An investigation into the effectiveness of student-led experiential learning for UG architects and the implications of incorporating AR into such pedagogical exercises

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Abstract. This paper focuses on a collaboration between three researchers from two universities in Zhejiang province to explore the pedagogical value of hands-on experiential learning using non-standard materials (in this case, bamboo). The second aim of the project was to explore how Augmented Reality (AR) might be used to improve the efficiency of the learning process for the participants. As a building project, the outcome was largely successful- the undergraduate (UG) student participants were able to construct a 4-metre-tall bamboo structure in the summer of 2020, using active bending, from a 3D computer model, within the timeframe. They were given complete autonomy as part of the project which resulted in problems but also arguably improved the learner autonomy and problem-solving abilities of the respondents over the timeframe. Concerning the use of AR in such projects, this researched identified the value for this purpose but also some very major obstacles, including cost and complexity.

1. Introduction

This paper will focus on the process of a student bamboo-building field trip. The stated goals of the exercise were to design and build a sitting pod to fit in a 3x3 metre footprint. The academics/tutors responsible for overseeing the project were Mia A. Tedjosaputro (University of Nottingham, Ningbo, China; Ningbo University- UNNC), Weishun Xu (Zhejiang University), and Matt Wallwork (UNNC). The 11 students in attendance were comprised of nine Zhejiang University Architecture undergraduate students from various years, and the two UNNC students were preliminary year. There were essentially two main components of the exercise- computational design using Rhino 3D and Grasshopper plugin, and Fologram on site, and the practical aspects of the construction itself. The process of computational design and active bending using non-standard materials have been covered separately by Yang and Xu [1] and this paper focuses therefore on the pedagogical implications for students after the design process, highlighting the main issues encountered when applying non-traditional building techniques- in this case, meaning computational design- to this non-standard material, and also gathering early indications of the use of AR in architecture pedagogy from first person experience. It follows the structure outlined thus: methodology, findings, discussion and conclusion incorporating recommendations.
2. Research method

2.1. Overview

Since the exercise was largely a pedagogical experiment, the research focused on the learning outcomes of the exercise rather than on trying to produce a ground-breaking design. These learning outcomes were 1) to successfully achieve the build from the 3D computational model within the timeframe; 2) to negotiate and collaborate throughout the exercise to achieve this aim without external direction (from the tutors); 3) to have experienced hands-on the technique of active bending with this non-standard material; and 4) to evaluate the use of AR in the initial visualisation process. The general focus was thus a hybrid of design and structural exploration for the students.

The use of active bending etc. has not been well explored in literature- with a few notable exceptions, such as Crolla & Fingrut [2] with regards to computational/ parametric design, but as mentioned above, this was addressed in a separate paper by Yang and Xu [1]. Bamboo was selected as the material for several reasons: It is a sustainable resource; it is plentiful in Zhejiang province where the exercise took place, simplifying logistics; and it does not require special equipment to work with, having been used as a building material in Asia for millennia.

It also complemented modules taught at UNNC focusing on sustainable architecture. The brief, after the design stage, was for the students to work from the 3D model (generated using Rhino 3D and Grasshopper; active bending was simulated in Kangaroo) using the available tools and materials and complete the structure. Day 1 involved travel to Siming (the bamboo forest area), taking stock of tools, a safety briefing for the tools to be used, making a sample bamboo arc using active bending to get a feel for the material, assigning groups, and a site analysis. Days 2-5 incorporated the actual building process. Data was collected from the students using Google Docs.

![Figure 1. The almost-completed structure.](image)

2.2. Rationale

Hands-on, or experiential learning, has been propounded by several notable scholars including Dewey [3] in his work on lifelong learning, and Kolb [4]. In the case of construction using non-standard materials this certainly has merit. Little and Dam [5] report that learner autonomy has been “central to the Council of Europe’s thinking about language teaching since 1979” and learner autonomy in all fields is now generally accepted to be something that should be promoted- as per the recommendations of King [6] who first coined the phrase “from sage on the stage to guide on the side.”

This is particularly germane in the Chinese context as Hua, Harris and Ollin (2011; cited in Machin, Richardson and Ryan [7] ) argue that some Chinese educators believe the erosion of Confucian educational values- in this case, the teacher-centric approach popular in China- are a negative influence.
Salama [8] provides a snapshot of the historical accounts and argues that in-depth examination of the method of architectural education is much needed as the discourse needs to be updated. His book aimed to re-examine traditional approaches and identify an approach which integrates active, experiential (as outlined above) and inquiry-based learning strategies.

Active learning, as opposed to passive learning, is deemed to be more suitable to apply higher-level skills such as ‘apply’, ‘analyse’, and ‘evaluate’ in Bloom’s Taxonomy; according to Gifkins [9]. Inquiry-based learning is concerned with learner autonomy and this was facilitated as far as was practical by the “hands-off” approach of the tutors—once the students had received the brief and safety training, they were given complete autocracy (with mixed success, as will be discussed later). This merely provides historical context; the salient point being that the (entirely domestic Chinese) student cohort involved in this activity have been raised in an educational environment very different from the learner-centric paradigm promoted at UNNC. Therefore, the students were given complete autonomy after the first day to assign their own teams and work allocations, with the aim of establishing the effectiveness of this approach.

There is a gap in research related to the use of Augmented Reality. This is a relatively new field in education. It is currently being addressed at UNNC with the V-Room (Virtual Classroom) project, but in many educational institutions is still in its infancy. As mentioned previously, one of the authors used Fologram (on a laptop computer and mobile phone, not an AR headset) but only for the purpose of visualising the structure in various locations to select the site. The students were involved in this process and were asked to consider, during the course of the project, how AR might benefit future building projects.

2.3. Research questions
The aims of this exercise, as described above, were manifold. The authors wanted to discover if active bending from computational designs was possible for students on-site. They also wanted to discover what was valuable from this hands-on, autonomous approach; and what needed to be improved. To this end, two research questions are posited: What is the role of non-standard materials in hands-on architectural pedagogy? How can augmented reality be used to minimise the information gap between 3d models and real site situation?

2.4. Research instruments
As mentioned in 2.1, Google Docs was used for data collection. To answer the first question, the students themselves were asked to evaluate the effectiveness of the project. There were two questions on the form related to the use of AR, the first was a closed question asking if the respondents considered that AR would be useful, and the second an open question to collect qualitative data. The questions are given below:

1. Overall experience: Poor/Fair/Satisfactory/Very good/Excellent
2. What did you like the most about this experience?
3. What did you dislike about this experience?
4. Did the team work well, in your opinion?
5. What is your opinion of bamboo architecture? Has it changed compared to before you joined this building exercise?
6. As bamboo is a non-standard material (tapered at the end, varied diameter); how did you think the team coped with it?
7. What do you think about the use of computational design in bamboo architecture?
8. Specify at least three notable problems which occurred during the construction process, based on your observations. And how did the team mitigate the issues?
9. Do you think there is potential use of augmented reality in bamboo architecture? If you think it is a YES, Please elaborate in next question.
10. Elaborate how augmented reality might improve bamboo architecture, although it might be hypothetical. Any suggestions please leave them in ‘Others’ section.
11. Contribution to learning architecture:
   o Construction skill
   o Project management skill
   o Collaboration skill
12. Would you do this bamboo building exercise again?
13. How would you improve this experience?

Figure 3. Application of the skin.

3. Findings
This section will list the responses from students to the questionnaire, to inform the answers to the research questions in the following section. Questions 1-8 and 11-13 relate to the first research question - *What is the role of non-standard materials in hands-on architectural pedagogy?* - while questions 9 and 10 suggest answers to the second research question (*How can augmented reality be used to minimise the information gap between 3d models and real site situation?*) For simplicity, the closed questions (1,2,4,6,9,10,11&12) are represented here by the graphical depictions generated by Google Docs-excluding questions 4, 9 and 12- as the data was less complex.

Figure 4 indicates that at a macro level, the students considered the exercise to be a valuable experience. Figure 5 expands on this with more focused detail- as can be seen, the experiential aspect was more highly valued than the computational design. This not unexpected as computational design does not require a prolonged on-site experience. Question 4 simply reported 100% agreement that the team worked well together.
Figure 4. Question 1.

Overall experience

What is your overall experience of this bamboo building exercise?

- Poor
- Fair
- Satisfactory
- Very good
- Excellent

Figure 5. Question 2.

What did you like the most about this experience?

- Exploring computational design: 3 (37.5%)
- Working with bamboo: 8 (100%)
- Hands-on architecture making experience: 8 (100%)
- Collaboration with other team members: 8 (100%)
- Student-led experience: 6 (75%)

Figure 6. Question 6.

As bamboo is a non-standard material (tapered at the end, varied diameter): how did you think the team coped with it?

- 0 (0%)
- 1 (12.5%)
- 4 (50%)
- 3 (37.5%)
- 0 (0%)
Figure 6 shows an interesting distribution of responses indicating weak agreement that the teams overcame the issues of the non-standard nature of bamboo. Question 9 again reported 100% agreement that bamboo architecture would potentially benefit from the use of AR.

![Figure 7. Question 10.](image)

Question 10 (Figure 7) collected detail about the ways in which AR might be useful in improving bamboo architecture, with improving construction accuracy being cited as the greatest potential benefit. Visualisation scored lower, perhaps due to the fact that the students at this stage had not used AR headsets for this purpose, as discussed below in section 4.

![Figure 8. Question 11.](image)

Question 11 reiterated the value of this type of activity for pedagogical purposes, with most areas scoring highly. Question 12 demonstrated that only one respondent would not consider participating in this type of activity again, though the reason for this was not given.

For the remaining, open-ended questions, the relevant responses are summarised here. For question 3, what students disliked, there was nothing related to the parameters of the exercise itself- responses were generally related to the hot weather and other variables extraneous to the focus of this paper. For question 5- opinions of bamboo architecture- most answers related to the scale and texture of the material. One respondent noted the environmentally friendly aspect while another noted “the error between the computational model […] and the real one[…]” which in part contributes to answering research question 2. For question 7, relating to opinions about computational design, all participants
without exception acknowledged the value of the digital 3D model but all also identified that due to the non-standard nature of bamboo, significant flexibility was required during the construction process with substantial deviation from the plan at times. For question 8- notable problems- these were divided among practical concerns relating to the weather and other difficulties related to the construction process itself, but three respondents again noted that deviation from the computational model was a significant issue. There were also comments about the team dynamics in the groups and this may be related to the expectations concerning learner autonomy, as will be discussed in the following section. The final question about improvements to the experience generated only four responses relating to avoiding the heat during the project and are thus not relevant to the research questions posited above.

4. Discussion

Though there were only eight questionnaire respondents, the data generated from the responses is nonetheless informative. Regarding the first research question- What is the role of non-standard materials in hands-on architectural pedagogy? – it is clear that this experiment was a valuable exercise and generally received very favourably by the participants. The comments surrounding the sustainability of bamboo indicate that this task was successful in raising awareness of sustainability issues but the answer to the research question can be posited from the comments in response to questions 5, 8 and 13. The students had used bamboo in previous activities during their studies but only for making small-scale models- this was their first time working on an actual 1:1 scale project. Several of the students noted the difference between model making- where the specifications of the material can be more rigorously controlled- and actual construction, where the properties of the bamboo sometimes deviated so significantly from spec that real-time modifications to the design were necessary. This is also germane to the second research question, as will be discussed later. They had complete autonomy regarding such design changes. One respondent noted that there was a problem that the groups were unable to resolve- described as “rough joint design solution.” The techniques for creating joints sufficiently strong to withstand the forces of the bamboo under active bending were not adequately refined. However, although this was only intended to be temporary structure for educational purposes, it was dismantled by two of the organisers over six months later, so the joints proved to be sufficiently durable to withstand a summer with 40 degree centigrade heat and rain followed by winter of mountain weather.

Regarding the amount of autonomy the students had to perform the task, this aspect was much more divisive. Several students noted that selection of the teams was problematic, as some students were less motivated and self-directed than others, despite having two nominated team leaders directing the activities. One student went as far as to say in response to question 8 that “…all the guys deciding on one problem is not useful as opinions may diverse. Only limited guys deciding and others working is more under control.” This was only explicitly stated in one response but it did appear to be a majority sentiment based on informal discussions with the participants. The reasons for this are largely speculative and outside the scope of this research question, but may be related to the hierarchical nation prevalent throughout Confucian Chinese culture, as noted in section 2.1.1 in the discussion of Chinese pedagogical values. Question 13 did not generate any meaningful data regarding improving the experience so is not discussed here. In terms of the posited research question concerning the role of non-standard materials in activities of this sort, it is apparent that this type of activity is very valuable in that it promotes learner autonomy (though with mixed success in some cases), it encourages flexibility in the area of problem-solving, and it promotes awareness (in the case of bamboo, and almost certainly in that of other non-standard materials, many of which are naturally occurring and renewable) of sustainability which is a key concept in architecture, and which is becoming increasingly important in the face of modern problems in architecture.

Concerning the second research question- How can augmented reality be used to minimise the information gap between 3D models and real site situation? – less data is available but there is enough to tentatively answer this question. Question 7 in the survey attempts to collect opinions about the value of computational design in bamboo architecture. As noted earlier, the responses to some of the problems encountered by the use of such a non-standard material suggest that although computational design is
useful as a guide, the process must be sufficiently flexible to allow response in real time to problems arising. Examples include constructing the joints as described previously, the fact that different samples of bamboo had varying flexibility and strength so the bending process was not always predictable, and material defects such as warping and splitting. Careful selection of materials may mitigate these problems to some extent but it cannot be completely eliminated for practical purposes. Computational design forms the underpinnings of augmented reality, which accounts for the significance of these questions. Question 9 ascertained that all of the respondents felt that there is value in the use of AR in bamboo architecture, and question 10 suggested ways in which this might be the case. It also asked for further suggestions not described in the closed questions but no respondents suggested anything further. Aiding collaboration was viewed as the least useful potential characteristic, which is perhaps unsurprising given what has been discussed above about teamwork. It is likely that the respondents were not aware of the possibilities for collaborative design, which is understandable given their limited exposure to this technology. This does however suggest a gap which needs to be addressed in future iterations of this architecture course since this collaboration incorporating new technologies is certainly the future direction of architectural practice.

What is more positive is that most respondents recognised the potential of AR for facilitating the design process and improving visualisation, with five of the eight respondents noting these aspects. The area which saw the greatest agreement however is in improving the accuracy of the construction process with seven of the eight respondents identifying this as a significant advantage. This is particularly interesting as it appears to contradict their anecdotal observations about the gap between computational design and actual on-site construction using non-standard materials. This paradox certainly suggests that further research is required in this area. It is tentatively posited here that the respondents, being unfamiliar with the use of AR technology, have not considered the possible applications and this is certainly borne out by the lack of responses in the open-ended comment which was available to complete for question 10. The respondents were very willing to contribute to this questionnaire and their other responses to the open-ended questions were rich, detailed and frank. Based on the above, a tentative answer to the second research question can now be suggested. It seems that with more research, it might be possible to use AR to improve construction accuracy, but the exact mechanism by which this could be achieved is as yet unclear. This is certainly the area the respondents felt had the greatest potential. With revisions to the architecture course to incorporate this technology at an earlier stage, so students have a better understanding of the fundamentals, and visualisation- another area they felt might be beneficial- could certainly be better accomplished through the use of AR. The students generally reported that seeing the digital model on Fologram superimposed onto the site in real time gave them an idea of the scale and proportion of their project in a way that was less disconnected than seeing the model in isolation (with no environmental perspective) on a computer screen. For this activity, Fologram was used on a laptop- the researchers did not take an AR headset on this occasion- but the use of the HoloLens or similar headset would almost certainly result in a more immersive experience.

Reference to the learning outcomes (outlined in 2.1) reveals that the task was completed successfully (LO1), the collaborative process was viewed by the students as partially successful (LO2), the experience of using non-standard materials was again partially successful (as revealed by Q6- LO3), and LO4- the use of AR- was felt by the students to have great potential, as outlined above. What can be inferred from this is that as initially posited by the researchers, students had some difficulty in adapting to the autonomous learning style championed in the literature. It also highlights some potential issues with regard to the hands-on practice using non-standard materials, and this is possibly something that could be addressed at an earlier stage in the students’ education since, as mentioned earlier, the majority of the students were in year 4 of their BArch programme.

5. Conclusion and recommendations
The research questions were answered largely satisfactorily but there is certainly scope for more research in this area. The construction project itself was generally very successful and certainly indicates the value of experiential learning using non-standard materials, particularly from the perspective of
encouraging learner autonomy and problem-solving skills. The area in which the researchers are less satisfied is in the role of AR to improve the learning experience. These early findings suggest that there is certainly a place for AR, the question really concerns the optimum way to implement this. Using AR with bamboo is not novel— it has been used for example to scan bamboo poles to feed into 3D design [10], but so far does not appear to have been used to scan battens in the way that the bamboo was used in this particular project (as poles would not have worked for the active bending concept). There are practical considerations regarding the use of AR also. V-Room is currently focused largely on coding, using Unity (a game graphics engine) as the coding platform, and this is extremely labour-intensive. It is also an extremely steep learning curve for the students involved in the project and the output thus far has largely been relatively simple virtual environments, such as classrooms, and the level of complexity required for 3D architectural models is yet to be achieved. There are GUI-based platforms available now which reduce the demand for the hundreds of hours of manual coding per project, and when they are sufficiently mature, they may present a viable option. The hardware requirements for a fully immersive experience are commercially available, but the headsets are expensive— a Microsoft HoloLens 2retails for $3500 (USD) MSRP at the time of writing, and it is impractical to purchase 50 sets for an entire student cohort. The option exists to use Fologram or similar software running on a phone, tablet, laptop or other mobile computing device but the experience afforded is more limited and less immersive, which may lead to reduced effectiveness.

Future research plans are thus indicated as follows. In response to the first research question, only minor changes based on participant feedback are required, so the focus of future research is on the AR aspect in response to research question 2. However, future projects are planned to incorporate other natural/ non-standard materials, with possibly a more permanent and purpose specific structure as the brief— a post-earthquake shelter design has been mooted, which should be easy to replicate and able to withstand tough conditions over a longer timeframe. The researchers have access to a limited number of HoloLens headsets, and these will be incorporated into a future project. The greater issue is that of the software used for the AR visualisations. It is planned to either find and modify an existing open-source coding platform to use bamboo battens, or in extremis to code an app from scratch.

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