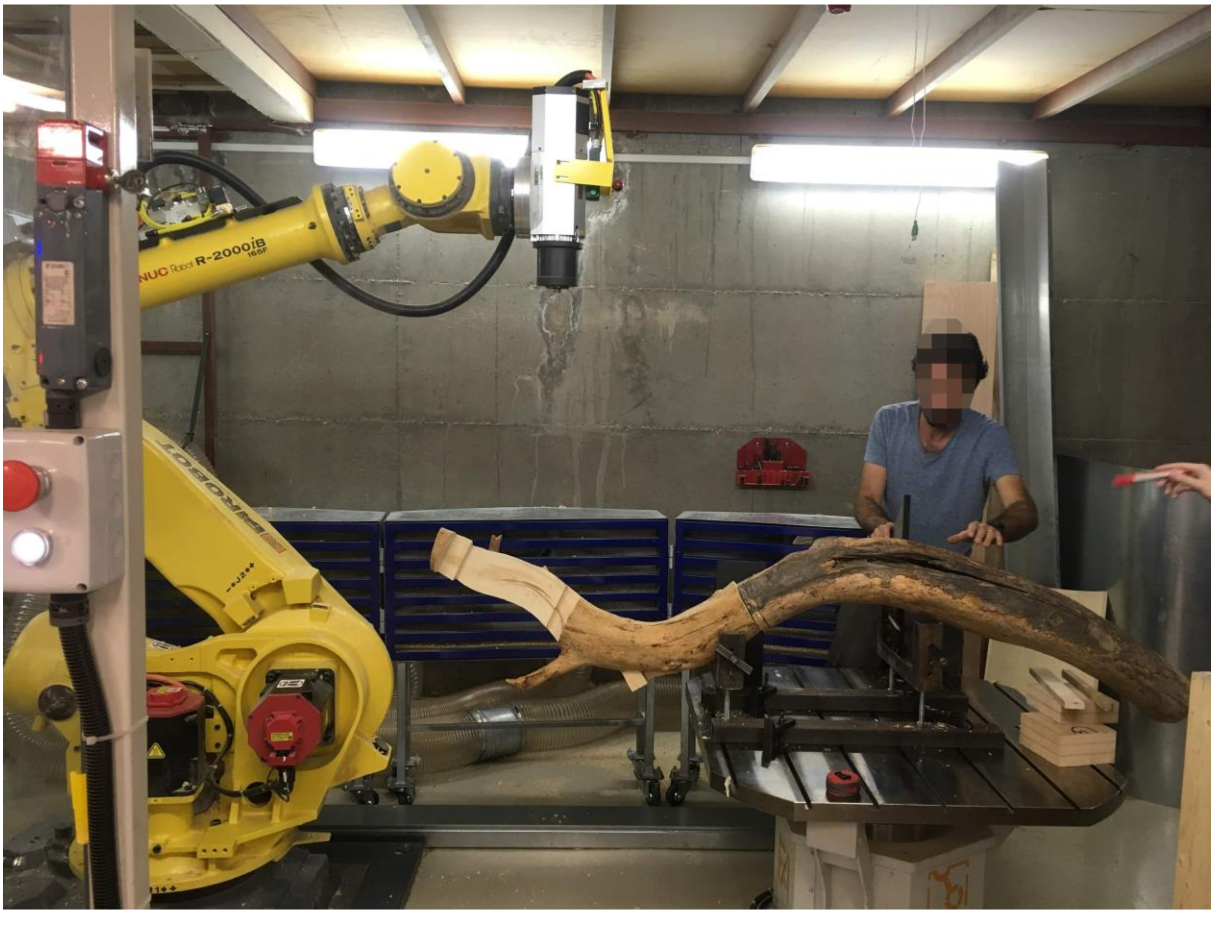


**FIGURE 7.** Working with the robotic arm. Image: Barak Pelman.

FIGURE 8. The final tree branches pavilion. Image: Yifat Zailer (reproduced with permission).

## CONCLUSIONS

From a historical perspective, the divorce of architectural education from materials and building processes is a relatively new trend. The last few decades have witnessed a growing movement of architectural writers, practitioners, and educators who have opposed this trend and have called attention to the importance of hands-on engagement with materials and fabrication processes in architecture education. Lately, this movement has gained support from new orientations in educational research in which learning processes are viewed as sociomaterial practices. Placed within this discourse, this study explores how materials and material experiences influence architectural teaching and learning. To do this, we analysed the learning processes of two designbuild studio courses, which differed mainly by the students themselves and by the predominant materials used in their designbuild processes.

During both courses, learning processes were driven by an open-ended 'design problem' (in this case, a design brief), which was to design an entrance pavilion to the architecture department's courtyard. This overreaching design problem was broken down into many smaller ones that could be approached in numerous ways. The students were thus encouraged to chart their own journeys towards developing their design solutions. These journeys provided ample learning opportunities that then opened to the students as they interacted with the elements that made up their learning environments. From a sociomaterial point of view, these elements can be seen as a network of learning agents.

In this study, several types of learning agents were reported to affect students' learning, including social agents (their fellow students, their teacher, and other experts), material agents (construction sites, classroom walls, building and modelling materials, architectural and structural models), technological agents (fabrication technologies such as 3D printers, CNC milling, simulation and modelling software), regulation (safety and structural), and financial and institutional agents (economic considerations and institutional holidays). Researchers have also recognised some of these agents in earlier studies (Corazzo, 2019; Hasling, 2015; Nottingham, 2017; Orlikowski, 2007), although very few empirical studies to date have addressed the nature of learning-agent networks in a design-education context.

We found that learning agents could interact not only with the students but also with themselves. In both pavilions, different pieces of software exchanged information in the process of digital joint carving and 3D joint printing. In each exchange, the data was translated, re-formatted, and re-designed and therefore presented a different affordance of design and learning opportunities. In both cases, materials acted as important learning agents, creating learning opportunities in both direct and indirect ways. They re-framed design problems and provided ample learning opportunities for specific structural schemes, joinery techniques, management tactics, and representation and fabrication technologies. Material engagement also affected the students' *learning journeys* as one learning subject led to another and new design decisions created further learning challenges. Materials not only created learning opportunities but also contributed to learning by eliciting curiosity and motivation and were able to add environmental values into the design intentions. Figure 9 sketches the learning process described above.

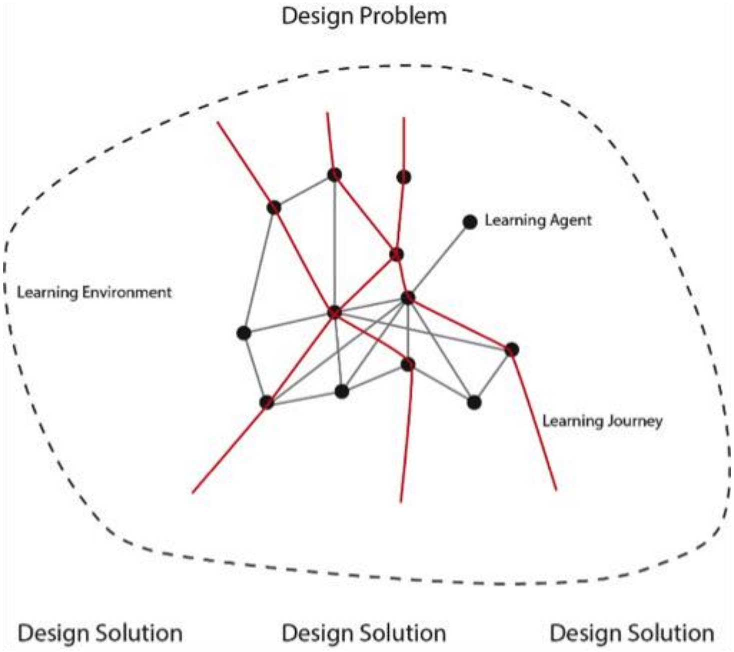


**FIGURE 9**. The designbuild learning model. Source: Barak Pelman.

In his seminal work *Educating the Reflective Practitioner*, Donald Schön (1987) describes the role of the architectural educator as a figure who designs architectural briefs and engages with students in processes of reflection. The designbuild pedagogical model emphasises another vital role, which is to design learning environments for students' learning journeys. By using the model discussed above, introducing materials, allowing access to technologies, and considering space characteristics, architecture educators can utilise learning-agent networks to enlarge the span and varieties of learning opportunities available for their students.

In summary, in this study we have aimed to find evidence that material experiences have agency on architectural teaching and learning. We followed two designbuild courses, analysed the students' personal learning dairies, and contextualised the analysis with the teacher's pedagogical reflections. We found correlations between specific materials' properties and specific knowledge, skills, and technological competencies and demonstrated how materials could be used as 'learning agents' in an architectural-education setting. In addition, we found evidence that student engagement with materials opened up new learning opportunities, affected their learning journeys, and contributed to better learning conditions. Material experiences also affected environmental-design values and contributed to creative design processes and innovative problem-solving. We also showed how materials could act in the broader network of human and non-human learning agents and sketched a new teaching and learning model that emphasises the importance of this network in architectural-education design. We believe that this model will open new directions for future research on the ways in which complex learning-agent networks can be used to construct design and architectural knowledge.

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