Assessing the Effectiveness of Augmented Reality on the Spatial Skills of Postsecondary Construction Management Students in the U.S.

Jeff Kim[a] and Javier Irizarry[b]

[a]School of Building Science, Auburn University, United States
[b]School of Building Construction, Georgia Institute of Technology, United States
E-mail: jsk0022@auburn.edu, Javier.Irizarry@coa.gatech.edu

Abstract –

There is a continual challenge within the construction industry to achieve schedule, budget, and quality expectations at a time when projects are more complex and their designs and assembly involve some measure of abstract spatial skills. In postsecondary institutions, these abstract spatial skills have routinely been taught through drafting and plan reading courses. The outcomes of this approach often fall short of meeting the needs of industry, therefore an alternative solution is necessary. As such, this research advocates the use of a group of technologies, collectively known as augmented reality, which allows one to view the "real" world with the addition of information intended to provide a new understanding of what is being seen. Augmented reality is fast proving advantageous in many industries (e.g. Architecture, Robotics, Entertainment, and Military). With the availability of smaller, more powerful consumer mobile devices, augmented reality can become a ubiquitous, practical tool for the construction industry as well. Research surrounding augmented reality is primarily focused on ways to improve the construction process; however, this study is focused on improving the learning process. The researcher studied the use of a mobile augmented reality tool during a spatial skills classroom assignment to determine if there was an improvement in the accuracy of these skills and retention of the concepts over time. A separate analysis was conducted to determine if the teaching tool was a benefit or disruption to the overall learning experience. The research and analysis resulted in significantly improved assessment scores for the group utilizing the mobile augmented reality tool during their completion of the spatial skills assignment. Additionally, a post-survey indicated that the introduction of this tool was non-disruptive to the students' overall learning experience. Therefore, the addition of these technologies, as a complement to drafting and plan reading, can enhance the postsecondary educational preparation of the future construction industry workforce.

Keywords –

Augmented Reality; Student Learning; Construction Management; Spatial Skill; Active Learning

1 Introduction

The success of today's construction process is sensitive to errors, mistakes, omissions, and inexperience that affect safety, cost, schedule, and quality of a construction project [1][2][3]. While some of the problems could be attributed to outside factors such as fluctuating demand of raw materials, changes in the financial markets, and unpredictable weather conditions, one should also appreciate the ongoing challenges of educating the next generation of construction managers. The newly graduated construction management (CM) student needs basic skills to solve unique, complex problems and visualize a finalized project in an empty three-dimensional (3D) space [4][5][6][7]. These skills are called spatial skills. The spatial skills required to visualize the unfinished product is an important part of construction; it becomes a skill set that constituents of the building process use to communicate new ideas and resolve issues. The problem in not refining these skills is that the CM student is less likely to meet the needs of industry when they join the workforce. Therefore, a focus on improving these skills is essential.

As early as the mid-90s, researchers concluded that visualization of abstract objects on paper and on computer screens was required to be a good communicator within the engineering trades [8]. Later, building information modeling (BIM) would replace paper by constructing the project in a virtual space [9], however, this transition did not replace a need for good spatial skills, in fact, it could be argued that it increased the need for better spatial skills. This technology has made a positive impact on the way that the architectural, engineering, construction and facility management (AECFM) industry communicates; however, one still needs to possess good spatial skills in order to create these models. While the increasing universality of BIM is significant, there are still many instances where communicating visually is done through two-dimensional (2D) sketches and verbal communication without the aid of BIM. Therefore, instances such as these illustrate the continual need for innate spatial ability. Fortunately, research has shown that spatial skills can be improved [10][6][11] and although experience is one way in which this can happen, many tests and studies have been conducted to show that spatial skills can also be learned [12][13][14][15][16].

Because the market demands higher quality graduates and having good spatial skills is essential in a growingly abstract and complex design world, improvements in spatial skills could benefit from a new pedagogical tool that supports active learning and engages the students visually. Augmented reality (AR), although not a new technology, has found more applications in today's world, especially with the increasingly widespread use of mobile technologies (smartphones, tablet computers, and ultra-light laptops). The benefit of using AR in the classroom is that learners can see supplemental digital information [17], assisting them in the understanding of highly abstract and complex assemblies [18]. As a result, students become active participants in their learning and by adding interactive visualizations while encouraging students to ask questions about their learning rather than being told what to learn [19] we enhance the overall learning experience.

More specifically, this research was conducted to respond to three questions:

1. Can a mobile augmented reality pedagogical tool be used to improve the accuracy of spatial skills in CM students at the postsecondary level?
2. Can a mobile augmented reality pedagogical tool be used to improve the retention of newly acquired spatial skills in CM students at the postsecondary level over time?
3. Will the use of a new pedagogical tool be an interference to the overall learning experience?

2 Literature Review

Modern day construction projects call for more advanced use of mathematical models, data analysis, and 3D modeling software, which in turn needs to be converted to a plan of execution by a construction manager. To interpret this kind of data, a CM employee needs good spatial skills that will allow them to visually predict where and how components of the project will be assembled. In the classroom, construction management (CM) students are often required to interpret complex and abstract images into 3D images in order to solve construction related problems [20][7]. However, past research [21][22][23] indicates that students struggle with visualization tasks and in today's CM classroom, educators would not hesitate to argue that shortcomings still exist.

2.1 BIM and Spatial Skills

There is no doubt that BIM has become an important part of the construction industry, and there is a steep learning curve that comes in making sure it is used to its greatest effectiveness. In "BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors", 2nd Edition [9], there are over 560 pages dedicated to successfully implementing BIM in all aspects of the AECFM space, and this does not include the software, which may require several days of training to begin using. Unfortunately, reading this handbook and undergoing days of training, still does little to enhance one's spatial skills, leaving them inadequately prepared to render objects and create complex models useful in the coordination of a construction project. While research has shown BIM to have a positive impact on the quality of learning, there is still an element of visualization necessary to support BIM itself [24].

2.2 Augmented Reality as a Mobile Teaching Tool

Augmented reality (AR) is the addition or subtraction of virtual (computer-generated) images superimposed on a real-world view [25]. Liarokapis & Anderson [17] define AR as harmonizing the virtual and real environment in order to provide an understandable and meaningful view. AR is a vision-based technology that requires a "marker" to create a connectedness between the real environment and the one that is generated by the computer [26]. A marker, also known as a fiducial, is a machine-readable optical label that contains information that can be decoded to produce an image on a device running software capable of interpreting the label [25]. However, if the AR software is unable to properly connect the real environment to the virtual one, the illusion that the two worlds coexist will be compromised [25]. Therefore, in this research, the use of markers that can be placed in very specific and controlled locations is a preferred method of rendering the augmented view because it eliminates complexity in setup and the need for high-powered computing currently necessary in non-fiducial rendered AR.

A survey of mobile applications available to most of today's mobile devices will show that several are making use of AR technology - for entertainment, marketing, and education. With today's visually motivated generation of media-conscious students [27], the application of the latest AR technology, along with mobile devices with which students are already familiar, will provide a visually active learning environment that has the greatest potential to improve spatial skills. In fact, some postsecondary CM students are already aware of AR and have good knowledge about the terms surrounding this technology. However, according to Shirazi & Behzadan [28] they are unable to relate the use of these tools to their own learning experience and therefore, rely on universities and schools to make this connection. Therefore, the researcher decided that the use of a mobile device would be fitting for this study because students are 1.) already familiar with its use, 2.) it is a platform that has the ability to easily render AR media when used with a simple to configure "marker" and 3.) because students are already familiar with mobile devices; their introduction in the learning experience will involve less distraction so as to provide clearer results during the experiment's intervention.

3 Methodology

The research questions presented in this study were developed to validate the use of a mobile augmented reality (MAR) tool that could be used in a conventional classroom setting. Moreover, this research is set to determine if the use of a MAR tool would improve the spatial skills of postsecondary CM students. Therefore, this study followed a quantitative between-group double-blind experiment model using pre-assessment and post-assessment surveys (see Figure 1.). The students completed a background survey followed by a pre-assessment and then the researcher conducted an educational lecture for both groups simultaneously. Immediately following, the group was divided into separate rooms. Both groups were administered a lab assignment that they were allowed to complete in smaller groups of 2 to 3 students per group. The test group intervention included a mobile hand-held device equipped with augmented reality software that the students could use to aid in the completion of their lab assignment. Following the lab assignment, and with the students still segregated, the post-assessment was administered along with a survey to ascertain the effort (self-perceived) that students underwent during the experiment. This procedure, start to finish, was completed twice to obtain a total population of twenty-five students (n=25).

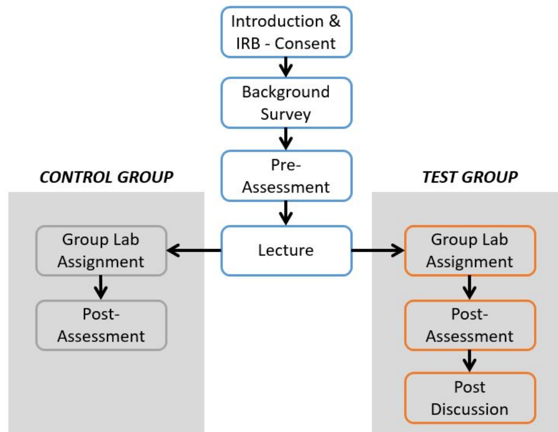

Figure 1. Experiment procedure workflow.

3.1 Setting and Sampling

This study took place at a U.S. postsecondary institution in Gwinnett County, Georgia; an adjacent surrounding county to Atlanta, Georgia. This postsecondary institution operates as a technical college and has an overall student population of 10,068 students as of 2015. The technical college operates a two-year construction management program that has an enrollment population of 60 students as of 2015. The sampling procedure used by the researcher was a nonrandom convenience sampling. The students for this study were restricted to willing students that were available at a predetermined time as coordinated with the students' instructor, hence, the sampling took place during the students' normally scheduled class time.

3.2 Student Demographics

A background survey was used to obtain the demography of the sampling. Of the 25 students, 76% were male and 24% were female. Within the control group, 85% reported male and 15% reported female, while within the test group, 67% reported male and 33% reported female. Age was nearly evenly distributed. Within the control group, 31% reported 18-25 years, 38% reported 26-35 years and the remaining 31% reported 36 years or older, while within the test group, 42% reported 18-25 years, 17% reported 26-35 years and the remaining 42% reported 36 years or older. In terms of previous work experience within the AECFM industry, a combined 68% reported more than one year of experience. Conversely, 20% of the students in the control group reported having less than one year of experience and 12% had no experience. This is important to note in that it may have an effect on the outcome of the assessment scores given the correlation between more work experience and improvement in spatial skills [20][7]. While all of the students reported a high school or equivalent education level, 19% had earned another Associates Degree and 5.4% had earned a Bachelor's Degree. All of the students were pursuing a Construction Management Associates Degree and reported some level of past experience with courses that used visual skills or visual technology. In an effort to gauge comfort level with the use of technology in the classroom, the students were asked if they were agreeably comfortable using mobile technology to obtain more information about things they had questions about. 80% of the students responded as "Strongly Agree" and the remaining 20% responded with "Agree". The students were asked to self-report their skill level in plan reading, as this skill, if practiced often, could have an effect on the students' spatial skills proficiency. The proficiency was spread between 12% claiming "Highly Proficient", 28% "Advanced Experience", 24% "Intermediate Experience" and 36% "Basic Experience". No one reported, "No Experience".

3.3 The Marker (Lab Assignment) and AR Software

Components used in this study included a marker (fiducial), 3D modeling software and augmented reality web platform. Markers were used by both the control and test groups as a lab assignment handed out in paper form (see Figure 2.).

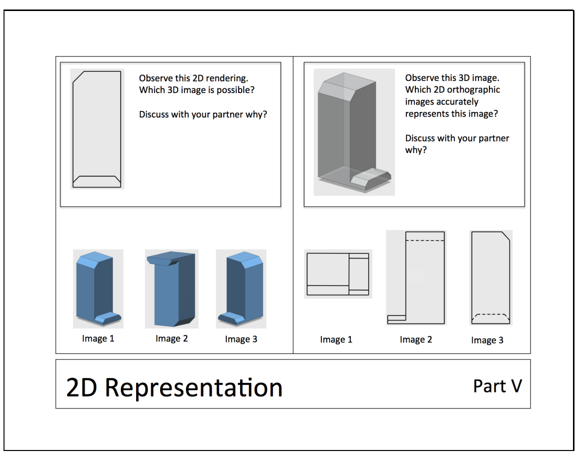

Figure 2. "Marker" (lab assignment) required for the AR software to render 3D images on the screen of a mobile device.

The marker was created using a standard off-the-shelf word processor editing package. The content on the marker was a standard spatial skills assignment. The 3D models used in this study were created by Autodesk's 123D Design (http://www.123dapp.com/design); a commercially available desktop software package capable of creating and editing 3D models. Once a 3D model was created in 123D Design, it was exported for use in the AR software. The AR software used in this study was Augment (http://www.augment.com); a commercially available mobile software package used to scan a marker (fiducial) and render a 3D model on the screen of a hand-held mobile device (HHMD). A student, along with a HHMD and the AR software, would scan the paper-form of the marker using the AR software (see Figure 3.). Once the image was recognized and matched with the inventory of stored marker images from the server, the HHMD's AR software would call the corresponding 3D model from the server and combine it along with the image of the marker being captured by the HHMD's back-facing camera (see Figure 4.).

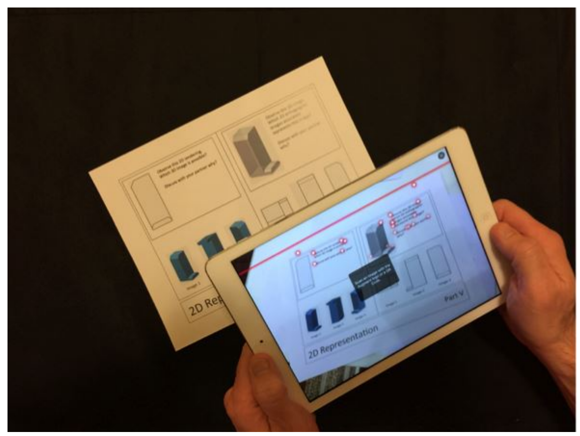

Figure 3. Scanning a "Marker" (Lab Assignment).

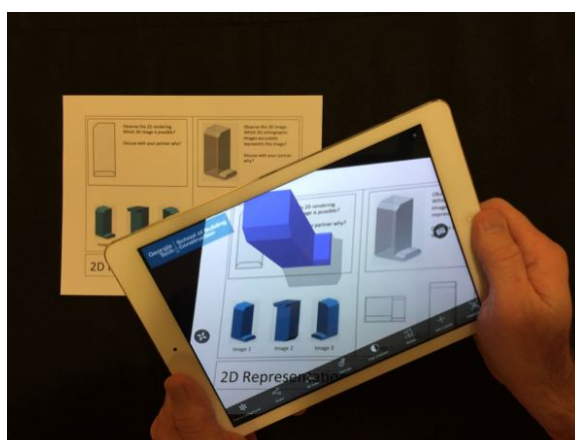

Figure 4. After scanning a "Marker".

The combined image on the HHMD showed the marker with a 3D AR model displayed on it. Lastly, the 3D model displayed on the HHMD's screen was superimposed over, and attached to, a live image of the marker that was being displayed by using the HHMD's back facing camera. The student could then interact by moving the HHMD or the paper-form marker (see Figure 5.).

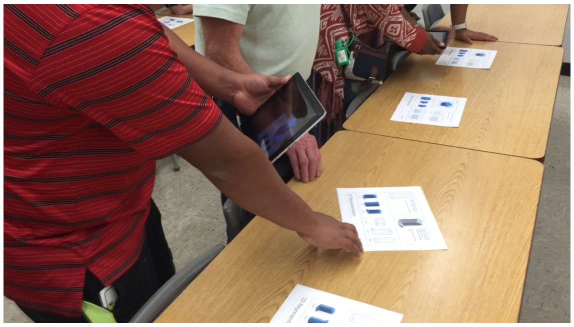

Figure 5. Students interacting with HHMD and "Marker".

4 Results

The results of this study measure the student's spatial skills by using isometric projections, 3D to 2D orthographic translations, building elevation translations and mental rotation of shapes in the form of a lab assignment. The content for the assessments and activities was modeled from a series of spatial tests that have current basis in ongoing research about spatial skills. Content from the following spatial skills research was used in this experiment: the Purdue Spatial Visualization Tests: Visualization of Rotation (PSVT:R) [14], Differential Aptitude Tests: Spatial Relations (DAT:SR) [12] and the Mental Rotations Test (MRT) [16]. The results of the assessment scores on the pre-assessments, post-assessment and the long-term assessment have been tabulated below in Table 1.

Table 1. Statistical analysis of results of pre-assessment, post-assessment and long-term assessment. Note: Maximum possible score = 10.

	Pre			Post			Long Term		
Group	**M**	**SD**	**n**	**M**	**SD**	**n**	**M**	**SD**	**n**
Control	5.2	1.6	13	5.8	2.1	13	7.2	2.3	9
Test	5.3	1.4	12	7.2	1.6	12	8.8	1.4	9

To further evaluate the data in Table 1, an improvement percentage (IP) was calculated and tabulated in Table 2. The following formula was used to derive a measurement of improvement between the assessments.

$$\frac{\text{Mean (New)} - \text{Mean (Original)}}{\text{Mean (Original)}} \text{ X } 100 = \text{IP}$$

Table 2. Tabulation of improvement percentages (IP) of assessment scores.

	Pre to Post		Pre to Long Term	
Group	**IP**	**n**	**IP**	**n**
Control	11.5%	13	38.5%	9
Test	35.8%	12	66.0%	9

It has been suggested that a certain measure of applied technology in the classroom can have an interfering effect on the learning experience [24]. When deploying new technology in the classroom, will its use equate to a better and more active learning experience [28]? For this facet of pedagogy to be measured in this study a NASA Task Load Index (TLX) survey was administered for the purpose of measuring the student's perceived effort on six independent sub-scales. The sub-scales and their associated results have been tabulated in Table 3.

Table 3. NASA TLX survey results data. In the NASA TLX scale -10 = very low demand and +10 = very high demand within the sub-scales measured.

	Control		Test		Mean Variance
Sub-scale	**M**	**SD**	**M**	**SD**	**△**
Mental	1.5	5.2	0.2	5.4	1.3
Physical	-7.7	5.3	-8.7	2.7	1
Temporal	-5.8	5	-5.3	3.5	-0.5
Performance	4.4	5.6	6.3	2.8	-1.9
Effort	0.8	4	1.6	6.1	-0.8
Frustration	-7.5	3	-7.2	3.4	-0.3

5 Discussion

5.1 Effect on Accuracy

Analyzing the mean assessment scores between the pre-assessment and the post-assessment, the data indicates an improvement in spatial skills for the test group's post-assessment scores (M = 7.2, SD = 1.6, n=12) compared to their pre-assessment scores (M = 5.3, SD = 1.4, n=12) (see Table 1). Furthermore, when comparing the IP of the test group (35.8%) to that of the control group (11.5%) the data indicates a greater improvement for those that used the MAR pedagogical tool to complete the lab assignment. For the purposes of this study, and in response to the research question, “Can a mobile augmented reality pedagogical tool be used to improve the accuracy of spatial skills in CM students at the postsecondary level?” an independent sample t-test was performed to measure the statistical significance of the mean scores for the test group. Assuming a Confidence Interval percentage of 95% (CI = 95%) then $t_{(11)} = -4.095$, $p = .002$ ($p \leq .05$), resulting in a significant improvement between the tests.

Likewise, analyzing the mean assessment scores between the pre-assessment and the long-term assessment, the data indicates an improvement in spatial skills for the test group’s long-term assessment scores (M = 8.8, SD = 1.4, n=9) compared to their pre-assessment scores (M = 5.3, SD = 1.4, n=12) (see Table 1). Furthermore, when comparing the IP of the test group (66.0%) to that of the control group (38.5%) the data indicates a greater improvement for those that used the MAR pedagogical tool to complete the lab assignment. For the purposes of this study, and in response to the research question, “Can a mobile augmented reality pedagogical tool be used to improve the retention of newly acquired spatial skill in CM students at the postsecondary level over time?” an independent sample t-test was performed to measure the statistical significance of the mean scores for the test group. Assuming a Confidence Interval percentage of 95% (CI = 95%) then $t_{(8)} = -6.932$, $p = .000$ ($p \leq .05$), resulting in a significant improvement between the tests.

5.2 Perceived Student Effort

The resultant measurements shown in Table 3 indicate that overall, the perceived effort between the control group and the test group were similar. The slight exceptions (the variance was greater than or equal to $|1|$) included mental, physical, and performance workloads. For the purposes of this study, and in response to the research question, “Will the use of a new pedagogical tool be an interference to the overall learning experience?”, the data indicates the control group expended more mental effort and physical effort than the test group during the lab assignment. And the test group perceived higher performance from the lab assignment than the control group. In order to derive a benefit from this type of intervention, it should be expected that there is either a negligible effect on these sub-scales (no difference between groups) or that the test group perceives lower levels of mental and physical effort than the control group. Likewise, higher levels of perceived performance for the test group over the control group would also prove this pedagogical tool as a benefit. Overall, having similar data between the groups indicates no additional perceived effort was expended because of the intervention, an outcome that has potential benefit for this intervention as a pedagogical tool.

6 Conclusion

The author has identified augmented reality as a technology with the potential of becoming a useful academic tool for improving spatial skills in construction management students. However, as noted earlier in this paper, there were several students that had significant work experience that could lead to results that would favor those with better spatial skills coming into the study. While the results of this study are significant, the author would suggest a broader sampling to include more students of varying background to validate the research questions. Nevertheless, this study presents a methodology for the introduction of a simple-to-configure mobile AR tool that can be easily employed within the CM classroom.

The outlying expectation of this research is to bring awareness and applicability of AR to the construction industry. It is the opinion of the author that in order for AR to gain acceptance in the greater AECFM industry there needs to be a workforce that is already familiar with the technology, therefore, the introduction of AR at all levels of the education spectrum is a great first step in bringing this awareness. As noted by Holt & Kearney [30],

> “BIM continues to be the leader of advancing technology, and a lot of emerging technology falls under the BIM umbrella. Augmented reality [is] about more efficiently gathering and communicating information about the project.”

This statement implies that there is a future for AR within the AECFM industry as it continues to find a foothold in the way that BIM has. And similarly, to the way BIM improves the quality of learning by supporting visualization [24], AR can also support visualization and therefore the learning experiences of CM students. There is optimism that AR will gain momentum in the construction industry by way of preparing CM students for this technology while they are in the classroom. As the graduating CM students become more familiar with AR technology and its ability to benefit complex visualization and collaboration, they are likely to be more comfortable with realizing its potential within the industry, thereby minimizing some of the barriers to its use.

References

[1] Clough, R. H., Sears, G. A., Sears, S. K., Segner, R. O., & Rounds, J. L. (2015). Construction contracting: A practical guide to company management. John Wiley & Sons. (pp. 1-29).

[2] Kelleher Jr, T. J., Mastin, J. M., Robey, R. G., Smith, C., & Hancock, L. L. P. (2014). Smith, Currie and Hancock's Common Sense Construction Law: A Practical Guide for the Construction Professional.

[3] Pierce Jr, D. R. (2013). Project scheduling and management for construction (Vol. 89). John Wiley & Sons. (pp. 7-10).

[4] Ahmed, S. M., Yaris, C., Farooqui, R. U., & Saqib, M. (2014). Key attributes and skill for curriculum improvement for undergraduate construction management programs. International Journal of Construction Education and Research, 10(4), (pp. 240–254).

[5] Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2013). Augmented reality in Education - Cases, places, and potentials. In Proceedings of the 2013 IEEE 63rd Annual Conference International Council for Education Media, ICEM 2013.

[6] Martin-Gutierrez, J., Guinters, E., & Perez-Lopez, D. (2012). Improving strategy of self-learning in engineering: laboratories with augmented reality. Procedia-Social and Behavioral Sciences, 51, (pp. 832–839).

[7] McCuen, T. (2014). Investigating the Predictors of Spatial Skill Essential for Construction Science Student Success in the Digital Age. (Doctoral Dissertation). Retrieved from: Department of Educational Psychology, University of Oklahoma.

[8] Hsi, S., Linn, M. C., & Bell, J. E. (1997). The role of spatial reasoning in engineering and the design of spatial instruction. Journal of Engineering Education, 86(2), (pp. 151–158). Retrieved from: https://doi.org/10.1002/j.2168-9830.1997.tb00278.x

[9] Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. (L. Khelmani, Ed.), John Wiley & Sons (2nd ed., Vol. 2). Wiley.

[10] John Hopkins Center for Talented Youth. (2015). What is spatial ability? Retrieved from: http://web.jhu.edu/cty/STBguide.pdf

[11] Shirazi, A. (2014). Context-Aware Mobile Augmented Reality Visualization in Construction Engineering Education. (Master's Thesis) Retrieved from: University of Central Florida Orlando, Florida.

[12] Bennett, G. K., Seashore, H. G., & Wesman, A. G. (1956). The differential aptitude tests: An overview. The Personnel and Guidance Journal, 35(2), (pp. 81–91). Retrieved from: https://doi.org/10.1002/j.2164-4918.1956.tb01710.x

[13] Caissie, A. F., Vigneau, F., & Bors, D. a. (2009). What does the Mental Rotation Test Measure? An Analysis of Item Difficulty and Item Characteristics. The Open Psychology Journal, 2(1), (pp. 94–102). Retrieved from: https://doi.org/10.2174/1874350100902010094

[14] Guay, R. B. (1976). Purdue Spatial Visualization Tests: Visualization of Rotations. Purdue Research Foundation.

[15] Maeda, Y., Yoon, S. Y., & Lafayette, W. (2011). Measuring Spatial Ability of First - Year Engineering Students With the Revised PSVT : R. American Society for Engineering Education, (p.19).

[16] Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. Perceptual and Motor Skill, 47(2), (pp. 599–604).

[17] Liarokapis, F., & Anderson, E. F. (2010). Using Augmented Reality as a Medium to Assist Teaching in Higher Education. In Eurographics 2010 (pp. 9–16). Eurographics Association. Retrieved from: http://eprints.bournemouth.ac.uk/20907/1/eg_eduAR10.pdf

[18] Schwald, B., & De Laval, B. (2003). An augmented reality system for training and assistance to maintenance in the industrial context. Journal of WSCG, 11, (pp. 1–3).

[19] Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. PNAS Proceedings of the National Academy of Sciences of the United States of America, 111(23), (pp. 8410–8415). Retrieved from: https://doi.org/10.1073/pnas.1319030111

[20] Martin-Gutierrez, J., Saorin, J. L., Martin-Dorta, N., & Contero, M. (2009). Do Video Games Improve Spatial Abilities of Engineering Students? International Journal of Engineering Education, Vol. 25 (Issue 6), (pp. 1194–1204).

[21] Alias, M., Black, T. R., & Gray, D. E. (2002). Effect of instruction on spatial visualization ability in civil engineering students. International Education Journal, 3(1), (p. 12). Retrieved from: http://eprints.uthm.edu.my/1815/1/EFFECT_OF_INSTRUCTION_ON_SPATIAL_MAIZAM_ALIAS.pdf

[22] Black, R. G., & Duff, S. (1994). A model for teaching structures: finite element analysis in architectural education. Journal of Architectural Education, 48(1), (pp. 38–55). Retrieved from: https://doi.org/10.2307/1425308

[23] Ryu, S., Kim, M. H., Kinnas, S. A., & Kang, J. H. (2003). Development of Web-based Numerical Wave Tank and Java Applets as an Advanced Tool for Teaching Wave Mechanics. In 2003 ASEE Annual Conference & Exposition.

[24] Wong, K. A., Wong, F. K. W., & Nadeem, A. (2011). Building information modelling for tertiary construction education in Hong Kong. Journal of Information Technology in Construction, Vol. 16, (pp. 467–476).

[25] Azuma, R. (1997). A survey of augmented reality. In Presence: Teleoperators and Virtual EnvironmentsPresence, 6(4), (pp. 355–385). Retrieved from: http://scholar.google.com/scholar?q=intitle:A+Survey+of+Augmented+Reality#0

[26] Feiner, S., Macintyre, B., & Seligmann, D. (1993). Knowledge-based augmented reality. Communications of the ACM, 36(7), (pp. 53–62). Retrieved from: http://dl.acm.org.prx.library.gatech.edu/citation.cfm?doid=159544.159587

[27] Moskal, B., Lurie, D., & Cooper, S. (2004). Evaluating the effectiveness of a new instructional approach. ACM SIGCSE Bulletin, 36(1), (pp. 75–79).

[28] Shirazi, A., & Behzadan, A. H. (2014). Design and Assessment of a Mobile Augmented Reality-Based Information Delivery Tool for Construction and Civil Engineering Curriculum. Journal of Professional Issues in Engineering Education and Practice.

[29] Cristia, J., Ibarrarán, P., Santiago, C., Santiago, A., & Severin, E. (2012). Technology and Child Development : Evidence from the One Laptop per Child Program. IZA Discussion Paper No. 6401. Retrieved from: https://doi.org/10.2139/ssrn.2032444

[30] Holt, P. E. A., & Kearney, N. (2015). Emerging Technology in the Construction Industry : Perceptions from Construction Industry Professionals. American Society for Engineering Education, (Paper ID#12604).