Camba, J. D., Soler, J. L., & Contero, M. (2017). Immersive Visualization Technologies to Facilitate Multidisciplinary Design Education. In P. Zaphiris & A. Ioannou (Eds.), *Learning and Collaboration Technologies. Technology in Education. 4th International onference, LCT 2017. Held as Part of HCI International 2017, Vancouver, BC, Canada, July 9–14, 2017. Proceedings, Part I* (pp. 3-11). Switzerland: Springer International Publishing. doi:10.1007/978-3-319-58509-3_1
The final publication is available at link.springer.com

Immersive Visualization Technologies to Facilitate Multidisciplinary Design Education

Jorge D. Camba[1], José Luis Soler[2], and Manuel Contero[2]

[1] Gerald D. Hines College of Architecture and Design, University of Houston
4200 Elgin St, Houston, TX 77204-4000, USA
jdorribo@uh.edu
[2] Instituto de Investigación e Innovación en Bioingeniería (I3B)
Universitat Politècnica de Valéncia, Camino de Vera s/n, 46022 Valencia, Spain
josodo@upv.es, mcontero@upv.es

Abstract. This paper reports on an integrated project-based course for undergraduate students in industrial design, architecture, and interior architecture, where emerging technologies are used to develop 3D visualization experiences for projects that effectively combine elements from the three design disciplines. The course emphasizes design as a multidisciplinary activity that can benefit from skills that span traditional departmental boundaries. The curriculum moves through the different types of mixed reality technologies such as virtual and augmented reality, and explores how these tools can be combined to harness the design potential across disciplines and create compelling and engaging outcomes. The course follows a student-centered collaborative approach where projects are completed as a team with members from different majors. Student to student collaboration is actively encouraged in an effort to promote dialogue and community and foster creative thinking. The proposed initiative provides an integrative and unifying experience for students and their design concepts and project outcomes, as well as an opportunity for expanding their creative portfolios.

Keywords. Multidisciplinary education, design disciplines, mixed reality, 3D visualization.

1 Introduction

Modern approaches to design pedagogy are largely influenced by constructivist theories, which emphasize the importance of interpreting and contextualizing educational contents to provide effective learning experiences [1, 2]. In constructivism, it is essential that the educational material is not only lectured but learners have the opportunity to experience it in their own context and reflect on those experiences [1].

To facilitate phases of individual construction and contextualization, design pedagogy generally takes the form of collaborative project-oriented learning where a studio-centered environment encourages teamwork, cooperation, hands-on activities, and the creative exploration of ideas [3, 4]. Design studio instruction is based on the premise that creative design is learned through the act of doing and making, or "learning-by-doing" [5]. A design studio is expected to promote a culture where students work side by side to share and benefit from exposure to a variety of ideas from peers and instructors [6, 7].

However, the unique characteristics and requirements of each individual design discipline often make it difficult to deliver an integrated curriculum that promotes truly multidisciplinary work. For example, a project that involves the design of a new line of urban bicycles may be exciting to industrial design students but would likely be of little to no interest to students majoring in architecture. Similarly, designing the interior space of an office building or a hotel lobby would likely be exciting to interior architecture students, but unstimulating to most industrial designers.

In this paper, we describe a new multidisciplinary course that is currently being offered to students of industrial design, architecture, and interior architecture at the University of Houston. The curriculum uses emerging visualization technologies as a catalyst for the creation of collaborative projects and the development of integrated outcomes. In this regard, this paper was written as a way of distributing the results of our initiative to the design education community.

2 Educational Needs and Multidisciplinary Programs

Researchers across various disciplines have stressed the importance of cross-disciplinary education. This kind of education aims to supplement traditional domain-specific knowledge skills with the development of "boundary-crossing" skills such as the ability to synthesize knowledge from different disciplines and being able to change perspectives based on specific aspects of a problem [8].

According to Berezin [9], the proper balance between specialized technical training and a general social human knowledge is essential to avoid fragmented knowledge in poorly interacting specialties [9]. Similarly, authors Borrego and Newswander [10] state that "researchers from other disciplines 'see' things differently, but by understanding the underlying differences and how these can expand possibilities for research, would-be collaborators can learn lessons invaluable to cooperation, communication, and ultimate understanding [10]." Evidence suggests that cross-disciplinarity facilitates comprehensive understanding [8, 11]

Cross-disciplinary collaborations can take the form of either multidisciplinary or interdisciplinary approaches. In a multidisciplinary approach, collaborators work together on a problem and each collaborator brings his or her own expertise to the team [12, 13] and split apart after the common work is completed. In contrast, in interdisciplinary collaborations, researchers from different disciplines work in a more integrated manner by combining their knowledge from their own disciplines to work toward a common goal [10, 12, 13]. As stated by Borrego [10], "at the end of a truly interdisciplinary collaboration, each collaborator is changed by the experience."

The differences between multidisciplinary and interdisciplinary approaches are illustrated in Fig. 1.

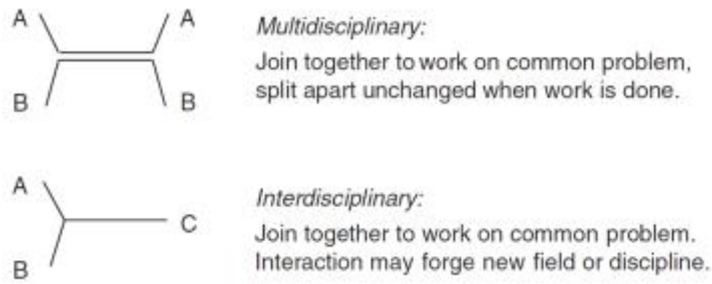

Fig. 1. Difference between multidisciplinary and interdisciplinary collaborations (adapted from [13]).

We are familiar with efforts at a number of universities (from faculty to departmental to college to university levels) to promote cross-disciplinary education. For example, successful collaborations between engineering, humanities, and applied sciences have been reported [14] as well as initiatives that combine design and communication [15], or engineering, business, and art [16]. A pilot interdisciplinary course on climate solutions was also reported which involved faculty from seven different disciplines including engineering, political science, philosophy, meteorology and foreign languages [17]. Researchers agree that support from the academic institution is a key factor to the successful implementation of interdisciplinary courses [10].

The integration of various disciplines into a cross-disciplinary curriculum is generally implemented as project-based team courses (particularly if the disciplines are closely related), which emphasize teamwork as the focus for learning. Some examples include partnerships among architecture, engineering, and construction [18] as well as civil, mechanical and electrical engineering [19]. Cross-disciplinary project-based education is also common among first-year engineering programs as a strategy to improve retention and attract new students into engineering [20, 21]. In some cases, students work closely with sponsors and external companies that support the course.

Some major obstacles to successfully implementing cross-disciplinary education were identified by Ackerson [22]. These obstacles include (1) fragmentation of disciplinary information, (2) inability to digest the extensive volume of existing information, and (3) a lack of access to relevant information [22].

The multidisciplinary course presented in this paper was designed to address the first obstacle (i.e., fragmentation of disciplinary information) by facilitating an environment where students can work in teams toward a common goal while naturally dividing tasks based on students‘ individual interests, backgrounds, and majors.

3 Emerging Visualization Technologies

For the purposes of this paper, the concept of “emerging visualization technologies” refers to advanced 3D visualization tools that can be used to present and experience design information, concepts, and outcomes in an immersive manner. These technologies include the various types of augmented reality technology (e.g., direct, indirect, marker-based, projection-based, etc.), virtual reality, and holographic visualization.

Augmented Reality (AR) is a visualization technology that combines real-time three-dimensional computer-generated imagery and real-life footage to create an enhanced representation of reality [23]. Augmented reality allows users to experience a modified version of the real world by blending virtual images and real views of the environment. It can be experienced in a variety of ways such as via computer screens and portable devices (indirect visualization), or using projection based techniques and special headsets (direct visualization).

Virtual Reality typically involves immersion. In a virtual reality environment, the user is immersed in a space that is entirely computer-generated (i.e. the real world is entirely replaced by a virtual world) [24]. There are many ways to experience virtual reality worlds. The most popular methods involve the use of specialized Head Mounted Displays (HMD) such as the Oculus Rift® [25] or the HTC Vive® [26].

Holographic visualization is a type of direct mixed (augmented) reality experience popularized by Microsoft and their recent Head Mounted Display, the Hololens® [27]. This technology offers a more integrated view of reality, as real spaces can be mapped in 3D, making virtual content “aware” of the real environment. According to Microsoft, holographic visualization allows users to “visualize and work with digital content as part of the real world” and “feel present in the environment by enabling them to move naturally, interact, and explore in three dimensions [27].”

Visualization technologies have always been at the heart of the design disciplines. In addition to CAD software, immersive technologies have been used to develop and visualize design concepts [28-30]; visualize construction processes and scheduling [31]; or analyze engineering and construction equipment [32, 33]. Research has shown that immersive technologies in design studios can increase the awareness of the designer and facilitate the selective reinterpretation and immediate evaluation of a particular design instance [34].

From an educational standpoint, however, immersive visualization technologies have generally been used merely as tools to complement or facilitate other tasks, but not necessarily as the focus of the course. In fact, these types of courses are often very technical and offered only to computer science students as a complement to a computer graphics course [35, 36]. Burdea identified some of the problems regarding the teaching of these technologies, particularly virtual reality [37].

Nevertheless, a number of educational initiatives on virtual reality courses have been reported, including some multidisciplinary ones. For example, an educational framework for developing VR applications was described by Miyata et al. [38]. Using this framework, graduate students worked in teams to develop a number of visualization experiences, mostly games. Authors Zimmerman and Eber [39] described an interdisciplinary course with students from computer science and art. Similarly, a practical course on virtual reality designed for engineering students from different fields (e.g., mechanical engineering, electrical, etc.) was also reported [40].

In this paper, we describe a pilot course for design majors where immersive visualization technologies are studied from a non-technical standpoint. The course examines how these technologies can benefit designers, particularly in terms of the presentation and delivery of visual content.

4 Approach

As part of an initiative supported by the College of Architecture and Design at the University of Houston to offer courses that are interdisciplinary among the degree programs within the College (Interior Architecture, Industrial Design, and Architecture), a pilot course on emerging visualization technologies was offered in the Spring 2017 semester. The goal of this initiative is aimed at providing new cross-disiplinary areas of inquiry to students in the context of the following four approaches: (1) Human Factors, (2) Materials/Systems, (3) History/Theory, and (4) Entrepreneurial Processes.

Although the new course is organized around a student-centered project-based collaborative curriculum, it is not offered as a traditional design studio but as a regular lecture/lab course. Upperclass undergraduates and graduate students from all three majors were eligible to enroll. The course is divided into four major learning blocks, each of which covering a relevant emerging topic on visualization technology:

- Fundamentals of 3D and stereoscopy
- Augmented Reality (Direct and Indirect)
- Virtual Reality
- Holographic Visualization

The course emphasizes (1) 3D visualization, presentation, and visual communication as fundamental skills that are common across different specialties; (2) the integrative and versatile nature of visualization technologies; and (3) their inherent applicability to different design fields. Through a combination of lectures and project-based exercises, students investigate emerging topics in 3D visualization, including the limitations, areas of application, and contexts of use. Students investigate how immersive 3D visualizations can enrich the delivery of design information; enhance presentations and simulations in their respective fields, and impact user perception, cognition, and engagement. The general schedule of topics of the course is described in Table 1.

Given the design background of the students enrolled in the course, topics and specific technolgies were discussed almost entirely from an “authoring” or content-creation point of view, emphasizing user experience. Emphasis was also put on the visual quality of the deliverables. No programming, software development, or computer graphics concepts were discussed beyond basic interactions and interface design.

Table 1. Schedule of topics

Week	Learning Block	Topic	Project
1	3D Fundamentals	Introduction	
2		Stereoscopic 3D	
3		360 Video	Project 1
4	Augmented Reality (AR)	Augmented Reality	
5		AR Indirect View	
6		AR Direct View	
7		Projection Mapping	Project 2
8	Virtual Reality (VR)	Virtual Reality	
9		Designing Immersive Environments	
10		User Experience in VR environments	Project 3
11	Holographic Visualization	Introduction to Holograms	
12		Interactivity	
13		Interactivity	
14		Spatial Mapping	Project 4

A team project was assigned for each major topic. Teams were comprised of no less than three students. Attempts were made to diversify all teams so at least one member of each team would be from a different design discipline. Projects involved the creation of an interactive visualization experience that combined elements of all three majors. The experience would be designed for the specific technology being discussed in class at the time the project was assigned. As an example, for the virtual reality learning block, an architecture student may create an immersive visualization of a building where all the details can be experienced at true scale. Similarly, an interior architecture student may build on the previous work by modeling a particular interior space within the previous building, whereas an industrial design student could do the same for a particular piece of furniture for that interior space. All three concepts are integrated in a seamless manner to provide a comprehensive visualization of a particular design space.

In addition, for each major learning block (described above), students were required to reflect back on their respective fields, describe how the technology can be applied and used effectively, and be encouraged to use their 3D models and designs (including those completed in previous courses and studios) to create additional experiences that are relevant to their specific area or interest.

The final deliverables for each project required a poster session, an oral presentation, a final report, and a demonstration of the experience. Project topics were discussed between the faculty and each individual team and reflected the interests of the students: immersive visualization of living spaces, public spaces and community development, furniture design and applications, customization of interior spaces and its impact on user perception, examination of immersive technologies as a tool to evaluate user preferences, urban farming, and visualization of large urban areas.

Student to student collaboration was actively encouraged in an effort to promote dialogue and community, foster creativity and unconventional thinking, and expand students' perspectives. The proposed initiative provides not only a multidisciplinary course for students, but also an integrative and unifying experience for their design concepts and project outcomes as well as an opportunity for expanding their creative portfolios.

5 Discussion

The development and affordability of innovative immersive 3D visualization technologies are opening new doors to design exploration, documentation, and presentation. Furthermore, visualization technology is increasingly influencing the design process itself, particularly during initial concept phases. As designers, being able to show the audience a virtual version of a future product or environment can foster reliability and consensus, reduce uncertainty, and help make decisions throughout refinement and planning processes.

Using visualization technologies, layers of digital information can be combined with traditional media and physical spaces to create truly unique and immersive experiences that go far beyond classic presentation boards and computer screens. As a practical hands-on exploration of emerging technologies for design visualization and presentation, we developed a new course where students learn to deliver three-dimensional experiences that merge the physical with the virtual and allow audiences to interact with the content.

The multidisciplinary experience of the course is founded on (1) 3D visualization as a fundamental component of design that is common to all disciplines; (2) the integrative and versatile nature of visualization technologies; and (3) their immediate applicability to different design fields. In this regard, new visualization technologies have the potential to drastically change the way design is experienced, shared, and presented.

A dedicated course that explores state of the art tools and visualization technologies was designed to prepare students with the means to provide richer and more engaging experiences to diverse audiences. The proposed course is intended to have a significant impact on the nature of the presentation deliverables that students submit to their studio courses and theses. In addition, the integrated curriculum offers students from Industrial Design, Architecture, and Interior Architecture (both at the undergraduate and graduate levels) a path toward experiencing state of the art visualization technology and applying it to their respective fields.

The difficulties encountered with the multidisciplinary format of this pilot course involve mostly administrative challenges. In some cases, however, the challenge is not a result of the multidisciplinary aspect of the course, but one involving teamwork. For example, working and managing small groups can often be difficult for both faculty and students, especially when one or more students are not fully engaged in the project.

In addition, faculty and students agreed that the lack of particular resources dedicated to the teams was unfortunate, as all specialized equipment had to be shared among multiple teams. The fact that the Head Mounted Displays such as the Oculus Rift and the Microsoft Hololens are costly and require powerful computers to run was a major obstacle for students. There were consistent complaints from the students that they could not test their experiences adequately because they did not have easy and exclusive access to the technology outside class meetings. They suggested that even a small budget to purchase more equipment could have been helpful. An alternative option was proposed where each team would complete each project at a different time during the semester to reduce scheduling conflicts for a specific device. This option would naturally add complexity in terms of course management, as more content would have to be delivered at the beginning of the semester in order to accommodate all projects.

There are several implications of our pilot experience. First, students benefit from exposure to a diversity of design backgrounds from their colleagues and opportunities to share their areas of expertise within their groups. Second, student also benefit from explicit instruction on cross-disciplinary teamwork, dynamics, and problem solving. Third, student get different perspectives on design by interacting with other students and being exposed to how other disciplines approach the design process itself. Finally, students benefit from the resulting project outcomes, which provide an integrated piece for their creative design portfolios. In the near future, we would like to examine how this course influences the quality and delivery of design information in other courses. We plan to collaborate with other faculty to track these students and determine whether the use of immersive technologies has a significant impact on their future presentations.

6 References

1. Piaget, J.: The child's conception of the world (No. 213). Rowman & Littlefield (1951).
2. Dewey, J.: Experience & Education. New York, NY: Kappa Delta Pi (1938).
3. Maitland, B.M., Problem-based Learning for an Architecture Degree. In: Boud, D. and Feletti, G. (Eds), The Challenge of Problem-based Learning. London: Kogan Page (1991).
4. Green, L. N., and Bonollo, E. Studio-based teaching: history and advantages in the teaching of design. World Transactions on Eng. and Tech. Edu, 2(2), 269-272 (2003).
5. Schön, D. The reflective practitioner. Basic books (1983).
6. Waks, L.J. Donald Schon's philosophy of design and design education. International Journal of Technology and Design Education Vol 11 pp 37-51 (2001).
7. Chiu, M.L. An organizational view of design communication in design collaboration Design Studies, 23(2), 197-210 (2002).
8. Spelt, E.J., Biemans, H.J., Tobi, H., Luning, P.A., and Mulder, M. Teaching and learning in interdisciplinary higher education: A systematic review. Educational Psychology Review, 21(4), 365 (2009).

9. Berezin, A., Interdisciplinary integration in engineering education, Proceedings, IECON'01. 27th Annual Conference of the IEEE Industrial Electronics Society (Cat. No.37243), 3, 1740–1745 (2001).
10. Borrego, M., and Newswander, L.K., Characteristics of successful cross-disciplinary engineering education collaborations, Journal of Engineering Education, 97(2), 123–134 (2008).
11. Newell, W. H. Decision making in interdisciplinary studies. In G. Morçöl (Ed.), Handbook of decision making. New York: CRC (2007).
12. Klein, J.T. Interdisciplinarity: History, theory, and practice. Detroit, MI: Wayne State University Press (1990).
13. Committee on Facilitating Interdisciplinary Research. Facilitating interdisciplinary research. Washington, DC: National Academies Press (2005).
14. Shields M., and O'Connell, J.P. Collaborative teaching: reflections on a cross-disciplinary experience in engineering education, Proceedings of the 1998 Annual ASEE Conference, Seattle, WA, June 28–July 1, (1998).
15. Hirsch, P.L. Shwom, B.L. Yarnoff, C., Anderson, J.C., Kelso, D.M., Olson, G.B., and Colgate, J.E. Engineering Design and Communication: the case for interdisciplinary collaboration, International Journal of Engineering Education, 17(4,5), 342–348 (2001).
16. Wesner, J.W., Amon, C.H., Bigrigg, M.W., Subrahmanian, E., Westerberg, A.W., and Filipski, K. Student team formation and assignment in a multi-disciplinary Engineering Design Projects course: a pair of suggested best practices, International Journal of Engineering Education, 23(3), 517–526 (2007).
17. Rhee, J., Cordero, E. C., and Quill, L. R. Pilot implementation of an interdisciplinary course on climate solutions. International Journal of Engineering Education, 26(2), 391 (2010).
18. Fruchter, R. Dimensions of teamwork education, International Journal of Engineering Education, 17(4,5), 426–430 (2001).
19. Skates, G.W. Interdisciplinary project working in engineering education, European Journal of Engineering Education, 28(2), 187–201 (2003).
20. Frolik, J., and Keller, T. Wireless sensor networks: An interdisciplinary topic for freshman design. In American Society for Eng. Education Annual Conference& Exposition, ASEE, pp. 1-7 (2005).
21. Knight, D.W., Carlson, L.E., and Sullivan, J.F. Improving engineering student retention through hands-on, team based, first-year design projects. In Proceedings of the International Conference on Research in Engineering Education. Honolulu, HI (2007).
22. Ackerson, L.G., Challenges for Engineering Libraries: Supporting Research and Teaching in a Cross-Disciplinary Environment, Science and Technology Libraries, 21(1,2), 43–52 (2001).
23. Azuma, R.T., A survey of augmented reality. Presence-Teleoperators and Virtual Environments, 6(4), 355-385 (1997).
24. Jerald, J. The VR book: Human-centered design for virtual reality. Morgan & Claypool, (2015).
25. Oculus Rift. https://www.oculus.com/rift/ (Accessed Feb. 20th, 2017).
26. HTC Vice. https://www.vive.com/ (Accessed Feb. 20th, 2017).
27. Microsoft Hololens. https://www.microsoft.com/microsoft-hololens (Accessed Feb. 20th, 2017).
28. Shibano, N., Hareesh, P.V., Kashiwagi, M., Sawada, K., and Takemura, H. Development of VR experiencing system with hemi-spherical immersive projection display for urban

environment design. Proceedings of the Seventh International Conference on Virtual Systems and Multimedia (VSMM'01) (2001).
29. Schmitt, G. Virtual Reality in Architecture. In N. M. Thalmann and D. Thalmann (Eds.), Virtual Worlds and Multimedia. Chichester, England: Wiley (1993).
30. Messner, J.I., Yerrapathruni, S.C., Baratta, A.J., and Riley, D.R. Cost and schedule reduction of nuclear power plant construction using 4D CAD and immersive display technologies. Computing in Civil Engineering: Proceedings of the International Workshop of Information Technology in Civil Engineering, 136-144 (2002).
31. Whisker, V.E., Baratta, A.J., Yerrapathruni, S., Messner, J.I., Shaw, T.S., Warren, M.E., Rotthoff, E.S., Winters, J.W., Clelland, J.A., and Johnson, F.T. Using immersive virtual environments to develop and visualize construction schedules for advanced nuclear power plants. In Proceedings of ICAPP, vol. 3, pp. 4-7. (2003).
32. Lipman, R., and Reed, K. Using VRML in construction industry applications. Web3D – VRML 2000 Symposium, Monterey, CA, 1-7 (2000).
33. Opdenbosch, A., and Hastak, M. Virtual reality environment for design and analysis of automated construction equipment. 2nd Congress for Computing in Civil Engineering, Atlanta, GA, 566-573 (1994).
34. Abdelhameed, W.A. Virtual Reality Use in Architectural Design Studios: A case of studying structure and construction. Procedia Computer Science, 25, 220-230 (2013).
35. Zara J. VR Course - A Natural Enrichment of Computer Graphics Classes. Computer Graphics Forum 25, 105-112 (2005).
36. Cliburn D. Incorporating Virtual Reality Concepts into the Introductory Computer Graphics Course, in: Proceedings of the SIGCSE. ACM, Houston, Texas, USA, 77-81 (2006).
37. Burdea, G. Teaching Virtual Reality: Why and How? Presence: Teleoperators and virtual environments, 13:463-483 (2004).
38. Miyata, K., Umemoto, K., and Higuchi, T. An educational framework for creating VR application through groupwork., Computers & Graphics, 34(6): 811-819 (2010).
39. Zimmerman, G.W., Eber, D.E. When worlds collide!: an interdisciplinary course in virtual-reality art, in: Proceedings of SIGCSE. ACM, New York, NY, USA, p. 75-79 (2001).
40. Häfner, P., Häfner, V., & Ovtcharova, J. Teaching methodology for virtual reality practical course in engineering education. Procedia Computer Science, 25, 251-260 (2013).