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# A USER STUDY FOR FACILITATING EFFECTIVE REMOTE EDUCATION IN DESIGN STUDIOS: TOWARDS INTEGRATION OF CYBER-PHYSICAL TECHNOLOGIES INTO DESIGN EDUCATION

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## ABSTRACT
As remote learning in design studios becomes ubiquitous, it is important to reflect on this shift and structure our path towards effective online learning. Taking an architectural studio as a case study, we held several interviews with students and instructors, and extracted essential user needs which we would do well to address in an online setting. Existing learning environments were then compared in their abilities to fulfil such needs, and thus facilitate effective teaching and learning. The contribution of this study is a new perspective on studio-education which exposes gaps between user-needs and the current online setting, which may be bridged by emerging cyber-physical technologies (CPTs), such as augmented reality (AR) etc. Our findings can inform the future development of CPTs for studio education, and thus aid to maintain the positive aspects of traditional practices, when shifting to a remote setting.

*Keywords: Remote learning, future of design education, project-based learning, cyber-physical technologies*

## 1 INTRODUCTION
One important lesson from COVID-19 is that, as design educators, we ought to take distance learning very seriously. The difficulty of co-inhabiting physical spaces has imposed a challenging situation, which demands adapting our traditional practices to the available remote communication tools. As design education relies on discursive methods, effective communication is essential for training future generations of designers. Evidently, design studios (which serve as the core of design curriculums worldwide, regardless of a specific discipline) commonly take a project-based learning approach - students are presented with a design problem, attempt to tackle it by generating various design solutions and continuously improve them based on instructor feedback. In face-to-face instruction, this activity takes the form of a multifaceted real-time interaction between students, instructors, and design representations (i.e., models, sketches etc.). Such rich interaction is difficult to facilitate with existing remote communication tools. A clear example for this would be their inability to fully capture the richness involved in human gestures, which are an essential form of non-verbal communication.
A major technological candidate for facilitating high-quality remote education is the class of cyber-physical technologies (CPTs, e.g., augmented reality). Considering the expected increase in the usage of collaborative computing, CPTs can potentially revolutionize the way we teach and learn to design. Since both instructors and students may be viewed as the end users of these technologies, an important task is to identify their user-needs, which may be served via the future development of CPTs.

### 1.1 Aim and objectives
Considering the current ubiquity of remote learning (brought upon us by recent world events), we believe that it is essential to build effective remote learning environments for design education. Thus, we aim to support their development, by clarifying the needs of their users.
This study focuses on an architectural design studio (ADS), as a case study. Our main objective is to identify key user needs which characterize traditional studio education (i.e., in a physical setting), which

current remote learning environments (e.g., Zoom, Skype etc.) fail to cater to. To do so, we conduct in depth interviews with expert studio instructors and their students, in the context of an ADS. In this work, we conducted a total of six interviews with instructors and students at a major technological university in Japan.

### 1.2 Significance

The study proposes concrete insights into the needs of instructors and students of design studios, as the end users of emerging technologies which increasingly facilitate our educational practices. These insights are valuable both for technologist (as they can inform the future development of remote-learning platforms for design education) and for educators (as a way to reflect on the core aspects of traditional practices which should be considered when adapting to the new technological reality).

## 2 BACKGROUNDS

The recent pandemic had laid a harsh blow on architectural design learners and educators. Educating students in a spatial discipline by relying on flat displays is clearly a challenge. Yet, ADSs are more than physical spaces for spatial model-making. It is a place in which unique learning cultures develop. Acknowledging that we cannot hold on to the studio of the past [1], where do we go from here?

While the shift to online learning in ADSs seems rather sudden, researchers have identified the potential of enhancing the traditional studio via remote-communication tools more than a decade ago. Morkel, for example, has conducted a participatory study in which a physical ADS was augmented by remote communication using Facebook [2]. More recently, yet still prior to the pandemic, it has been further suggested that the traditional ADS is lagging behind advances in the professional world of architectural design, and that remote learning should be considered as one potential solution for this [3].

More specifically with respect to CPTs, Recent years show an increase in studies of CPTs and their potential to support design from the perspective of concept generation [4], product visualization [5], thought externalization [6] and more. Brown and Cowling, for instance, have examined mixed reality systems in the context of design education, and have concluded that such tools can be of value in supporting critical thinking and problem solving [7]. These signal a light at the end of the tunnel, thus motivating the development of CPTs for educational practices.

Thus, while the transition to online learning has been inevitable, imposed and rushed, we would do well to carefully consider and thoughtfully design our path for establishing effective long-term remote-learning environments. This study furthers these efforts, by focusing on the needs of users, as reflected in the traditional ADS, which we may need to leave behind.

## 3 METHOD

To identify key user needs in ADSs, a series of interviews was held with studio instructors and learners. Considering that the work with physical models (PMs) is a distinctive feature of the physical studio, the interviews focused on the contribution of such models for teaching and learning in ADSs. In this, we follow Alexander's basic distinction of form vs. context [8], such that models which embody the students' original thoughts or architectural creations are considered as "form", and those which display the physical environment in which the former will be positioned are considered as "context" (see 4).

All interviews were conducted at a major technological university in Japan via a remote communication platform (Zoom). Instructors were assistant professors at minimum, who regularly teach ADSs. Learners were graduate-level students majoring in architecture (Table 1). All interviews were conducted by an expert in human-centred design, who possesses extensive experience in conducting user interviews (over 15 years in the field of service design).

*Table 1. List of interviewees*

| Role | Rank | ADS Teaching Experience | | Role | Rank |
|---|---|---|---|---|---|
| Instructor | Associate Professor | 8 years | | Student | Masters' 3rd year |
| | Assistant Professor | 5 years | | | Masters' 2nd year |
| | Assistant Professor | 3 years | | | Masters' 1st year |

The line of questioning focused on the identification of issues related with the usage of PMs, which may demand attention when shifting to remote learning. Interviews were transcribed live and then revised from audio recordings. The resulting protocols were then used to extract specific user-needs that could potentially be served by future CPTs. The minimal duration of each interview was two hours.

# 4 RESULTS

## 4.1 Physical models as multipurpose tools for simulation and communication

The making of PMs is a traditional practice in (architectural) design studios. The fact that such models are regularly made, despite the time and effort which this demands, implies on their importance for this practice. How do such models contribute to studio education?

First, in ADSs, two basic types of models exist – building models and environment models, and students are often requested to make both. As explained by one interviewee: "We make a model of the surrounding houses and a simple volume model, and then set one's own building on the model to see how big or small it is compared to the surrounding buildings, or to see how the road compresses the building." This comment also reflects a fundamental need which such models serve – being able to visually examine the relationships between the design (form) and its environment (context).

By extension, a second reason for using PMs is the desire to identify strong/weak points of the current design alternative: "When we had a site model made and there was a station of a Yurikamome (train) line, I (the instructor) advised like this: If you put the building you are planning in there, how would it look from the station's side? How does it look when you get closer to a person's line of sight? If you get off at the station and see this building, it looks like a building you wouldn't want to enter". Notice that here the model is used both as a means for visualization of the form and as a means for assuming a specific (and perhaps important) perspective, based on the context.

Another advantage of PMs is that they encourage or even "force" students to develop a concrete understanding of how various parts of the design are related in space. As explained by one of our experts: "…many students think in terms of planes and…It's not clear how the first floor is connected to the second floor. With a physical model, they are forced to think three-dimensionally."

Additionally, instructors have expressed an explicit desire to use the model for exploring various ideas in real-time, for example: "In fact, I would like to crack the model open and say, 'why don't you just split this into two pieces?' But, since they are physically glued together, I am not doing that for the sake of humanity…I feel like tearing up people's drawings....Breaking things would be a little bit is easier if it's not physical. I want to operate it while saying, 'like this'…It would be nice to be able to edit together on the spot, just like when you add a (piece of) code when teaching programming." In other cases, directly manipulating the model is used for instruction regarding specific aspects of the design which demand attention or revision: "Sometimes wildly, I remove parts from the model. When he had a very open atrium space, but had 3-4 stories above it, I asked 'what is the use of this?'. And he had no reason to do so, I took it off…I think it is easier to understand because it is visible. I sometimes add to a sketch of a floor plan. When I want students to change their mind, it's easy to understand visually, isn't it? I do it in a performative way, aiming for impact." Indeed, students utilize such possibilities of real-time simulation by themselves as well: "When I think about the placement of the walls, I think about whether it will be dark here or not, and I shine light on it…it is easy to understand the feeling of openness and so on."

Finally, PMs are important for collaborative reference, and for coordinating our perceptions and perspectives. As a student explained: "If the teacher remarks which view he/she is looking at it from, I would immediately try to look at it from that perspective, and by doing so, I think I can come up with other issues."

## 4.2 Looking beyond physical models

The previous sub-section provided a brief account of the richness of PMs as learning aids in ADSs. However, such models are not without faults. This sub-section introduces some issues which arise when using PMs in an ADS and touches on the possibility of replacing them with digital ones, as attempted in current remote learning environments.

One fundamental issue with using PMs is the fact that they demand space and storage. Consequently, one instructor suggested to replace them with digital representations of the relevant information: "…we cannot use one (environment model) for each person. It is too large...If possible, it would be better if we could superimpose open data such as Google Maps, etc., so that they can be placed in 3D and discussions can have a more realistic feel."

Another limitation of PMs is their capacity for simulation, which is restricted to a basic visualization of light conditions: “Indeed, when a student designs rooms without windows, I can say that this is no good at the stage of building if we have a simulation function (interviewer: What if they could feel how dark it would be?) Yes, that’s useful. I often tell students that, in a building, sunlight comes from the south and the north side becomes darker and shadier. It is good to be able to include such things digitally, and to say that the building will be in shadow due to the surrounding environment.”

While the above issues may be addressed by individually using digital models on a personal computer (e.g., using a CAD system), other issues arise when incorporating these into remote learning. One such issue is the inability of instructors to control their point of view – a matter which is trivial in a physical setting: “…face to face, when a student is explaining, I listen to the explanation and crouch down to look at what I am interested in on my own. Sometimes, when a student is explaining, I look at the place with them; other times, I want to look at it on my own.” To resolve this, instructors must verbally instruct students to set the display on a specific point of view, which often does not yield the desired result, and is time costly as well: “When they start up a 3D model, I often say, ‘Try to rotate it and show it from this side,’ and the student says, ‘Like this? Like this?’ It takes time to get them to move it around.”

Such miscommunication relates with the need to engage in collaborative reference freely and effectively: “It is difficult to communicate only verbally (in an online setting). I want to point the specific part and say, ‘here.’ If I can trace a specific image in my mind with my finger... Just telling them ‘here’ orally is too rough, so I want to write directly on the model.” Another expert phrased this differently, emphasizing the aspect of coordinating attention: “If we can tell students where the faculty members focus their attention and how we look at it (the model), it could be an important point…the current situation is (that we) just tell them in words.”

Finally, unlike digital models, PMs are commonly situated in the physical environment of the studio, which is of importance to the instructional process: “In addition to what the students themselves describe, there are also scattered traces of other models they have made, photos of buildings they refer to and sketches in the face-to-face environment. That is frustrating because we can see only those (sketches etc.) they have prepared.” Such important clues for tracing the students’ thought process and their individual perspective are lost in the transition to an online setting.

### 4.3 An activity-based characterization of working with models in ADS

*Table 2. Activities in ADS and their facilitation in physical/virtual settings*

| **Activity** | **Needs** | | **Facilitation by Learning Environment** | |
|---|---|---|---|---|
| | **Student** | **Instructor** | **Physical** | **Online (current)** |
| Collaborative reference | Signify specific things | | Facilitated (scale-dependent; often ambiguous) | To an even more limited extent than the physical setting |
| | Help the other party keep track of the conversation | | | |
| Manipulate the model | Explore various ideas visually in real-time | | Facilitated (but some teachers hesitate to do so) | One-sided (only one party can manipulate) |
| | - | suggest changes to the design | | |
| Visually examine the model | Visually evaluate the current design from multiple perspectives (bird’s eye views/eye-level views) | | To a limited extent (hard to see interior) | One-sided (only one party controls the view) |
| Point out potential issues | Share concerns and get advice | Raise points that were not considered | Facilitated | Facilitated (depends on collaborative reference) |
| Simulate various aspects of the design | Learn about performance of the design; observe consequences | | To a limited extent (mainly natural light) | Not facilitated |
| Introduce relevant references | Share own’s sources of insp. | Inspire student and expand their view | Partially (printed material nearby) | Facilitated (share webpages etc.) |
| Examine student’s work environment | Trace student’s thought process and understand his/her perspective | | Facilitated (hints scattered on desk) | To a limited extent (if stud. have notes) |

User needs derived from interviews with respect to using spatial models in ADSs were organized in Table 2. We listed the various activities of student-instructor-model interaction and matched them with underlying needs, from the perspective of both parties. Physical/online settings were then evaluated in their ability to facilitate these activities and fulfil the corresponding needs.

# 5 DISCUSSIONS

## 5.1 Reimagining spatial models as design aids

We have seen that the current practices of using either physical or purely digital models in ADSs entail both advantages and disadvantages for learners and instructors. A third alternative may be to use digital models, yet display them using a CPT, thus resulting in what we term a "cyber-physical model" (CPM). Since CPMs are both spatial and non-spatial in some sense, they may enable to reap the benefits of both. Consider the building-mass model presented in Figure 1 below, which was used for real-time light simulation via a CPT, by calculating light conditions at three different hours of the day in Barcelona.

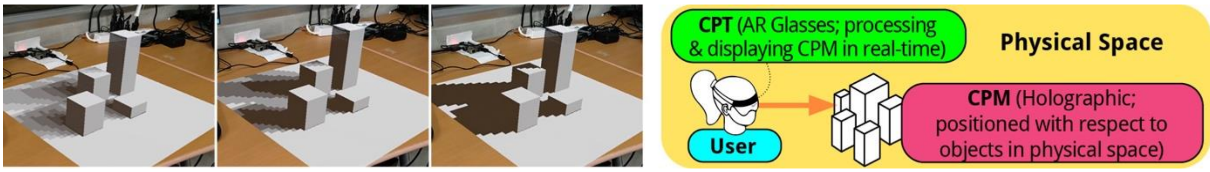


*Figure 1. Real-time light simulation in a CPT viewed via a Microsoft HoloLens 2 headset*

First, note that the model is spatial in the sense that it is viewed as a 3D object in the context of the physical space in which the viewer is found. Yet, it is non-spatial in the sense that it does not consume any physical space. As such, it maintains the spatiality of the physical setting (we can walk around similarly to a PM) and the cost-effectiveness of the digital model in terms of storage space.

Second, given that the model is stored digitally, it is expected that instructors would not fear "touching" students' creations, as they do with PMs. Using CPMs in an ADS may thus result in increased interaction and richer feedback from instructors, enabling students to witness them in-action. Considering the emphasis placed by Schön on the ability to reflect in-action for performing professionally [9], it seems essential that students witness this practice in real-time.

Third, owing to its digital nature, the above CPM shows the possibility of easily simulating light conditions at various times of the day. Should a PM be used for the same task with a lamp, for instance (as done by one our interviewees), the user would be required to calculate the light source's angle according to the building's location etc. This would be both time consuming and imprecise, thus leading to inferior results compared with the CPM. Further, other types of simulation (e.g., usage of escape routes during emergency) are strictly impossible using a PM.

Fourth, recall one instructor's proposal to replace the environment model with a digital representation. Notice that this suggestion not only expresses a desire to save space, but also to increase the level of realism of the discussion, which seemed of importance to the instructor. While making a realistic environment in a PM is extremely costly, both in terms of time and materials (and practically impossible at certain scales), doing so with a CPM would only require drawing on existing data sources and selectively visualizing them. This is not only feasible, but also entails extremely low costs (mostly in terms of electric power) once the CPT-based learning environment is established.

Fifth, one of our students remarked that they find it important to be attentive to the instructor's point of view when he/she examines the model. This is another type of activity which is trivial in a physical space yet is not facilitated by existing remote learning environments. Using a CPM in combination with a live model of the instructor's body posture (potentially in the form of an avatar) could enable the student to replicate it, and thus assume the instructor's current perspective. Furthermore, while in a PM is it impossible for two people to view a single object from the exact same position simultaneously, placing a digital representation of the instructor in the form of a hologram in the student's view would not preclude the student from assuming that specific view.

## 5.2 Towards a cyber-physical design studio

We have identified essential user need in ADSs and examined the ability of current learning environment to facilitate them. Following this, we have pointed out the potential benefits of embracing CPTs in studio education. Such a shift, however, poses significant challenges for learners, instructors, and institutions.

On a basic level, current CPTs are not affordable from the perspective of individuals, and costly from the perspective of institutions. For example, the price of a single augmented reality headset currently ranges between 2000-4000$ USD, depending on the brand and specification. This means that students cannot be expected to purchase these and use them for remote learning from the comfort of their homes. Beyond such practical difficulties, however, lies an even greater challenge – the traditional practice of design studios is strongly tied with the physical space in many ways, which would require a major reconsideration of the educational activity as a whole. In other words, it is essential to look beyond the (important) practice of interacting with models and uncover the deeper values of teaching and learning in physical studios, so that these are not lost when shifting to the cyber-physical setting. An obvious example would be the famous "studio culture" which develops when working in the same space for prolonged periods of time. Such aspects of ADSs are highly valuable for teachers and learners, but extremely difficult to develop and nurture in a remote setting. We conclude the discussion with Brown's hopeful image of ADSs' future: "The question…is how we can liberate our discipline from the assumption that an ill-defined space, time, pedagogy and culture is the only way to teach design. It is an opportunity to reconstruct architecture education in a more critical, inclusive and democratic way" [1]. We hope that, despite the challenges ahead of us, we can capitalize on emerging CPTs to realize this vision.

## 6 CONCLUSIONS

Essential user needs in ADSs were identified and discussed. Current learning environments (physical/virtual) were compared in terms of their ability to facilitate these. Following this, a potential shift to a cyber-physical studio setting and its expected outcomes were considered. Such a shift would demand a significant re-evaluation of the core values of the traditional setting which we wish to maintain and integrate with the new possibilities offered by CPTs, towards the development of a new educational practices. The authors believe that it is essential for both educators and technologists to resist the tendency for replicating existing physical practices in digital settings. Instead, efforts should be made to both broaden and deepen our inquiry of user needs, towards establishing a coherent framework for translating them to CPT-based environments. As education focuses on learners, a first step would be to collect larger amounts of data from students in varying levels of education. Such an investigation may provide a strong basis for identifying the positive aspects of past practices from learner's perspective, while reaping the benefits that future technologies have to offer for education in our design studios.

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