Application of Low-Cost 3D Scanning Technologies to the Development of Educational Augmented Reality Content

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***Abstract*— This paper builds on the authors' previous work with Augmented Reality (AR) technology as a tool to enhance traditional visualizations and facilitate the understanding of complex information. In this paper, we expand our previous work with AR technology by focusing on the process of creating custom content. Based on users' feedback, we describe and compare various strategies to create 3D models from real objects that can be subsequently integrated into augmented reality scenes. Specifically, we evaluate current 3D scanning technologies that are affordable and suitable for educational applications. We present a comparative analysis of low-cost 3D scanning technologies, its use, integration with AR, and implementation as educational tools. Factors considered in our study include portability, model size, resolution, and post-production requirements.**

Keywords*— *augmented reality; 3D scanning; 3D content creation; visualization

I. Introduction

Although lectures and traditional teaching practices remain the primary method of instruction for most educators in their respective disciplines, research shows that these approaches do not necessarily succeed at eliciting comprehension of complex concepts [1]. Furthermore, many scholars have suggested that learning becomes more effective when it is interactive, student-centered, and technology-driven [2-4]. In this context, Augmented Reality (AR) technology has been shown to be an effective resource to complement traditional instructional materials, which are typically based on printed media, while promoting the development of self-assessment and self-directed learning skills [5, 6].

The beginnings of AR date back to the late 1960s, when Sutherland developed a see-through head-worn device to display 3D graphics [7]. Today, AR is a well-established research field, with applications in many disciplines.

Augmented Reality (AR) refers to the real-time visualization of a physical environment whose elements are enhanced by computer-generated imagery [8]. Ideally, from the user's standpoint, it would appear that the virtual and real objects coexist in the same space, so the combined environment is perceived as a whole. AR can be experienced directly (through the use of see-though displays such as AR glasses and head-mounted displays, or the application of projection techniques [9]), or indirectly by using "magic mirror" implementations (where the user sees herself in an augmented world that is displayed in a computer screen) or "magic window" (also called "magic lens") applications (such as mobile augmented reality tools where overlaying digital information onto the real world is viewed through a camera phone) [10].

In educational environments, AR has been used successfully in many disciplines such as engineering design graphics [11-13], architecture [14], medicine [15, 16], and repair and manufacturing training [17]. In addition, AR technology has been consistently listed by the Horizon Report [18] as a tool that will be widespread in both K-12 and higher education in the near future. The potential of AR for learning and assessment allows students to build new knowledge based on interactions with virtual models that bring the underlying data to life [18].

In terms of practical implementations, however, many problems exist beyond merely cost and technical considerations that prevent AR technology from fully and effectively entering educational arenas. For example, many existing educational AR applications provide predefined content with limited or no customization options. Therefore, it is difficult for instructors to create their own materials. Authors Kerawalla et al. [19] reported that teachers value the potential of AR technology as an educational resource, but demand more control of the assets, so they can adapt them to the specific needs of their students.

In our previous study [20], we described an image-based modeling strategy to rapidly create custom augmented reality content by using three-dimensional data from real objects and an authoring tool developed in-house. In this paper, we expand the modeling aspect of this methodology by evaluating alternative 3D scanning technologies that are affordable and suitable for education. We present a comparative study of current low-cost 3D scanning technologies, its use, integration with AR, and implementation as educational tools. Factors considered include portability, model size, resolution, scene preparation, and post-production requirements.

II. 3D Content Creation

The development of high quality 3D content is a fundamental component of the augmented reality experience. 3D computer modeling refers to the process of developing a three dimensional representation of an object in the computer. Requirements and strategies for 3D modeling depend on many factors such as the level of detail, reliability, accuracy, costs, and operational aspects, among others [21].

While 3D modeling software packages allow full control of the geometry during the modeling process and provide powerful tools to build highly realistic, accurate, and sophisticated shapes, they typically require a high level of proficiency, training, and skill, which beginners typically do not possess [22]. Additionally, 3D modeling can be a tedious and time consuming activity, which can easily discourage educators from creating custom materials.

In addition to the numerous 3D repositories currently available online (which can certainly be an affordable option when generic 3D models are needed), automatic or semi-automatic methods such as 3D scanning or photogrammetry exist to rapidly reconstruct 3D models from acquired data. These techniques have been successfully applied in areas where large volumes of three-dimensional information are commonplace. Examples include ancient architecture and cultural heritage [23-25] and large-scale urban scenes [26]. In this regard, approaches to AR content development that require no 3D modeling skills or CAD expertise are more suitable for novice users. Techniques that automatically create models from real objects provide a powerful resource for custom content creation.

As discussed in our previous paper [20], photogrammetry allows content designers to set up AR experiences in a few minutes by automatically generating 3D content from a series of photographs of an object acquired from different viewpoints. The manner in which photographs are acquired largely impacts the overall quality of the resulting reconstruction [27].

Recent advancements in specialized hardware have made 3D reconstruction accessible to non-expert users. Although these tools have traditionally been costly and not portable or scalable, modern digital cameras and smartphones combined with the appropriate software (both commercial and free/open source) are starting to provide attractive alternatives to more expensive systems [21].

In this paper, we explore various 3D scanning technologies, its advantages, limitations, and costs in order to accelerate the first step of our original AR content creation method [20]. From a user's standpoint, the method requires no 3D modeling skills and no expertise with CAD packages. Only basic post-processing operations are required. The conversion of the model to an interactive AR element is performed by a custom authoring application which links the scanned 3D model to a two dimensional monochromatic image that can be physically manipulated by the user, and sets up a software viewer to visualize the augmented content. To interact with the model, a computer with the proper software and a web camera are required. A mobile version is also available. When the user's web camera or tablet is pointed at the 2D marker, it is immediately recognized by the augmented reality software viewer and the 3D model is displayed on the user's screen. The marks can be seamlessly integrated within printed lecture notes and assignments descriptions, allowing instructors to enrich their educational resources, and students to truly visualize the objects being described on paper in full 3D.

III. Low-Cost 3D Scanning

In 2012, Friess described 3D scanning technology and its application to paleo-anthropology [28]. In his paper, the author classified 3D scanners by price range and considered only those below $5,000 to be "low-cost." Some of the scanners in his classification include the David 3D scanner and the Nextengine, which cost around $2,500. Modern personal scanners, however, cost significantly less.

The advent of videogame peripherals that can detect depth in 3D space has facilitated the emergence of low-cost scanners. For example, when the Microsoft Kinect is used in conjunction with scanning software, a functional and inexpensive 3D scanner can be built, as shown in Fig. 1. Although many low-cost scanners provide a reasonable model quality, resolutions are naturally not as high as those created by professional devices. Nevertheless, the quality is sufficient for most educational AR applications.

Fig. 1. Scanning process using Kinect Xbox 360 (left) and software Skanect Pro (right)

Most handheld scanners use laser scanning technology. These scanners project a laser line or dot onto the object or environment and a sensor measures the distance to the surface based on the reflected laser beam, which can then be translated into coordinates of a 3D mesh.

In this section, we describe and evaluate different 3D scanning technologies and its application to the creation of augmented reality experiences. Some factors that were considered in our study include:

- Type of connection: most devices must be permanently connected to a computer or tablet. Some also require an external power supply.
- Object size: for small objects, turntable scanners are generally preferred. For larger objects or a person, handheld devices work best.
- Lighting requirements: most scanners for personal use require good illumination so that sensors and cameras can capture the spatial information accurately.
- Scene background: in most cases, unwanted artifacts of the environment appear in a model when a scan is performed. Thus, certain software parameters such as size and depth need to be adjusted.
- Post-production: once a scan is complete, the resulting 3D model needs to be digitally edited prior to the creation of the AR scene.

In general, low-cost scanners can be classified as handheld and desktop. Handheld scanners such as the Structure Sensor or the Sense 3D scanner are fast and portable devices that can digitize objects in a matter of minutes.

The Structure Sensor is a device that attaches to an iPad, which increases the overall cost of the system (see Fig. 2). Free scanning software such as ItSeez3D can be used. This application requires an internet connection, as an external server is used to process the point clouds generated by the scanner. Similarly, the Sense 3D scanner is a handheld device that needs to be connected to a PC to operate. It can scan objects up to 75 feet tall. The device includes custom software that is intuitive and easy to use. However, it is not suitable for objects smaller than a foot (see Fig. 3).

Desktop 3D scanners are devices designed to sit on a desk, so there are inherent limitations in terms of size and weight. A turntable is usually integrated in the scanner. The object to be scanned is placed on the rotating turntable surface, which is automatically digitized by the device. Examples of this type of scanners include the MakerBot Digitizer (Fig. 4) and the Ciclop BQ (Fig. 5).

A comparative list of the 3D scanners tested for this study is shown in Table 1.

Fig. 2 Scanning process using Structure Sensor for iPad and software ItSeez3D

Fig. 3. Scanning process of a coral using Sense 3D scanner

Fig. 4. Scanning process of a fossil using MakerBot Digitizer

Fig. 5. Scanning process using Ciclop BQ

TABLE I. COMPARISON OF LOW-COST 3D SCANNERS

Device	Type	Device Cost	Software	Software Cost	Object Size	Resolution	Observations
Kinect Xbox 360	Handheld (adapted)	$	ReconstructMe Skanect Pro	Free $$	> 7.5 cm	0.9 mm	It requires external power supply. Not ergonomic, but handles and tripods can be purchased separately.
Structure Sensor + iPad	Handheld	$$	ItSeez 3D Skanect Pro	Free $$	> 40cm and < 3.5 m	0.9 mm	Portable and compact. iPad required.
Sense 3D	Handheld	$$	Sense 3D	Included with Hardware	> 35 cm and < 3.5 m	0.9 mm	Simple and easy to use. PC connection. Powerful editing software. No post-production needed.
Ciclop BQ	Desktop	$$	Horus	Free and Open Source	< 25 cm diameter and <20 cm tall	0.5 mm	Open Source project. Needs assembly. Auto-calibrating software. Large or heavy objects not supported.
Makerbot Digitizer	Desktop	$$$	MakerWare	Included with Hardware	< 20.3 cm	0.5 mm	One of the first low-cost scanners. Large or heavy objects not supported.

The maximum diameter of the Makerbot Digitizer is 20 cm. Maximum and minimum height is 20.3 cm and 2 cm, respectively, with a precision of 0.5 cm. The device is designed for beginners, as the scanning process is completely automatic. The Ciclop BQ is a device that is ideal for scanning small objects. Both the software and the mechanical and electrical designs are available to users as open source projects.

Because of the nature of 3D scanning technology, objects must be set up in a certain manner prior to scanning. In order to obtain an optimal 3D reconstruction, the following factors that might influence the result must be taken into consideration: (1) ambient light; (2) object characteristics such as material, color, and shape; and (3) the scene background.

For example, when conducting our study, objects with shiny, glossy, or reflective surfaces did not scan properly. Similar problems occurred with transparent or translucent materials, and objects with completely black or very dark surfaces. Nevertheless, our team was able to successfully scan objects with these types of surfaces by simply spraying the object with a white coating prior to scanning. The white coat was removed from the object after finishing the scan.

In terms of shape, special attention must be given to areas of the object with hidden faces, folds, or undercuts. It is also important that the object does not move during the scanning process. Otherwise, missing parts and other artifacts may appear in the resulting model.

It is recommended to have a controlled environment and set up the scene with a medium intensity ambient light that does not point directly to the object or the 3D scanner. In our tests, models with missing parts and holes were occasionally obtained because of poor lighting conditions. Additional artifacts were obtained when the background has a color that is similar to the object. In most cases, however, basic editing tools can be used to remove these elements.

Finally, the scanned 3D model needs to be exported and processed by the AR authoring tool, so the AR scene can be created. Several formats such as OBJ, STL, PLY, and FBX are available depending on the scanning software. Because of the formats supported by our AR authoring tool, we exported our models to FBX so they can be easily processed.

IV. CREATION OF THE MARKER-BASED AUGMENTED REALITY SCENE

The models obtained though 3D scanning processes can be converted to and experienced as AR scenes by importing them to the authoring software (*Aumentaty Author*) and using the techniques described in [20]. The authoring tool is available at http://author.aumentaty.com.

The tool provides an intuitive system to create AR content without any technical or programming skills by linking the scanned 3D model to a two dimensional tangible marker which is used to interact with the scene. The most basic and common type of markers take the form of black and white patterns, which allow the AR software to identify the proper AR content that is linked to that particular marker.

AR scenes created with *Aumentaty Author* can be experienced through a desktop PC with a webcam or via a mobile device. The device camera captures real world footage and the AR viewer software generates the augmented content in real time, which is automatically positioned and oriented with respect to the real footage on the screen (see Fig. 6). From an educational standpoint, fiducial AR markers can be easily integrated into traditional notes and printed materials [11].

Aumentaty Author uses tracking algorithms to determine the position and orientation of the marker with respect to the camera and render the 3D content in real time. The creation process is visual and user friendly. First, scanned 3D models need to be imported into the software library. Supported formats include FBX, DAE, and OBJ. Textures and animations, if any, need to be embedded in the 3D file. Imported 3D models are then linked to a specific marker by simple drag-and-drop actions of the icons over the markers. A visual cue in the software interface will indicate whether a marker has attached information.

A preliminary view of the AR scene can be displayed in the graphics area. Parameters such as scale, orientation, and position of the 3D model with respect to the marker can be adjusted, if necessary, via the main panel by using the available controllers.

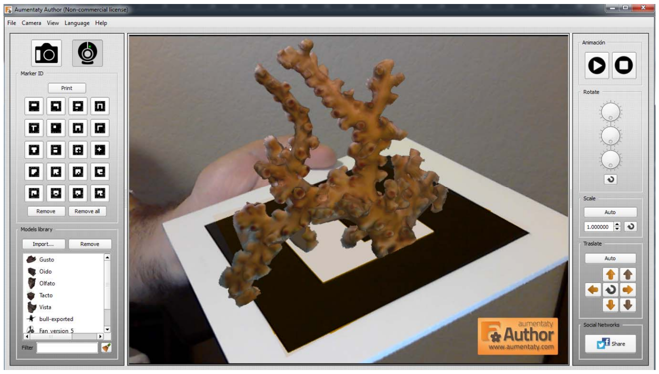

Fig. 6. AR coral scene from scanned 3D model

V. PRELIMINARY STUDY

A pilot study was conducted with a group of 44 freshman engineering students at Universidad de la Laguna, Spain to determine the adequacy of 3D scanning technologies as an educational resource in the classroom. The study ran as part of a digital fabrication workshop that emphasized original design and the introduction of "real world" issues to expose students to a variety of technologies, such as 3D scanning, rapid prototyping, and digital sculpting. The "independent project method" described by Lee [29] was used. As described by Bell et al. [30], a well-designed scenario has the potential to: (1) "create opportunities to integrate the learning outcomes from lectures and laboratory-based teaching sessions," (2) "enhance teamwork, problem solving, and communication," and (3) "extend knowledge using some of the principles of Project-Based Learning." Throughout the workshop, students worked in groups of five to complete a series of hands-on activities that emphasized the use of a specific technology. A total of 87% of the participants had no previous experience with 3D scanning.

The first activity involved building a custom articulated toy. Students were asked to model and 3D print various parts of the toy such as the torso and limbs, and 3D scan their own heads so it could be attached to the printed parts. The activity required significant editing of the model to correctly design the neck joint of the figure. In a second activity, students scanned an object and physically recreated it using stacked layers of EVA foam. Finally, students scanned a section of the classroom to perform measurements on the digital file and compare them with the real values. All models were later converted to augmented reality content.

A psychometrically validated satisfaction questionnaire was distributed at the end of the workshop to capture the students' opinions, views, and reactions to the technologies and their use as educational materials. A set of questions were presented to participants using a standard five-point Likert scale: Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree. To assign a quantitative value to these Likert items, progressive positive integer values from 1 (Strongly Disagree) to 5 (Strongly Agree) were used, which allows the use of mean and standard deviation to quantify the parameters of interest. The questions relevant to the use of 3D scanning technologies in educational environments as well as the statistical measures used to analyze the results are shown in Table II.

TABLE II. SURVEY RESULTS (N=44)

Question	Mean	Std. Dev.
The use of the 3D scanner (Structure sensor) is useful in engineering	4.68	0.52
Working with 3D scanned meshes boosts creativity.	4.50	0.76
Having a 3D scanner in a educational environment is important for design disciplines.	4.77	0.42
Being able to 3D scan an object or a person is interesting and exciting.	4.75	0.57
I prefer to determine the dimensions of an object by using traditional methods as opposed to 3D scanning.	2.63	1.28
Point clouds provide accuracy (digital measurements) for reconstructing existing geometry.	4.20	0.76
Reverse engineering techniques with 3D scannig tools are useful in engineering.	4.56	0.58
Custom design and fabrication is an interesting and relevant field in engineering.	4.61	0.58
There is a clear relationship between 3D models and digital scanning and fabrication technologies.	4.45	0.69

All aspects of 3D scanning scored notably high. The vast majority of participants considered the technology both appropriate and useful in a classroom environment, particularly for engineering. They also reported that the technology is intuitive and easy to use. All participants seemed engaged from the beginning and completed the assignments successfully. None of them experienced significant difficulties using the scanners. Excitement could be observed during the exercise, although this could be attributed to the novelty effect, as many participants had never used or experienced 3D scanning technology before.

VI. CONCLUSIONS AND FUTURE WORK

As augmented reality technology continues to evolve and more powerful and affordable hardware is developed, the demand for content will continue to increase. In educational environments, both content and tools need to be flexible and adaptable, so educators can accommodate the technology to serve the specific needs of their students.

In our previous research, we proposed a strategy for developing 3D content for augmented reality experiences from real objects. The method is based on image-based modeling techniques and significantly reduces the time required to build a 3D model. It also eliminates the need for modeling skills and technical expertise.

In this paper, we extended our work by introducing and demonstrating an alternative approach to our original method that uses low-cost 3D scanning techniques to generate 3D models. In general, the method is faster and more direct, especially if desktop 3D scanners are used. All the scanners tested have resolutions that are appropriate for the development of augmented reality scenes.

Although certain parameters such as lighting conditions and scene background need to be carefully considered to avoid scanning errors and guarantee the accuracy and consistency of the geometry, the low-cost and ease of use of these devices and techniques facilitate and accelerate the creation of high quality augmented reality experiences for education.

The new methodology (a variation of our image-based modeling technique) provides similar results in terms of resolution as the original method, and still relies on users having access to real objects (so they can be 3D scanned). However, the time involved in reconstructing a scanned 3D mesh is significant less than the time required to process the source images in the original method. In this regard, the use of scanning devices (both handheld and desktop) simplifies the process and reduces the workload. We are preparing a usability study with a group of engineering educators to formally validate both the new methodology and the scanners used.

In the future, we are interested in collaborating with K-12 educators in the creation and integration of custom AR materials. Current efforts include the application of AR technology in classrooms with special needs students. As a technical challenge, we are interested in exploring methods for capturing animations and objects in motion, which can be useful in a wide variety of applications, such as visualizing engineering mechanisms or simulating physical systems.

References

[1] Terenzini, P.T., and Pascarell, E.T. Living with myths: Undergraduate education in America. Change, 1994, 26(1), pp. 28-32.

[2] Levin, D. and S. Arafeh, The Digital Disconnect: The Widening Gap between Internet-Savvy Students and Their Schools. 2002.

[3] Kolb, D.A., Experiential learning: Experience as the source of learning and development. Vol. 1. 1984: Prentice-Hall Englewood Cliffs, NJ.

[4] Millar, S. B. Effecting faculty change by starting with effective faculty: Characteristics of successful STEM education innovators. In National Research Council, Improving Undergraduate instruction in science, technology, engineering, and mathematics: Report of a workshop, 2003, pp. 101-117.

[5] Chen, Y., et al., Use of Tangible and Augmented Reality Models in Engineering Graphics Courses. Journal of Professional Issues in Engineering Education and Practice, 2011. 137(4): p. 267-276.

[6] Martín-Gutiérrez, J., M. Contero, and M. Alcañiz, Evaluating the Usability of an Augmented Reality Based Educational Application, in Intelligent Tutoring Systems, V. Aleven, J. Kay, and J. Mostow, Editors. 2010, Springer Berlin Heidelberg. p. 296-306

[7] Sutherland, I., 1968. “A Head-Mounted Three-Dimensional Display,” Fall Joint Computer Conf., Am. Federation of Information Processing Soc. (AFIPS) Conf. Proc. 33, Thompson Books, Washington, D.C., 1968, pp. 757-764.

[8] Azuma, R.T., A survey of augmented reality. Presence-Teleoperators and Virtual Environments, 1997. 6(4): p. 355-385.

[9] Reed, S., Kreylos, O., Hsi, S., Kellogg, L., Schladow, G., Yikilmaz, M.B., Segale, H., Silverman, J., Yalowitz, S., and Sato, E., Shaping Watersheds Exhibit: An Interactive, Augmented Reality Sandbox for Advancing Earth Science Education, American Geophysical Union (AGU) Fall Meeting 2014, Abstract no. ED34A-01.

[10] Rohs, M. Oulasvitra.A. Target acquisition with camera phones when used as magic lens. In Proceedings of the 26th International Conference on Human Factors in Computing Systems, CHI ’08, pp. 1409–1418. ACM, 2008.

[11] Camba, J., Contero, M., and Salvador-Herranz, G. Desktop vs. mobile: A comparative study of augmented reality systems for engineering visualizations in education. 2014 IEEE Frontiers in Education Conference (FIE), pp. 1-8.

[12] Dorribo-Camba, J., Contero, M., Incorporating augmented reality content in Engineering Design Graphics materials, 2013 IEEE Frontiers in Education Conference (FIE), pp. 35-40.

[13] Dünser, A., et al. Virtual and augmented reality as spatial ability training tools. in Proceedings of the 7th ACM SIGCHI New Zealand chapter's international conference on Computer-human interaction: design centered HCI. 2006. ACM.

[14] Webster, A., et al. Augmented reality in architectural construction, inspection and renovation. in Proc. ASCE Third Congress on Computing in Civil Engineering. 1996.

[15] Sielhorst, T., et al. An augmented reality delivery simulator for medical training. in International Workshop on Augmented Environments for Medical Imaging-MICCAI Satellite Workshop. 2004.

[16] Tang, S.-L., et al., Augmented reality systems for medical applications. Engineering in Medicine and Biology Magazine, IEEE, 1998. 17(3): p. 49-58.

[17] Feiner, S., MacIntyre, B., & Seligmann, D. (1993a). Knowledge-based augmented reality. Communications of the ACM, 36 (7), 52-62.

[18] Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A., and Hall, C. (2016). NMC Horizon Report: 2016 Higher Education Edition. Austin, Texas: The New Media Consortium.

[19] Kerawalla, L., Luckin, R., Seljeflot, S., and Woolard, A. “Making it real”: exploring the potential of augmented reality for teaching primary school science. Virtual Reality, 2006, vol. 10, pp. 163-174.

[20] Camba, J. D., & Contero, M. (2015). From reality to augmented reality: Rapid strategies for developing marker-based AR content using image capturing and authoring tools. In Frontiers in Education Conference (FIE), 2015. 32614 2015. IEEE (pp. 1-6). IEEE.

[21] Kersten, T.P., and Lindstaedt, M. Potential of automatic 3D object reconstruction from multiple images for applications in architecture, cultural heritage and archaeology. International Journal of Heritage in the Digital Era, 2012. 1(3), pp. 399-420.

[22] Nguyen, M.H., Wunsche, B.C., Delmas, P., and Lutteroth, C. 3D models from the black box: Investigating the current state of image-based modeling. Communication Proceedings, Pilsen, Czech Republic, Union Agency, pages 25--28, 2012.

[23] Gaiani, M., Gamberini, E. and Tonelli, G. VR as work tool for architectural & archaeological restoration: the ancient Appian way 3D web virtual GIS, Proceedings of Seventh International Conference on Virtual Systems and Multimedia, 2001. pp. 86.

[24] Lu, S.Z. Virtual Reconstruction of FouGuang Temple Based on Virtual Reality, International Conference on Management of e-Commerce and e-Government ICMECG '08, 2008.

[25] Yao, J., Zhang, H. and She, F. Research on Method of 3D Reconstruction of Ancient Architecture (Nanputuo Temple), International Conference on Cyberworlds, 2008.

[26] Yao, J., Ruggeri, M.R., Taddei, P., Sequeira, V. Automatic Scan Registration Using 3D Linear and Planar Features, 3D Research, 2010, Vol. 1, No. 3, pp. 2-18.

[27] Butnariu, S., Gîrbacia, F., and Orman, A. Methodology for 3D reconstruction of objects for teaching virtual restoration. International Journal of Computer Science, 2013, 3(01), 16-21.

[28] Friess, M. (2012). Scratching the surface? The use of surface scanning in physical and paleoanthropology. Journal of Anthropological Sciences, 90, 1-25.

[29] Lee, N. Project methods as the vehicle for learning in undergraduate design education: a typology. Design Studies, 30, pp. 541-560, 2009.

[30] Bell, S., Galilea, P., and Tolouei, R. Student Experience of a Scenario-Centered Curriculum. European Journal of Engineering Education, 35, pp. 235-245, 2010.