BASIC VISUAL DISCIPLINES IN HERITAGE CONSERVATION: OUTLINE OF SELECTED PERSPECTIVES IN TEACHING AND LEARNING

Anna Lobovikov-Katz*

Faculty of Architecture and Town Planning, Technion - Israel Institute of Technology Technion City, 32000 Haifa, Israel
anna@technion.ac.il

KEY WORDS: Conservation of Cultural Heritage, Heritage Education, Sketching, Descriptive Geometry, E-Learning

ABSTRACT:

Acknowledgement of the value of a basic freehand sketch by the information and communication community of researchers and developers brought about the advanced developments for the use of sketches as free input to complicated processes of computerized visualization, so as to make them more widely accessible. However, a sharp reduction and even exclusion of this and other basic visual disciplines from education in sciences, technology, engineering and architecture dramatically reduces the number of future users of such applications. The unique needs of conservation of cultural heritage pose specific challenges as well as encourage the formulation of innovative development tasks in related areas of information and communication technologies (ICT). This paper claims that the introduction of basic visual disciplines to both communities is essential to the effectiveness of integration of heritage conservation needs and the advanced ICT development of conservation value, and beyond. It provides an insight into the challenges and advantages of introducing these subjects in a relevant educational context, presents some examples of their teaching and learning in the modern environment, including e-learning, and sketches perspectives to their application.

1. INTRODUCTION

Significant progress in modern conservation of cultural heritage has brought advanced technologies and innovative methods to diverse areas of this field, including heritage *documentation and analysis*, and heritage *education*. Given the mainly visual character of cultural heritage, these two areas have a basic element in common - visual data and visualization. Advanced technologies in digital documentation have an important impact on heritage education, and especially in digital-based domains of both, i.e. digital heritage, and distance learning and e-learning. For example, digital models of archaeological and built heritage sites are used for visualization in e-learning of cultural heritage; virtual 3D and 4D models and animations facilitate a virtual learner's understanding of the changes that historic buildings and sites undergo with time. Furthermore, the use of "serious" digital heritage games which combine education theory with digital technologies and the advancements in computer sciences, has become a well-known feature in the heritage education landscape, especially e-learning (Ioannides et al. 2017, Duguleana et al. 2016, Hazan and Lobovikov-Katz 2017).

Education for conservation of cultural heritage can be subdivided into two types: the *direct* and the *indirect*. The first one, *the direct*, - is focused on providing or upgrading the relevant education of professionals and experts involved in the conservation of cultural heritage. The other one, *the indirect*, - aims at preparing the general public as a supporting force to heritage conservation. Indirect heritage education patterns vary widely in their aims, scope and targeted audience. The digital "bonding" mentioned above has great advantages for developing appealing learning programs for raising the awareness of the general public (virtual) learners of the values of cultural heritage, the reasons for its preservation and the challenges and the principles involved (Ioannides et al. 2016, Lobovikov-Katz 2015; Lobovikov-Katz et al. 2012; 2014).

The advantages of digital applications in *direct* heritage education are numerous. However, we step down here below the current mainstream of high automation and learning of advanced digital technologies (though not abandoning their application), in order to pay attention to the underlying layer of visual core disciplines like perspective, descriptive geometry and freehand drawing. This paper demonstrates that proficiency in these basic visual disciplines is highly relevant to conservation and ICT experts, and outlines the selected perspectives of their contribution to conservation of cultural heritage in the modern digital context.

2. BASIC VISUAL DISCIPLINES AND CONSERVATION OF CULTURAL BUILT HERITAGE: OVERVIEW, RETROSPECTIVES AND PERSPECTIVES

2.1 Basic Visual Disciplines Overview

2.1.1 Descriptive geometry and perspective: We start here in reverse historical order of development, with the relatively recent history of basic visual disciplines - D*escriptive Geometry*. It was invented by a young French mathematician, Gaspard Monge, in the late 1760s, and since then it has made a significant contribution to various areas of mathematics. For its groundbreaking theoretical nature of a practical benefit, descriptive geometry was France's military secret for more than two decades after its invention (Lawrence 2003). A common misconception about descriptive geometry reduces it to its mere "façade" which is visible and understandable from outside, confusing it with "precise drawing", i.e. orthographic

* Corresponding author

projections, like a view from above, the side, etc. Such misleading notion totally overlooks the essence of descriptive geometry, its aims and methodology, which actually focuses on providing a set of rules and methodological tools for enabling graphical solutions in two dimensions to complicated spatial problems. Through the use of its theoretical mechanism, descriptive geometry, among its other contributions, allows for correct two-dimensional representations of results of three-dimensional solutions or transformations on 3D objects, hence underlying practically all areas of technical and engineering drawing. According to Stachel (2013) *Descriptive Geometry* […] *is the interplay between the 3D situation and its 2D representation, between intuitive grasping and rigorous logical reasoning*.

Descriptive geometry is used as a basis for perspective, though historically, the principles of perspective had been formulated more than three hundred of years earlier, in the age of the Renaissance. Perspective applies *central projection*. Besides its association with painting and other fields of visual arts, perspective has also made a significant contribution to the development of mathematics.

2.1.2 Freehand drawing and painting: Freehand sketching has been used since ancient times. Since the Renaissance, perspective has been widely used in painting, drawing and architecture, including specific areas of development highly dependent on inter-relationships of 2D artistic images and 3D architectural and sculptural forms, e.g. relief perspective (theatrical setting of *Tetro Olimpico* in Vicenza by Palladio-Scamozzi: Fig. 1; Ghiberti's *Gates of Paradise* in Florence), *Trompe l'oeil* paintings, and their combinations (Bramante's San Satiro in Milano: Fig. 2). Nowadays, with regard to conservation of cultural heritage, artistic images can be used as historical references or be specifically produced by conservation experts for conservation purposes. In the latter case, understanding and conclusions reached in the course of the sketching process can be of equal or even greater importance than the result of this process - the sketch itself (Lobovikov-Katz 2016a, 2016b, 2008).

Figure 1. Perspective of the theatrical setting of Teatro Olimpico in Vicenza by Scamozzi, in continuation of design by Andrea Palladio. Perspective of each "street" is designed to be perceived from a specific seats and rows area (photo©Anna Lobovikov-Katz)

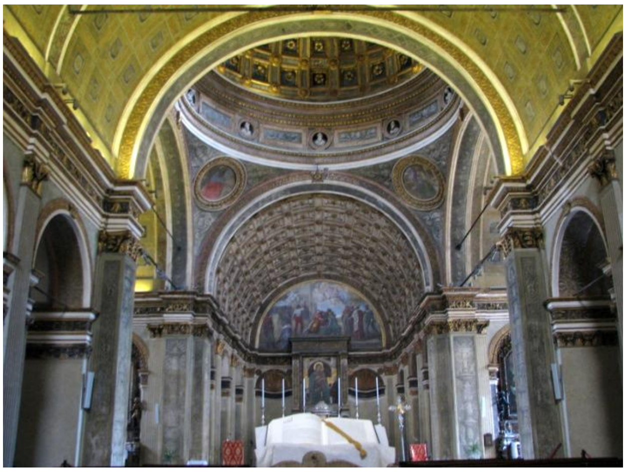

Figure 2. Domenico Bramante designed the illusory extension beyond the dome of the central nave of the Church San Satiro in Milan, which is perceived as a real architectural space from a designed point of view at the main entrance (top). A closer view from the side reveals that actual depth of the nave beyond the dome is only about 94 cm (bottom). (photo©Anna Lobovikov-Katz)

2.2 Teaching, Learning and Using Basic Visual Disciplines in Built Heritage Creation and Conservation: Between the Past and the Present

2.2.1 Spatial ability: Spatial skills and reasoning have a proven value in education in science and technology (Newcombe 2010, Sorby 2009). Spatial ability and spatial visualization are indispensable in the conservation of built cultural heritage. Learning the basic visual disciplines, including descriptive geometry, perspective and freehand drawing, has a significant impact on the development of spatial ability of students (Nemeth 2007, Shepard 1971). Therefore, learning basic visual disciplines contributes directly and indirectly to the conservation of cultural heritage.

2.2.2 Retrospective: In this section we outline the core uses of basic visual disciplines with regard to built heritage, with special attention given to some characteristics specific to this part of heritage. Perspective might be seen as a connecting link between descriptive geometry and freehand drawing and painting. Perspective leads to the understanding of spatial relationship between the location of an observer, the spatial structure of a three-dimensional object, and the resulting three-dimensional result of this static or dynamic interaction - [image and/or perception and/or view] of an object by an observer. We will use an example of the metamorphoses of basic visual disciplines in architectural education, including their freehand applications, as a showcase for our statement. Architects are presumed to possess an ability of understanding spatial inter-relationships between the observer, a complex three-dimensional building and its parts. Architects, besides other skills, are expected to have mastered creating a desired impression of the future buildings through architectural design. In the past, architectural education included profound learning of basic visual disciplines like descriptive geometry and perspective[1]. This led to knowledge and understanding in solving complicated spatial problems and of their expressions in 2D and 3D, and allowed for developing an ability and skills to design a three-dimensional prognosis for a future building/ group of buildings/ complicated three-dimensional structures. Such knowledge and ability to mentally visualize and develop unseen future shapes and their complex interconnections, including such issues as foreseen cast shadows, reflections, etc., have been a powerful tool of architectural design. Freehand drawing, basic painting and sculpture were part of traditional education, and the ease of their application was handy in visualizing such mental shaping of invisible architecture under design process (Tichonov et al. 1983). Freehand sketching summarized and benefited from the knowledge of descriptive geometry and perspective, and was indispensably helpful in the first stages of the design process. Freehand sketch could be immediately transformed in an architect's mind into a spatial "picture", helping to understand what should be changed in plans, sections or facades in order to improve the freehand sketch, and therefore - to improve the spatial object under design. Such command of mental back-and-forth journeying to the entire three-dimensional - two dimensional information array was an effective design instrument. The understanding of mental images of yet non-existing objects, helped and was assisted by freehand drawing of real built heritage objects. This was also part of education, together with on-site measurements, and learning to understand specific historic buildings and sites, and through them - specific chapters of the history of building techniques, durability of building materials, and others. Such "educated freehand sketching", backed up with the knowledge of descriptive geometry and perspective, revealed important information on a building through its visual expression.

From numerous examples of many architects in different historic periods (e.g. Santiago Calatrava stated in his lecture at the Technion in 2006 that he started his design from sketching), we might zoom into this process on a sole example of a sheet of sketches by Michelangelo Buonarroti (1525) of his design of the staircase of Biblioteca Laurenziana in Florence (Michelangelo 2002, Hill and Kohane 2015, Calatrava 2006). These sketches shift with ease from large-scale details of the columns' profiles to two versions of an overall perspective view of the staircase, which show a visual comparative study of the two versions of an idea of spatial inter-relationship between the flights of stairs ascending to the entrance to the library: parallel or converging. A glance at the sketches fully brings the viewer to appreciate the complete mastering of a real three-dimensional space and its 2D imaging.

[1] Projective geometry, though highly relevant to teaching perspective, is not included in this list, because of its rare presence in architectural curricula.

Figure 3. View of the staircase of Biblioteca Laurenziana in Florence, designed by Michelangelo Buonarroti (photo©Anna Lobovikov-Katz)

2.2.3 Present: Nowadays, due to the extended use of digital visualization in computer-aided design, any architectural shape can be achieved "automatically", which makes a mental spatial voyage in a planned-to-be-designed edifice, and, therefore also teaching and learning basic visual subjects seem unnecessary. This leads to two main consequences: reducing the scope or total exclusion of basic visual subjects from the modern education in architecture and engineering, causing a lack of knowledge, which brings about the lack of understanding of the causes and reasons underlying the easily and "automatically" acquired computer-generated results. Furthermore, the abundance of visualization in many areas of learning causes some students to get used to the easily acquired, shallow results in learning. Hence, teaching descriptive geometry to architects becomes a real challenge, and has to be "wrapped" in an attractive visual wrapping (Putz 2001).

Here is a sadly anecdotic example from my teaching practice: after the introduction to perspective, an architectural student concluded that perspective was something similar to comics, As proof, he showed primitively-drawn architectural surroundings from the latter. Such confusing between cause and result, between a basic discipline and its specific limited application, is not uncommon among the students who get an impression of irrelevance of basic disciplines because of the abundance of high technologies. In general, an architectural student turns from a creative leader of the process of architectural design, into a consumer of advanced technologies. It is not uncommon for a student or an architect to be surprised by the results of a computer-generated visualization of his/her own design, instead of having anticipated them in advance. On the other hand, some students realize the not very obvious connection between descriptive geometry, and freehand sketching. In a questionnaire given to participants of my course "Architectural design at the tip of a pencil", many students mentioned that learning and understanding specific subjects as part of the descriptive geometry course, e.g. shadows and sections (topics which are interconnected, though not commonly seen as such) helped them in learning and developing the practical ability of freehand sketching. The course for beginners in architectural freehand drawing consisted of introduction to its basic principles, and of a subsequent study of an "architectural sketching toolkit" and its application to architectural design

doi:10.5194/isprs-archives-XLII-2-W5-459-2017 | © Authors 2017. CC BY 4.0 License.

studio given in the same semester. During the course, among other skills, the students were taught how to "pull out of their mind" their primary amorphous architectural idea using the tip of a pencil, namely the sketch.

In spite of a general decline in teaching and application of basic visual disciplines in architectural and engineering education, the value of freehand sketching as input into the design process is understood by ICT community, resulting in rapid development of sketch-based modeling (Kazmi et al. 2014, Olsen et al. 2009). Therefore, we might face a situation, when ICT development would provide a wide spectrum of excellent technological tools, while users of their applications would be hardly found, because most likely very few would possess the necessary sketching skills to enjoy them. Their number might be even more limited, if the search accepted only people possessing skills in "educated" freehand sketching, i.e. whose practical sketching would be enriched by knowledge and understanding of descriptive geometry and perspective

2.3 Perspectives: between the human and the digital

2.3.1 Applications: Recent revolutionary developments in computer sciences provide new possibilities for visual areas. We bring here examples of applications which use freehand sketches as input. An area much in demand in both new design and conservation of cultural heritage, - 3D modeling, - has inspired advanced developments in sketch-based modeling. The advantages of freehand sketching seem clear to the ICT community. Sketching, and specifically pencil-and-paper sketching is described by ICT developers and researchers in computer sciences as "*a natural way to communicate ideas quickly: with only a few pencil strokes, complex shapes can be evoked in view*ers" (Olsen et al. 2009), and as "*the fundamental first step for expressing artistic ideas and beginning an iterative process of design refinement [which] allows artists to quickly render their ideas on paper*" (Simo-Serra, Iizuka et al. 2016). According to Kazmi et al. (2014), *3D modeling has a very long way to cover to match the convenience of drawing on paper and expressing imagination on paper*. Therefore, the main aims of sketch based modeling are seen as *to automate or assist the sketch-to-3D translation process* (Olsen et al. 2009), *to bridge the gap between concept design and computer-based modeling programs* (Kondo 2009). According to Shtof et al. (2013), *it would be nice if simple 3D models could be created easily from 2D sketches for quick previews and as a starting point for further editing and creation of more complex models*.

Conservation of cultural built heritage has some processes in common with architectural design, e.g. with regard to visualization of a building after restoration, in conservation projects or adaptation to modern use, or in specific cases of modern design in the existing architectural environment. 3D modeling is widely applied for simulation of visual compatibility of the old and the new in the architectural environment. Furthermore, 3D modeling can be useful for examining and visualizing historical hypotheses on reconstruction of archaeological sites from sketches. However, unlike new design, conservation of cultural built heritage focuses much more on understanding and analysis of visual data about real physical conservation state of historic buildings and sites and on visible traces of historical transformations.

Recent, advanced developments in e.g. vector graphics aim *at automatically converting rough sketches into simplified clean drawings* (Simo-Serra, Iizuka et al. 2016). This allows for smoothing rough freehand sketches, concentrating on achieving a clean image. This and other advanced developments might direct our attention to specific conservation tasks, e.g. to the advantages of focusing, or, on the contrary, the analysis and interpretation of seemingly unessential visual information provided in freehand sketches and other types of artistic images. In the conservation of cultural heritage, rough visual characteristics of a freehand sketch of historic building or site contain valuable information on its history, values, or material deterioration, and a freehand image's visual "noise" of deterioration is a key to its understanding, and is often part of the "music" of the patina of time.

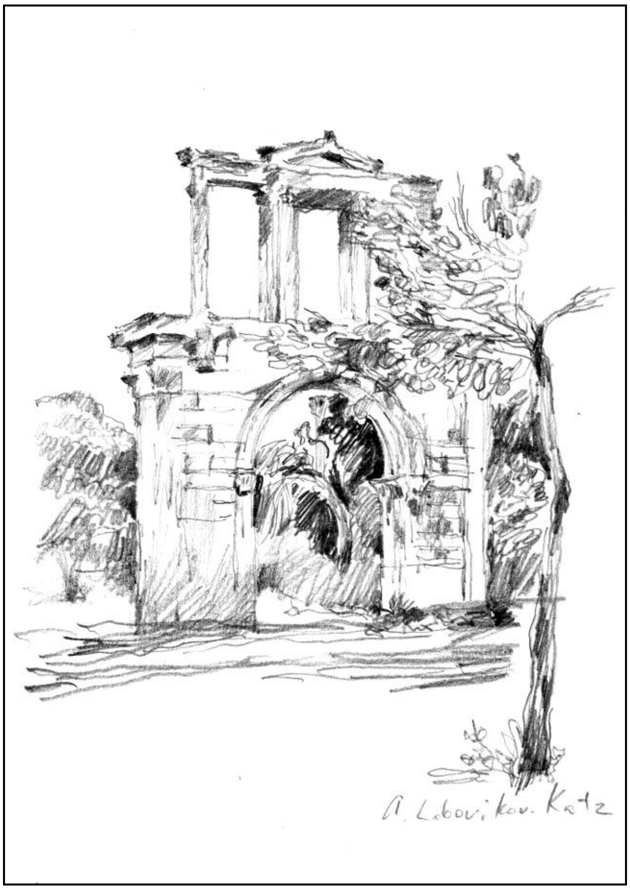

Figure 4. Sketch showing architectural values and material deterioration of a historic structure (©Anna Lobovikov-Katz)

A pencil is a very common sketching tool. It's easy to use, it allows for corrections, and therefore can be easily handled by a large number and by a wide spectrum of sketchers, - beginners and professionals alike. One of basic characteristics of a pencil sketch is the changing character of a pencil line: it varies in width and density. One same line of sketch, produced through one hand movement, might change its visual parameters several times. Sketches of historic buildings or sites might be produced specifically for conservation purposes (to study and understand them), or by artists for mere appreciation. In both cases, aspects of lines matter with regard to visual characteristics and conservation data encoded in them. For example, a change in line density might reflect a specific pattern of material deterioration, or a loss of structural stability, etc. It might reflect both major conservation problems such as structural cracks, and also subtle details. A change in a pencil line density might be an immediate reaction of a sketcher to a change of color or texture of e.g. mortar pointing caused by repair using an incompatible composition of a new mix and subsequent accelerated deterioration.

Seeking to achieve picturesque qualities of their artistic images, artists have frequently looked for irregularities and visible "impurities" in the visual character of depicted buildings and sites. This aesthetical search favored producing artistic images which might be rich in valuable information for researchers and experts in conservation of cultural built heritage. A combined approach to both conservation-oriented sketches and historical images of cultural heritage buildings might enrich the formulation of new tasks in ICT development, and create new opportunities in the analysis of hand-made visual data in the conservation of cultural heritage. For example, noticing the original hand-made "visual noise" of freehand images (e.g. auxiliary lines which seem to disturb the integrity of the image, seemingly out-of-place line density or width of specific lines), with a view to the specific character and needs of conservation of cultural heritage, might be beneficial to both fields. In this case, it is important to look deeper into the basic visual disciplines. We suggest extending to the ICT community the knowledge and understanding of basic visual disciplines, such as descriptive geometry and perspective. This will equip and provide ICT developers and researchers with a better insight into this area, and also make a significant contribution to the development of spatial skills, understanding of complicated forms and of complex spatial transformations.

2.3.2 Teaching and Leaning: Here we focus on a) contribution of e-learning, and b) 2D - 3D inter-relationship. *E-learning* is an integral part of our educational reality, and it has contributed significantly to teaching and learning in practically all areas of knowledge, including different levels of education – from primary to tertiary, life-long learning and courses for the general public. In conservation of cultural heritage e-learning is widely used for raising the awareness among the general public of the values and significance of cultural heritage, thus helping to prevent its involuntary damage or vandalism (Lobovikov-Katz et al. 2014). We concentrate here on specific issues of applying e-learning to basic visual subjects.

Sketching in two-dimensions remains easier than 3D modeling for professional 3D modelers and novices alike. Professional 3D modelers nearly always begin the modeling process by sketching, either on paper or in a 2D sketching application (Shtof et al. 2013). Frequently, people try to explain their ideas through a 2D sketch.

In descriptive geometry, solving complex spatial problems is achieved by spatial three-dimensional transformations with the use of a virtual, theoretical "mechanism" of this discipline, through a mental back-and-forth voyage between the three-dimensional object and its two-dimensional projection planes. Understanding that descriptive geometry "works" in space is a key to mastering this discipline. This is also true with regard to perspective, where the inter-relationship between a perspective image of a three-dimensional object, and its representation in e.g. orthographic projections (façade, plans, sections) should be clear to students. Teaching and learning these disciplines is challenging. Fig. 5 provides some insight into a short 24 hours' course *Introduction to descriptive geometry* for the first year architectural undergraduates. In this course the students are required to design a physical kinematic model of a descriptive geometry mechanism, with regard to a set of specific problems, to solve them in projection planes, and to demonstrate their application in action, between the "flat" and spatial positions of the model in a short video. Fig. 6 shows a fragment of explanation of a possible approach to such a model.

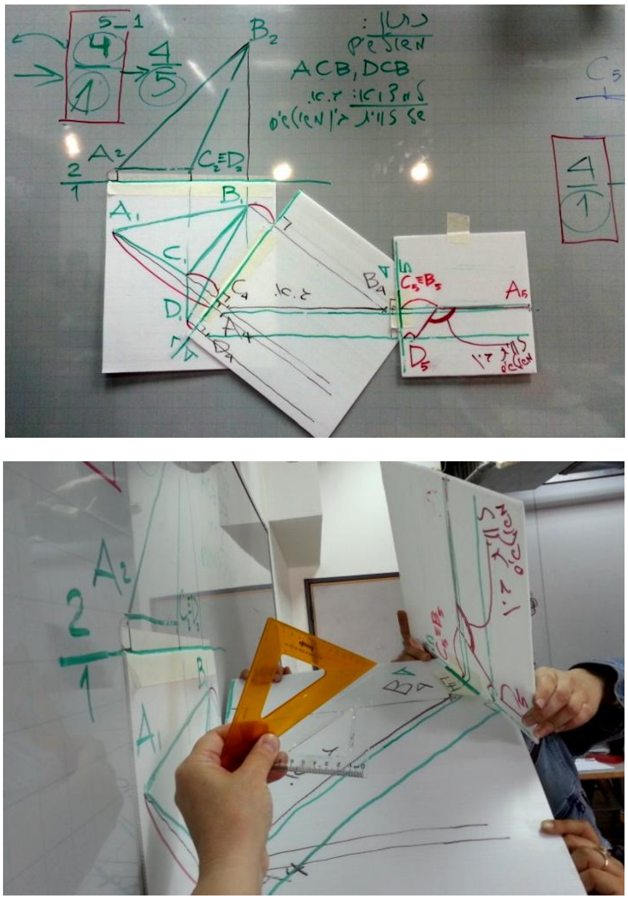

Figure 5. Solving problems between two and three dimensions in a descriptive geometry course: spatial angle defined by two planes a) a flat folded model (top), b) (almost) unfolded model (bottom,) ©Anna Lobovikov-Katz

One of the challenges in combining 2D-3D transformations in teaching descriptive geometry can be exemplified by its introduction to e-learning. We focus here on the visual challenges of this introduction. It would be nice to have the possibility of providing every student with a hologram, or three-dimensional virtual model in virtual or augmented reality, which could be spatially manipulated in real time through both teacher-guided and independent spatial transformations and manipulations, and be used for demonstrations and learning of solving spatial problems by means of e.g. descriptive geometry. Meanwhile, e-learning explanations are shown on a flat computer screen. While in a real classroom or blended learning, we can let students watch, turn over, and examine physical models, it is also important to develop the students' ability to mentally connect between the two- and the three-dimensional. I will show such "linking" exemplified in a recorded course in descriptive geometry, in the introduction of a systematic approach to one of the simplest topics in the course, - axonometric projections. One of the major factors which contribute to defining each specific type of axonometric projection output is the spatial inter-relationship between the axonometric projection plane, and the axes' system (x, y, z). At this point, it is important to instill in students the understanding of spatial correlation between this inter-relationship, which brings to a realization that on a deeper level all diverse types of axonometric projections that look so different in their visual outputs, are defined by merely three "actors": projection plane, projection rays and the axes system. The three-dimensional model of the axes, shown from different perspectives, has been subsequently combined with its two-dimensional version as typical of specific types of axonometric projection, with the use of document camera, and simultaneous 2D transformations on the second screen. Special attention is given to axes and planes defined by each pair of axes (x, y), y, z), (x, z). (Fig. 6)

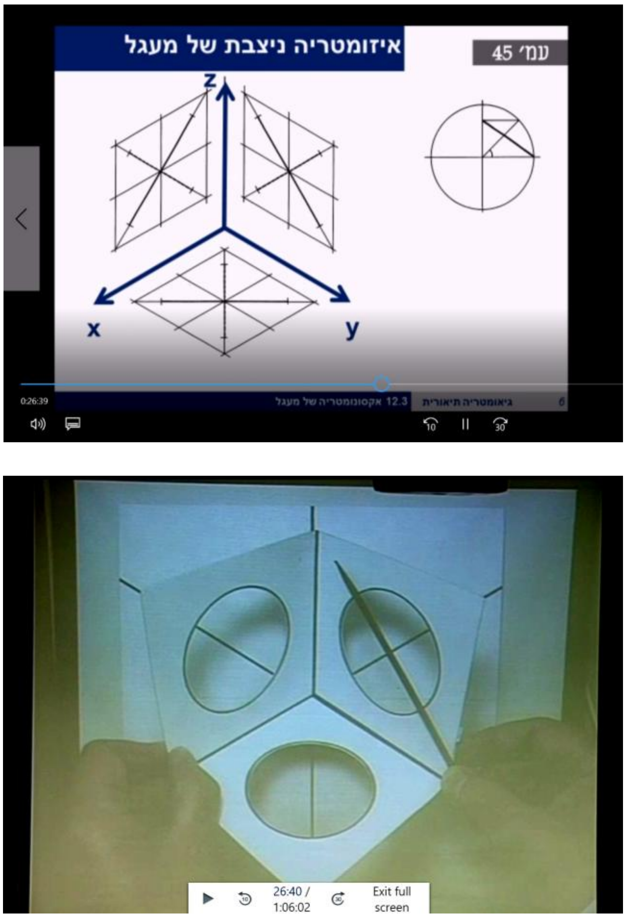

Figure 6. Exemplifying axonometric projections typology and structure in a recorded Descriptive Geometry course by author: isometric projection of a circle in a nutshell: physical 3D model of axonometric axes and circles versus their 2D representation on the projection plane, including 2D - 3D correlation between relevant x/ y/ z axis and major axis of an elliptical projection of a circle (in this demonstration it is an elliptical view of a circle in the model). © Anna Lobovikov-Katz

Basic visual disciplines can be combined in teaching and learning, and subsequently taught as one package, or in layers. Understanding that the basic laws and rules cross-cut into all three disciplines and may actually be applied in space, rather than limiting their understanding through a focus on a specific projection, can bring knowledge and understanding to a deeper level. This is especially useful for students, experts and researchers in the ICT and conservation communities.

3. CONCLUSIONS

Understanding by the ICT community of the specific and unique values of freehand sketching and of its direct value in design and contribution to other areas, has resulted in the advanced development of sketch-based modeling. Conservation of cultural, and especially, built heritage, can benefit from specific focusing of development in this area, and can also encourage and contribute to formulating new foci and tasks for research and development in areas related to 2D images, 3D models, their analysis, interpretation and transformations. This also brings new opportunities for the integration of both fields on a visual basis, with increasing importance of basic visual disciplines. At the same time, along with expanding possibilities offered by computer-generated processes, their popularity and ease of use has caused a contradictory mainstream process, - the reduction of the scope of teaching visual disciplines to architects and engineers, - which, in turn, threatens to reduce the effectiveness and applicability of those ICT applications. Based on the advantages of these subjects, and exemplifications of insight to teaching-learning in the modern teaching environment, the paper advocates their continued use Furthermore, it suggests to step beyond the traditionally associated architectural and engineering curricula, and make basic visual disciplines accessible to information and communication community of researchers and developers, especially, but not only in the context of conservation (preservation) of cultural heritage.

ACKNOWLEDGEMENTS

My appreciation is addressed to the Neri Bloomfield School of Design and Education, and to the Technion - Israel Institute of Technology; to the Technion Centre for Promotion of Learning and Teaching - for recording the course in Descriptive geometry; and to students in my various courses, whose enthusiasm and learning curiosity during and after their studies has never failed in encouraging my teaching methodological research.

REFERENCES

Calatrava, S., 2006. *Lecture Series at the Technion- Israel Institute of Technology*, https://www.youtube.com/watch?v=byl6lapNJ4M

Duguleana M., Brodi R., Girbacia F., Postelnicu C., Machidon O., Carrozzino M., 2016. *Time-Travelling with Mobile Augmented Reality: A Case Study on the Piazza dei Miracoli*. In: Ioannides M. et al. (eds) Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. EuroMed 2016. Lecture Notes in Computer Science, vol 10058. Springer

Hazan, S., Lobovikov-Katz, A., 2017. *The Willing Suspension of Disbelief: The Tangible and the Intangible of Heritage Education in E-learning and Virtual Museums, Chapter in Mixed Reality and Gamification for Cultural Heritage,* Eds.: Ioannides, M., Magnenat-Thalmann, N., Papagiannakis, G., Springer-Nature

Hill, M., & Kohane, P., 2015. *'The Signature of Architecture': Compositional Ideas in the Theory of Profiles*. Architectural Histories, *3*(1), Art. 18. DOI: http://doi.org/10.5334/ah.cu

Ioannides, M., Magnenat-Thalmann, N., Papagiannakis, G. (Eds*.)*, 2017. *Mixed Reality and Gamification for Cultural Heritage*, Springer-Nature

Ioannides, M., Pavlos Chatzigrigoriou, P., Bokolas, V., Nikolakopoulou, V., Athanasiou, V., Papageorgiou, E., Leventis, G., Sovis, C., 2016. *Educational Creative Use and Reuse of Digital Cultural Heritage Data for Cypriot UNESCO Monuments*. In: Ioannides M. et al. (eds) Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection. EuroMed 2016. Lecture Notes in Computer Science, vol 10058. Springer

Kazmi, IK., You, L., Zhang, JJ., 2014. *A Survey of Sketch Based Modeling Systems*.: 11th International Conference on Computer Graphics, Imaging and Visualization (CGIV) (2014)

Kondo, K., 2009. *Interactive Geometric Modeling Using Freehand Sketches*. Journal for Geometry and Graphics 13, No. 2, 195—207

Lane, R. (Ed.) 2016. *Understanding Historic Buildings: A Guide to Good Recording Practice*, Historic England

Lawrence, S., 2003. *History of Descriptive Geometry in England*, Proceedings of the First International Congress on Construction History, Madrid, Proceedings of the First International Congress on Construction History, Madrid, 20th-24th January 2003, ed. S. Huerta, Madrid: I. Juan de Herrera, SEdHC, ETSAM, A. E. Benvenuto, COAM, F. Dragados

Lobovikov-Katz, A., 2015. *The virtual and the real: e-learning in interdisciplinary education – the case of cultural heritage*, The 13th Annual MEITAL National Conference "New Technologies and Their Evaluation in Online Teaching and Learning" Technion - Israel Institute of Technology, Haifa, June 2015 http://meital.iucc.ac.il/conf2015/papers15/A3_3.pdf

Lobovikov-Katz, A., 2016a. *"Human" technology in the digital era: freehand images and analysis of cultural heritage – the know-how and its applications, Chapter in Ioannides, M., Fink,E., Moropoulou,A., Hagedorn-Saupe, M., Fresa, A.,Rajcic, V., Grussenmeyer, P. (Eds.), Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection Volume 10058 of the series Lecture Notes in Computer Science pp 337-349*, Springer

Lobovikov-Katz, A., Bueno G., Marcos, V., Martins, J., Sojref, D., 2016b. *Training schools for conservation of cultural heritage: between expertise, management and education, Chapter in Ioannides,M., Fink,E., Moropoulou,A., Hagedorn-Saupe, M., Fresa, A.,Rajcic, V., Grussenmeyer, P. (Eds.), Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection Volume 10058 of the series Lecture Notes in Computer Science pp 880-890*, Springer

Lobovikov-Katz, A., Konstanti, A., Labropoulos, K., Moropoulou, A., Cassar, J., De Angelis, R., 2012. *The EUROMED 4 Project "ELAICH" e-Tools for a Teaching Environment on EU Mediterranean Cultural Heritage*. M. Ioannides et al. (Eds.): EuroMed 2012, LNCS 7616, pp. 710–719, 2012. Springer-Verlag Berlin Heidelberg

Lobovikov-Katz, A., Moropoulou, A., Konstanti, A., Ortiz Calderón, P., Van Grieken, R., Worth, S., Cassar, JA, De Angelis, R., Biscontin, G., Izzo, F., 2014. *Tangible Versus Intangible in e-Learning on Cultural Heritage: from Online Learning to on-Site Study of Historic sites*: in M. Ioannindes et al. (eds.): Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation and Protection, LNCS 8740, pp 819-828, Springer

Lobovikov-Katz, A., 2008. *Freehand sketching in the contemporary conservation of monuments*, Water and Cultural Heritage, Zezza, F., Perthuisot, V., Plancon, A. (eds.), Proceedings, 7th International Symposium on the Conservation of Monuments in the Mediterranean Basin, June 2007 - Orleans, France

Michelangelo, 2002. *Letters. Poetry*, Azbuka, St Peterburg (Микеланджело *Письма. Поэзия*, Издательство "Азбука" Санкт Петербург)

Nemeth, B., 2007. *Measurement of the development of spatial ability by Mental Cutting Test*, Annales Mathematicae et Informaticae, 34 pp. 123-128

Newcombe, N., 2010. *Picture this: increasing math and science learning by improving spatial thinking*, American Educator

Olsen, L., Samavati, F., Sousa, M. C., Jorge J., 2008. *A Taxonomy of Modeling Techniques using Sketch-Based Interfaces*. Eurographics state of the art reports 1 (1.4)

Olsen, L., Samavati, F., Sousa, M. C., Jorge, J., 2009. *Sketch-based modeling: A survey*. Computers & Graphics. 33, 85–103

Putz, C., 2001. *Teaching descriptive geometry for architects: didactic principles and effective methods demonstrated by the example of Monge projection*, IV Internationsl Conference for Graphics Engineering for Arts and Design, Sao Paolo, Brasil, 5-9 November 2001

Shepard, R. & Metzler, J., 1971. *Mental rotation of three-dimensional objects*, Science, 171, 701-70

Shtof, A., Agathos, A., Gingold, Y., Shamir, A., Cohen-Or, D., 2013. *Geosemantic Snapping for Sketch-Based Modeling*, EUROGRAPHICS 2013 / I. Navazo, P. Poulin (Guest Eds), Volume 32 (2013), Number 2, 245-253, 10.1111/cgf.12044

Simo-Serra, E., Iizuka, S., Sasaki, K., Ishikawa H., 2016. *Learning to Simplify: Fully Convolutional Networks for Rough Sketch Cleanup*, ACM Transactions on Graphics (TOG) - Proceedings of ACM SIGGRAPH 2016, Volume 35 Issue 4, July 2016, Article No. 121 ACM New York, NY, USA 10.1145/2897824.2925972

Sorby, S. A., 2009. *Educational Research in Developing 3-D Spatial Skills for Engineering Students*, International Journal of Science Education, 31: 3, 459 – 480

Stachel, H., 2013. *Descriptive Geometry – vision guided spatial reasoning*. Lecture. Politecnico di Milano: The visual language of technique, between science and art. Heritage and expectations in research and teaching