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Representational Ecosystems in Architectural Design Studio Critiques

Do changes in the representational ecosystem affect tutors and students behaviors during design critiques?

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Design studio critiques are key moments for students' learning and designing processes. During critiques, the representational ecosystem provides a setting for the critique to unfold. Tutors and students, while presenting and discussing students' designs, interact with each other and the representational ecosystem. In this article, a case study illustrates our method to measure the effect of a change of representational ecosystem on the critiques' activity. Our three settings include traditional desk critiques, 1/50 scale mockup critiques and immersive Virtual Reality critiques (with HYVE-3D). Each type of critique is analyzed by using video coding as well as protocol analysis.

Keywords: *studio critiques, representational ecosystem, protocol analysis, pedagogic strategies, cognitive behavior*

INTRODUCTION

The design studio is a cornerstone in architectural education. Its pedagogic format fosters a learning-by-doing situation. The studio organization focuses on a designing task, where students develop a project to answer design requirements, synthesized in the design brief set by tutors. Design critiques and juries are milestones in the students' design development and learning process. Design representations act as a designing tool while students work individually on their project, and as a communicational and designing tool when they present and discuss their design

with tutors during studio hours. In this article, we explore the effect of the use of three different representational ecosystems on tutors and students interactions, manipulation of representations and cognitive design behaviors during studio critiques. A representational ecosystem includes all the types of external representations produced or used during a design activity (Dorta et al. 2016). The first representational ecosystem we studied is the traditional desk critique, where students bring printed drawings, sketches, and 3D models; the second one is a large scale mockup critique (scale 1/50) and the

last one is a critique set in the HYVE-3D (Dorta et al. 2014), which is an immersive scale 1 representational ecosystem.

Systems using Virtual Reality or interactive Augmented Reality tabletops are increasingly brought into design studios (Angulo 2015; Dorta et al. 2016; Schubert et al 2016; Sopher et al. 2017) but there is a lack of empirical research to study the impacts of such an alteration of the design space. In this article, we make a first step to fill that gap by proposing an illustrated methodology to study the effect of a change in the representational ecosystem (here a 1/50 scale model and HYVE-3D). We specifically focus on its impact on three key elements that define design studio critiques: its format (pedagogic strategies and feedback), its content (design cognitive behavior) and interactions with its settings (representational ecosystem). Pedagogic strategies are molds to convey design knowledge during critiques. In it, the center of activity is akin to design itself since tutors might demonstrate how to reframe a problem to try a new solution (see for example Petra and Quist in Schön 1985). Design representations, embedded in the representational ecosystem, act as materials for reflexive conversations (Schön 1992) during the critique. Our three key elements are connected and offer a global approach to better grasp what happens during design studio critiques. Our methodology, based on in situ observations and protocol analyses (Ericsson & Simon 1984), proposes a framework to analyze whether the use of different representational ecosystems impacts how the critique unfolds. Our case study of six students, comparing three critiques settings, will highlight their differences and similarities regarding each element.

PEDAGOGIC STRATEGIES AND FEEDBACKS DURING DESIGN CRITIQUES

The design critiques create situations and design experiences where students build their designerly ways of knowing by seeing their tutors designing, reflecting on their design and proposing new solutions. Collaboration is promoted in the studios and gives

students an opportunity to co-construct their designing skills. Tutors act as coaches (Adams et al. 2016) to provide suitable feedback to help students bridge the gap between the design knowledge they need to reach their goal and their current design knowledge. The literature on tutors' type of feedback or strategies during studio critiques is rich (Adams et al. 2016; Cardoso et al. 2016; Cennamo & Brandt 2012; Dannels & Martin 2008; Goldschmidt et al. 2010; Heylighen et al. 1999; Marbouti et al. 2017; Schön 1985; Uluoglu 2000; Yilmaz & Daly 2016). Based on our literature review, we propose a classification of tutors' feedback types into four main categories : scaffolding implies reasoning, questioning and reflecting on a design issue, explaining / instructing illustrates a descriptive and explicit approach of discussing a design issue, demonstrating / proposing involves the formulation of new ideas, changes in the design and suggesting / exploring calls for experimentations and opening the design process (Table 1). For our study, we analyzed if a change in the representational ecosystem impacted the use of each of those feedback strategies.

DESIGN COGNITIVE BEHAVIOR DURING DESIGN CRITIQUES

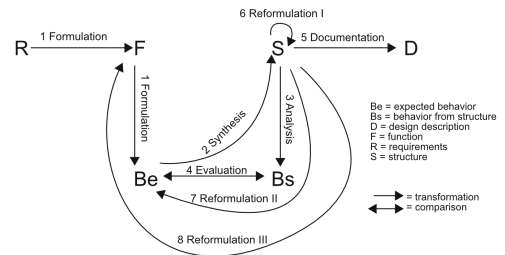
The content of feedback during the critique focuses on design as a process or as an object. Tutors may point out a problem in students design and engage in a design activity to demonstrate how to resolve it or explain why a part of the design is problematic. The content of feedback is of interest while studying critiques because they convey design knowledge. A general way to describe design knowledge is given by the Function Behavior Structure ontology (Gero 1990). The FBS framework represents six design issues: a Requirement (R) includes the design brief and is outside of the designer, a Function (F) is what the design object is for, a Behavior (Be) represents an expected behavior of the design object, a Structure (S) is an element or a structure of elements of the design object, a Behavior (Bs) is a behavior derived from a structure and a Description (D) is an ex-

Table 1
Description of four categories of feedbacks during design critiques based on a literature review

| Feedback types | Feedback characteristics |
|----------------------------------|--|
| Scaffolding | <ul style="list-style-type: none"> • Questioning design so student can reflect on it (Adams et al. 2016 ; Cardoso et al. 2014 ; Dannels & Martin 2008 ; Schön 1985 ; Uluoglu 2000). • Articulate elements of design (Adams et al 2016 ; Yilmaz and Daly 2014). • Design evaluation / judgement positive or negative (Goldschmidt et al. 2010 ; Marbouti et al. 2017 ; Schön 1985 ; Uluoglu 2000 ; Yilmaz and Daly 2014). • Design interpretation, make meaning based on representations (Adams et al. 2016 ; Dannels & Martin 2008 ; Uluoglu 2000) • Investigation to clarify design (Dannels & Martin 2008 ; Goldschmidt et al. 2010) • Analogic reasoning, metaphors (Dannels & Martin 2008 ; Uluoglu 2000) • Brainstorming to bring new ideas (Marbouti et al. 2017) |
| Explaining / instructing | <ul style="list-style-type: none"> • Instruction, direct recommendation, particular advice on a specific part of the design (Adams et al 2016 ; Dannels & Martin 2008 ; Marbouti et al. 2017 ; Schön 1985 ; Yilmaz and Daly 2014). • Analyses of a design problem (Schön 1985). • Questioning to formulate an explanation or describe some facts (Cardoso et al. 2014). • Explanation of meta-data on design (norms / principles) (Cennamo & Brandt 2012 ; Goldschmidt et al. 2010 ; Heylighen et al. 1999 ; Uluoglu 2000) • Description of design process (reflection-on-action) (Cennamo & Brandt 2012 ; Heylighen et al. 1999 ; Uluoglu 2000). • Explanation of the effect of a decision making on the design, anticipation (Yilmaz and Daly 2014). • Draw priorities on concepts (Yilmaz and Daly 2014). • Focus on project rationale, focus on the main concept (Yilmaz and Daly 2014). |
| Demonstrating / proposing | <ul style="list-style-type: none"> • Demonstration and sketch (reflection-in-action) to communicate and design with the student (Cennamo & Brandt 2012 ; Heylighen et al. 1999 ; Schön 1985). • Proposing ideas / design changes (processes, concept) (Dannels & Martin 2008 ; Goldschmidt et al. 2010) • Reflecting and questioning to bring new ideas (Cardoso et al. 2014). |
| Suggesting / exploring | <ul style="list-style-type: none"> • Propositions for new experimentations, exploration of parallel concepts (Schön 1985 ; Yilmaz and Daly 2014). • Inspiration and comparison with elements external to architecture (Yilmaz and Daly 2014). • Making a prototype, a mock-up (Yilmaz and Daly 2014). |

Figure 1
FBS framework (source Gero 1990; Gero & Kannengiesser, 2004)

ternal representation of the design object. The FBS framework accounts a total of eight cognitive design processes showing transitions between the six design issues: Formulation, Synthesis, Analysis, Evaluation, Documentation, Reformulation 1, Reformulation 2 and Reformulation 3, as showed in Figure 1 (Gero 1990; Gero & Kannengiesser 2004). The FBS framework provides a theoretical model of design activities that can be mapped onto the studio critique to analyze tutors and students cognitive design behaviors (Gero & Jiang 2016; Milovanovic & Gero 2018).



In this study, we explored how a change in the representational ecosystem impacted the occurrences and distribution of FBS design processes as well as tutor / student interactions while designing.

REPRESENTATIONAL ECOSYSTEM TO SUPPORT DESIGN CRITIQUES

Feedback are delivered within the representational ecosystem. During the critiques, it sets a designing and learning environment. Tutors and students act on it, manipulate representations while presenting and discussing potential design issues. According to Dorta et al. (2016), this ecosystem should have four qualities: support hybrid representations, which means that it should include physical and digital representations; integrate multiple types of representations (2D, 3D, animations); include multiple scales, architectural scales and an immersive scale 1 representation; and foster an intuitive co-design situation. Another characteristic to be added is a synchronization of the design representations, to offer an updated holistic perception of the project. It implies that representations forming the representational ecosystem are connected to each other. Five different characteristics defined the ecosystem, which we can synthesize into materiality, dimensions, scales, interactions and synchronization. In our analysis, design critiques occurred in three different settings with different representational ecosystem characteristics that are further developed in the data description section.

Based on our observations of studio critiques, we identified several actions tutors and students take to create or interact with design representations. Representation are pointed out to refer to a special element of the design. Tutors and students might generate a physical representation by drawing on a paper or tearing down a part of the mockup. If a digital model of the project was brought for the critique, the design space can be navigated by walk through or fly over. Some authors like, Visser (2009), noted the importance of gesture during design meetings and we also observed occurrences of spatial gesture to represent or explain a spatial quality of students design project.

RESEARCH QUESTIONS

In the light of the description of each of our three key elements, we can refine the research questions we introduced. Our comparative study aims to tackle the following: Does a change in the representational ecosystem affect tutors' feedback strategies and students reactions to feedbacks? Does a change in the representational ecosystem impact tutors and students' cognitive design behavior? Does a change in the representational ecosystem have an effect on tutors and students' actions on and interactions with design representations?

METHODOLOGY

In our study, the protocol analysis method (Ericsson & Simon 1984; Gero & Mc Neill 1998), is exploited to study how the critique unfold. Each critique was video recorded to be further analyzed. We used two levels of coding for our dataset. The first level of coding focuses on feedback types and actors interactions with the representational environment. Videos are directly coded with four types of feedbacks (scaffolding, explaining / instructing, demonstrating / proposing and suggesting / exploring) and four types of interactions with the representational ecosystem (pointing, navigating, generating a physical representation and spatial gesture) using Atlas.ti software. The second level of coding focuses on design cognitive behavior. This analysis is at a finer grain and is based on the verbal transcripts of the design critiques. Each transcribed protocol is segmented and encoded with one of the six FBS design issues (Requirement, Function, expected Behavior, Structure, Behavior form structure and Description). For both level of coding, protocols are also coded with the speakers, either tutor or student. The double coding gives more information on actors' interactions during the critique. For example, it reveals if design processes are constructed by a single actor or co-constructed between tutors and students. Each video and transcribed protocol was coded twice several weeks apart, by the same researcher, to ensure more reliability. The two versions of each protocol

were compared and arbitrated when a different code was associated with the same verbalization.

DATA DESCRIPTION

A case study with six students was conducted within two master architectural design studios selected at the Graduate School of Architecture of Nantes (France).

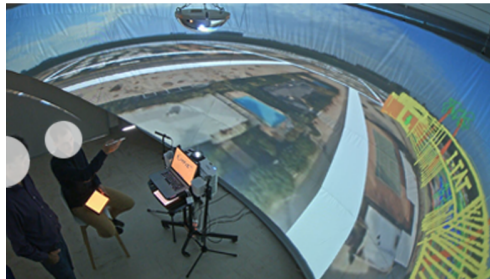
Figure 2
Three
representational
ecosystems tested
for critiques



(a) Desk critique



(b) Mockup critique



(c) HYVE-3D critique

We studied three different representational ecosystems, with two students for each setting. In the first studio, we observed the desk critique setting as well as the mockup critique setting (Fig.2a and 2b). Students had to design an hybrid public equipment in the Parisian suburb, that includes a city museum, a sports and spa center and co-working spaces. From the beginning of the studio, it was required for students to build a 1/50 scale mockup of the site so students could experience design critiques in that setting. Our case study includes two desk critiques (week 7 out of 14 studio weeks) and two mockup critiques (week 10 out of 14 studio weeks) from that studio. The two other cases of our dataset are HYVE-3D critiques (Fig.2c). A two-day workshop was organized with a few students of the second master studio in order for them and the tutor to learn how to use the HYVE-3D (in collaboration with the LID lab in Bordeaux, France and the Hybridlab in Montreal, Canada). The design brief was also a hybrid program including a museum and a hotel situated in Palm Springs, California, to explore Jacques Tati's filmmaking world. At the end of the two days' workshop, students presented their project in the HYVE-3D. The workshop took place during week 7, out of the 14-week long studio.

The specificities of our three settings can be described based on the representational ecosystem characteristics we defined (Table 2). The desk critique is a traditional setting where students brings plans and sections, printed or hand sketched. The mockup critiques focus mainly on the mockup itself but some students also brought plans and sketches. The HYVE-3D critiques are immersive since the device offers a 180° screen. Actors can navigate the virtual space with the 3D cursor, which also serves as a 2D sketching interface (Dorta et al. 2015).

RESULTS

Feedbacks strategies

Based on the video analysis with Atlas.ti, we extracted the time spend by tutors formulating each of the four types of feedback: scaffolding, explaining / instruct-

| | Desk critiques | Mockup critiques | HYVE-3D critiques |
|------------------------|--|------------------------------------|---|
| Materiality | Hybrid : physical and digital | Physical | Digital |
| Dimensions | 2D (plans and sections) and 3D (model) | Mainly 3D (mock up) and 2D (plans) | 2D (plans and section) and 3D (immersive) |
| Scales | Architectural scales, no scale 1/1 | Architectural scales, no scale 1/1 | Architectural scales, immersive scale 1/1 |
| Interactions | Graphic, visual and verbal | Graphic, visual and verbal | Graphic, visual and verbal |
| Synchronization | No | No | Yes |

Table 2
Description of the characteristics of each setting used in our case study

ing, demonstrating / proposing and suggesting / exploring (Fig. 3a). Students' reactions to feedback were also coded with the same categories (Fig.3b). Moments where the current project was described are not coded. For all the critiques, tutors spent between 60 and 90% of their time speaking, formulating feedback on students' design (Fig.3a). The distribution of the feedback types varies across the critiques. In this dataset, no trend appears concerning the effect of the representation of the ecosystem of tutors' feedback formulation. Students spend most of their time speaking, presenting their project. The most active students spend around 20% of their time reacting to feedback with similar strategies as tutors', and the less active between 5 and 10% of their time (Fig. 3b). We can notice that the two students

from the HYVE-3D critiques are part of the most active ones in terms of feedback reactions.

Interactions with design representations

Concerning actors' interactions with design representations, we can see that the time spent speaking while interacting with design representations varies from 25% of the time (HYVE_3D critique 2) to 57% of the time (Desk Critique 2) (Fig.4). For desk critiques and mockup critiques, pointing is the prevailing interactions. For HYVE-3D critiques, pointing is not as dominant as for the other setting. Navigation was mainly used in the HYVE-3D critiques. Generating a new representation (in our case by sketching) occurred only in two critiques, one in the HYVE-3D and one in the desk critiques.

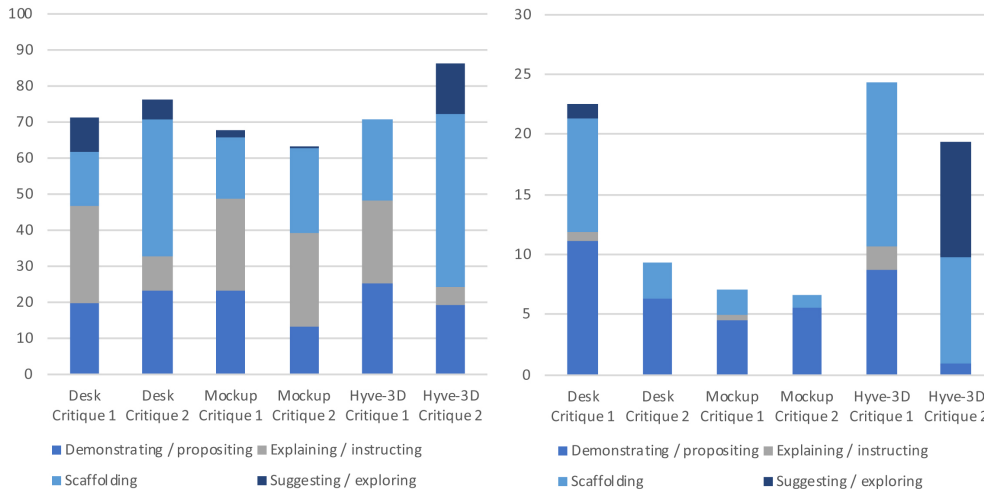


Figure 3
(a) normalized distribution of tutors' feedback strategies for each critiques (b) normalized distribution of students' feedback reactions for each critiques

Figure 4
Normalized
distribution of
actors' interaction
with representation
for each critiques

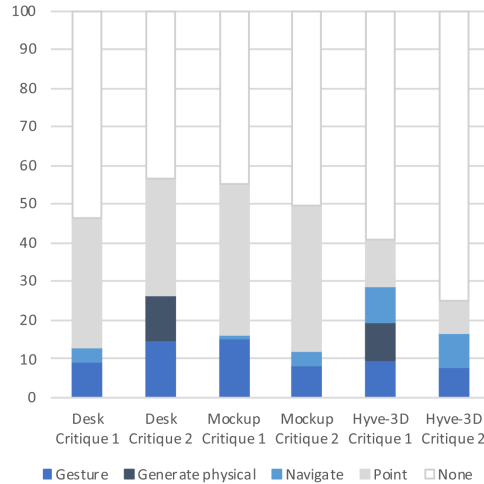


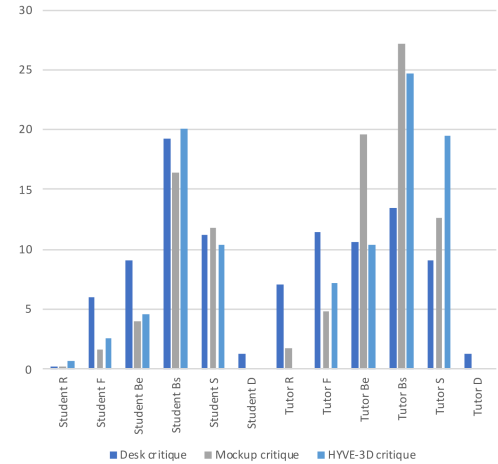
Figure 5
Normalized
distribution of
design issues per
actor for each
critiques

Cognitive design behavior

To study cognitive design behavior, we exploited the FBS framework and first order Markov models to reveal design patterns specific to our dataset. Critiques conversations were transcribed and coded with both FBS design issues - Requirements (R), Function (F), expected Behavior (Be), Behavior from structure (Bs), Structure (S), Description (D) - and the actor speaking - tutor or student. Each protocol was coded twice for better reliability. Since coding was time-consuming, we were able to analyze only three students' protocol for this study, one for each representational ecosystem. The distribution of the design issues for a session gives a description of the nature of the design activity (Kan & Gero 2017).

The normalized distribution of design issues per actor for our three critiques is represented in Figure 5. Behavior derived from structure (Bs) is always dominant, for both tutors and students for every critiques. The distribution of design issues formulated by students is similar for each representational environment except for Function (F) and expected Behavior (Be). For those two design issues, the student from the desk critique formulated twice as much as the other two. Concerning tutors' distribution of de-

sign issues, we notice more variation than for students. The tutor from the desk critique shows a more balanced distribution of design issues than the other two tutors. For the tutor from the mockup critique, Behaviors, either expected or derived from structures (Be / Bs), are the dominant design issues. Behaviors from structure (Bs) and Structure (S) are prevailing for the tutor from the Hyve-3D critique.



The interest in using the first order Markov model to analyze our data set is to reveal its design patterns (Kan & Gero 2010; Milovanovic & Gero 2018; Yu & Gero 2016). The Markov model offers a quantitative probabilistic description of the design transitions, that mapped onto FBS design processes. For each critique, we can capture qualitative information on the probability a design transition will occur. Indeed, a first order Markov model shows the probability of transitioning from a given state to another state (in our case design issues). The Markov analysis produces a probability matrix based on the sequence of event states in our data set. The sequence is given by the actor and the FBS design issue. In our data, 12 states are described, that are associated to design issues (one of the 6 design issues from the FBS ontology) and actors (tutors or students). The transition

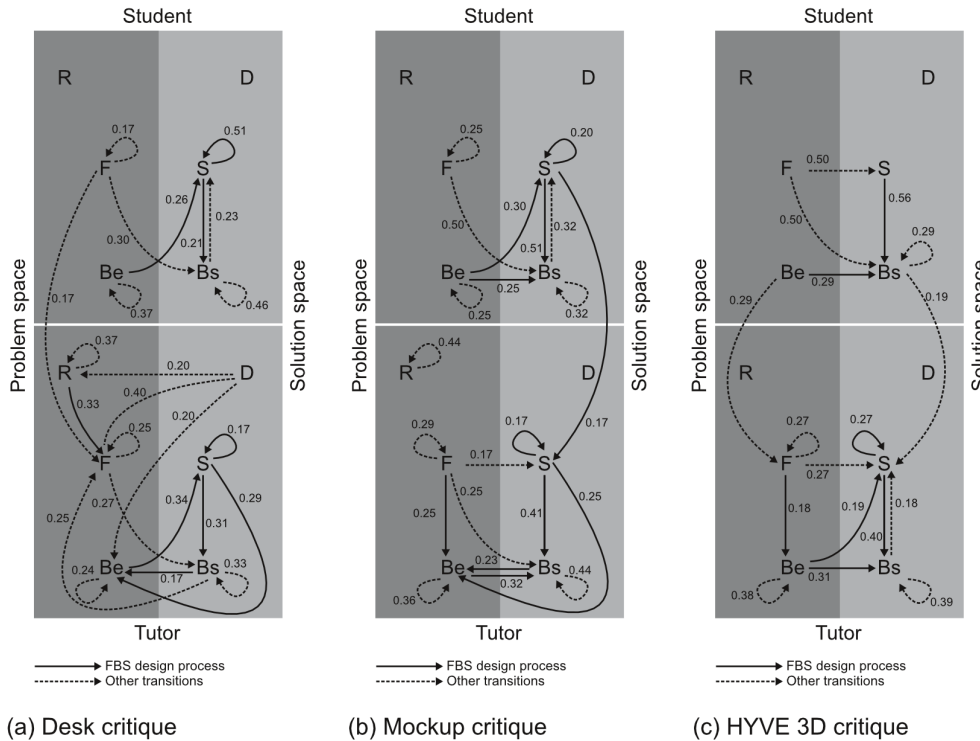


Figure 6
Representation of main design issue transitions based on their probability: (a) Desk critique, (b) Mockup critique, (c) HIVE-3D critique

probability varies between 0 and 1. Transitions with a high probability (above the selected threshold of 0.17, two times the random probability) are representative of the most probable design transitions from the starting design issue.

Figure 6 represents design issue transitions with the highest probability for each type of critique. The diagram shows transitions that are formulated by a single actor, either tutors or students, as well as transitions that are co-constructed. Moreover, we distinguished two spaces within the design space: the problem space that includes Requirements (R), Function (F), and expected Behavior (Be); and the solution space that includes Behavior from structure (Bs), Structure (S) and Description (D). Designing entails a navigation of the problem and solution space, which

co-evolve across time (Dorst & Cross 2001; Maher & Poon 1996). In the graphic representation of the Markov transitions in Figure 6, we can notice when design processes occur within a single space or show a transition from the problem space to the solution space and reversely.

Most design transitions in our data set are solo constructed, either by the student or by the tutor. For each critique, only one or two co-constructed transitions' probabilities are above our threshold, from a student's formulated design issue to a tutor's design issue (Fig.6). Transitions occurred mainly in a single space, the solution space or the problem space, or show a shift from the problem space to the solution space. We observe more transitions from the problem space to the solution space in the desk cri-

tiques when the tutor leads the critique's activity (Fig.6a). Students from the desk critique (Fig.6a) and the mockup critique (Fig.6b) have similar design transition patterns, whereas the student from the HYVE-3D critique (Fig.6c) shows different ones. Tutors from the mockup critique (Fig.6b) and the HYVE-3D critique (Fig.6c) have similar design transitions patterns. In the desk critique (Fig.6a), some similar design transitions appear but we can see that the activity is mainly situated in the problem space or going toward the problem space.

DISCUSSION, LIMITS AND PERSPECTIVES

Our results illustrate differences regarding the type of feedback formulated by tutors, although it does not seem to be related to the representational ecosystem used. Students' reaction to feedback, on the other hand, are more dynamics in the HYVE-3D critiques than during the other critiques. That could be a sign that this setting is more engaging for students to participate. Previous studies showed how the HYVE-3D environment fosters collaboration during design studios that relates to our observations (Dorta et al. 2012). The type of interactions with the design representations differs depending on the critique representational ecosystem, especially for the HYVE-3D critiques. In the HYVE-3D, actors did not point at representations as much as in the other settings, which could be a consequence of being immersed in the representation. We found similarities and differences in the dominant design cognitive processes occurring during critiques. In a study, Yu and Gero (2016) showed how the use of a different modeling environment for solo design sessions impacted on the occurrence of design processes. In our case, we also found differences in the occurrence of main design processes but that can hardly be connected to the representational environment used. Students' cognitive behaviors during the desk critique and the mockup critique are alike, and different from the students' cognitive behavior in the HYVE-3D critiques. That difference does not match with the difference in tutors' design cognitive behavior depending on the setting.

We were expecting to observe a richer design interactions through co-constructed design processes in the HYVE-3D critiques but co-constructed processes were not the most probable in our case study.

Our sample is small to infer any general conclusions on the impact of the use of different setting on feedback strategies, actors' interactions with design representations or specific design patterns. Tutors and students form the HYVE-3D critiques only used this representational ecosystem for a limited time, so its manipulation is not as seamless as the desk critique setting or the mockup setting. For that reason, the results presented in our study are to be taken carefully. Nonetheless, this case study illustrates the complexity and diversity of the designing and learning activity during critiques. Actors' behavior during the critiques was different but we need a wider study to better grasp if those changes are correlated with the representational ecosystem used. Design critique, similarly to design itself, is a situated activity, actor-dependent and evolving through time. The situatedness of design critiques affects tutors and students' behavior during critiques that can also be a reason for changes in the way feedback are delivered and designing unfold. Our future work will consist on conveying similar analysis using the same methodology on a bigger sample, and better training for experiential settings to confirm trends that appeared in the presented case study.

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