A New Extended Perspective System for Architectural Drawings

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Abstract. This paper presents the work carried out by a multidisciplinary team of researchers, gathering knowledge in architecture, drawing, geometry, mathematics and computation. The research was directed in order to create a computational tool for architectural visualization - a new digital perspectograph - with the use of a new theoretical and operative approach to linear perspective. A new kind of projection surface, a parametric one, is added to the perspective concept under current tools. The mutations of this surface are explained and a set of graphical outputs is shown. A workshop with architecture students took place to help test and validate the concept and the computational prototype.

Keywords: Linear perspective, visualization, drawing, perspectograph

1 Introduction

Perspective principles determine the fundamental geometric structure of drawings when these aim to be graphical simulations of direct visual experience. If we take "visual experience" in a broad sense - not just the result of a static gaze, but an overall product of dynamic visual perception and also visually based cognition - the notion of perspective has to be more inclusive. It has to gather the dominant classical linear perspective and the alternative curvilinear perspective systems, each one with specific capabilities. Therefore, a multidisciplinary research project conceived and implemented a novel digital perspectograph: a tool for producing vectorial drawings from three dimensional architectural models, using new alternative projection procedures.

Throughout the history of perspective, classical linear perspective, the mainstream, was counterpointed by several authorial propositions defining alternative curvilinear perspective systems. Although generally based on criticism of the appropriateness of classic linear perspective to translate visual perception, a matter that is vastly debatable, the alternative systems never gained a broad use or acknowledgement, probably because of the intrinsic difficulty of their graphical procedures. In fact, such complexity turns its teaching and practice intricate. But their sheer existence emphasizes that linear perspective is just a particular intellectual construct for pictorial purposes, and other ways to translate visual data into depictions may be considered.

Hansen [1] developed a *hyperbolic linear perspective*, trying to respond graphically to the historically alleged curvatures sensed in vision. Casas [2] and Moose [3] developed graphical methods to obtain 360º degrees spherical perspective depictions of space. Barre and Flocon's *La perspective curviligne* [4] establishes the use of a sphere surrounding the viewer as the ideal depiction surface, where equal visual magnitudes would have corresponding equal projected magnitudes. However, for pragmatic purposes, the depiction is then transferred to a picture plane with the cartographic procedure that less distorts those magnitudes. A very similar method, *Perspective Spherique*, was also proposed by BonBon [5]. Another curvilinear system, with a diffuse origin, is the *cylindrical perspective*, where projections are set upon a cylindrical surface. This surface is then unrolled in order to obtain a final depiction on a picture plane. This kind of perspective has recently gained a broader visibility through digital panoramic photography.

A common characteristic of all these approaches to curvilinear perspective is that they configure static concepts of perspectograph, by electing a single kind of projection surface and stipulating unique graphical procedures. In our approach, as will be described, a more versatile concept is found, based on different premises: the curved projection surface becomes mutable, within specific constraints, and graphical results are consequence of adaptive analytical procedures.

The starting point for the research project was previous work by members of the team: a systematic review and a holistic approach to the issue of perspective that resulted in the general formulation of a new representational method, called Extended Perspective System (EPS) [6]. This concept gathers current perspective systems in a unified theoretical build, turning them into just boundary states of a broader dynamic system that contains an unlimited set of new in-between states. The outcome is a significant increase in the variety of graphical perspective structures, and therefore the enhancement of the overall ability of computer drawings to respond to direct visual perception, matching, in a way, the increasing versatility of current digital photography.

In the following sections, ideas behind the formulation of the EPS and its definitions will be addressed, followed by a description and preliminary evaluation of its computational implementation. Sections 2 and 3 will address foundational goals that led the team to develop such a tool and also explain its vision of the interest for the architectural practice. Section 4 explains the EPS concepts and specifications for the algorithm. In section 5, graphic outputs are shown and characterized. Section 6 will describe the EPS Visualizer. In section 7, the results of a preliminary evaluation of the tool are presented. In the final section, some possible repercussions of the EPS in the domain of architectural drawing will be discussed.

2 Aims

The aim of this work is to improve the role of perspective in graphical representation of space, within architectural and urban design, by introducing a new concept of perspective and a corresponding computational working tool.

Architects' drawings nowadays merge manual and computational procedures. Although based on geometric principles, freehand drawings often escape from their theoretical corset, sometimes blending the representation systems, other times spontaneously disrespecting its graphical rules. Particularly, in the gestural process of drafting, which includes both the dynamics of the hand and gaze, the graphical curving of lines in many architects' perspective drawings seems to suggest the presence of flexible and dynamic visual thinking above the strict observance of the graphic rules of linear perspective, which would imperatively keep lines straight.

On the other hand, computational drawing allows the dynamic manipulation of parameters that has so much improved the display of architectural concepts and proposals. Particularly, perspective visualization has been turned into a real-time interactive experience, where dynamic depictions also counterpoint and feedback the architect's reasoning. But the appropriation of perspective science by current CAD systems is restricted to linear perspective, neglecting alternatives that could enrich drawing capabilities of conveying spatial data.

Linear perspective is the prevalent system, regarding the production of figurations that intend to simulate the direct visual appearance of things. But, despite its effectiveness, it remains purely a code, a set of conventional concepts and rules, and has its limitations. For example, it cannot deal with large fields of view, where raised distortions will, at the limit, compromise the recognition of the represented objects. Alternative curvilinear systems, cylindrical and spherical perspectives, much less known and hardly used, can overcome this difficulty. These systems can translate graphically the result of a viewer's sight in motion, conveying a sense of dynamic vision, although at the cost of bending the represented straight lines. The three systems: linear, cylindrical and spherical perspectives, despite being separate theoretical builds, can have complementary roles, in terms of representational capabilities.

Furthermore, beyond the obvious differences, any particular set of corresponding linear, cylindrical and spherical perspective depictions reveals noticeable affinities, as if they were transitory states of a mutable graphical structure. Consequently, a single unified perspective system can be conjectured and its implementation is feasible with a computational approach, regardless the eventual complexity of the required mathematical calculations. This was the main purpose that led the team: the design of a tool with which a much wider range of possible perspective representations of an object or a scene can be generated.

3 Significance

The graphical description of architectural objects may refer to its geometric properties (shape, dimension, etc.), by multiple orthogonal views, or to its visual appearance (the way they are visually perceived), by perspective views. While geometric properties are stable features, visual appearance is always changeable, by depending on the viewer's relative location and personal subjective perception. Here, the rules of graphical representation are demanded to match the complexity of visual perception, which turns every single depiction someway incomplete. Therefore, a set of complementary graphical responses, as much diverse as possible, is desirable.

Hand drawing intrinsically generates such a variety of responses, since it is an individual mind/gesture process that includes both the dynamics of the hand and the dynamics of the gaze. On the other hand, computer drawings are essentially a finish result of a process that partially transcends the user: the kinds of depictions obtained are bounded by the algorithms and graphical codes imbedded in the specific computational tool that is used.

The EPS concept is mainly based on a mutable projection surface to be interactively controlled by the user, with real time display of consequent final projections. This single feature provides a set of perspective representations that is much more inclusive and diversified. With the EPS computational implementation, the user will have a greater variety of graphical responses to meet his own visual assessment of an architectural scene, either real or being conceived in his mind, thus expectedly helping on the conceptual cycles of analysis, evaluation and decision.

At this stage, we can suppose the EPS shall promote a further complicity of geometry science with the plasticity of freehand drawing. A widespread use of this tool will permit a more complete analysis and evaluation of its repercussion in the practice and didactics of drawing in architectural design.

4 The EPS concept

In the formulation of the EPS, linear (or planar), spherical and cylindrical perspectives were considered fundamental landmarks to take into account.

Planar perspective is a deeply rooted graphical mechanism. It has indeed a strong commitment to vision, by usually depicting straight lines and depth in a recognizable way, and has a major importance in architectural history and practice. Despite this, it has severe technical limitations regarding the conveyance of complete spatial information.

Spherical perspective allows captivating, although rather odd, curvilinear depictions of the entire space surrounding a viewer. It is in this sense a very complete graphical mechanism, but not popular among architects.

Cylindrical perspective allows a pleasant curvilinear depiction of space in a full horizontal field of view, while keeping vertical lines straight and parallel: a feature that is appreciated in architectural depictions.

Three fundamental ideas characterize the framework of the EPS: first, the separation of the projection surface (PS) from the representation surface (RS); second, the mutability of the projection surface; and third, the selection of a method for transferring the projections from the PS to the RS.

The PS is the surface upon which the scene is initially projected. The RS is the surface on to where the projected information is then transferred, thus producing the final result or depiction.

These guidelines led to the following particular specifications of the EPS: (a) the RS is a plane; (b) the PS is a spheroid (an ellipsoid with a vertical axis of revolution), initially having its center on the viewer position, and tangent to the RS at a point on its equator, which is also the viewer's target point; (c) the spheroidal PS is subjected to parametric transformations, controlled by two parameters: radius (Rad) and eccentricity (Ecc).

The Rad parameter defines the distance between the target point and the centre of the PS. By incrementing Rad, the center of the PS detaches from the viewer and moves backwards along the visual axis, so the PS is progressively up-scaled. With an infinite Rad, the PS becomes a plane, coinciding with the planar RS. Along variation of the parameter Rad, in both directions, an infinite number of intermediate states of PS is found. This parameter determines the overall curvature of depicted lines and attainable field of view.

The Ecc parameter defines the ratio between the vertical axis and the equatorial diameter of the spheroidal PS. By incrementing Ecc, the spheroid becomes progressively elongated. With Ecc at its lower limit (1:1), the surface is a perfect sphere, and at infinity the surface is cylindrical. Again, an infinite number of intermediate ellipsoidal states can be found. This parameter determines the curvature of the vertical lines in the final depiction.

So, with the combined effect of the two parameters, the PS can assume diverse forms, going from spherical, to cylindrical or planar and through an infinite number of intermediate states. This relationship is seen in Figure 1.

Therefore, the EPS is able to reproduce planar, cylindrical or spherical perspectives and, moreover, an infinite number of in-between hybrid perspectives. When implementing and testing the EPS algorithm, it proved necessary to separate the calculations of cylindrical projection, planar projection and spherical/ellipsoidal projection. While in initial conception cylindrical projection corresponded to ellipsoidal projection with an infinite eccentricity value, they turned out not to be entirely identical and required different methods of mapping onto the representation surface. Furthermore, infinity is not a concept computers can deal with easily, and as such both cylindrical and planar calculations must be done with their own methods.

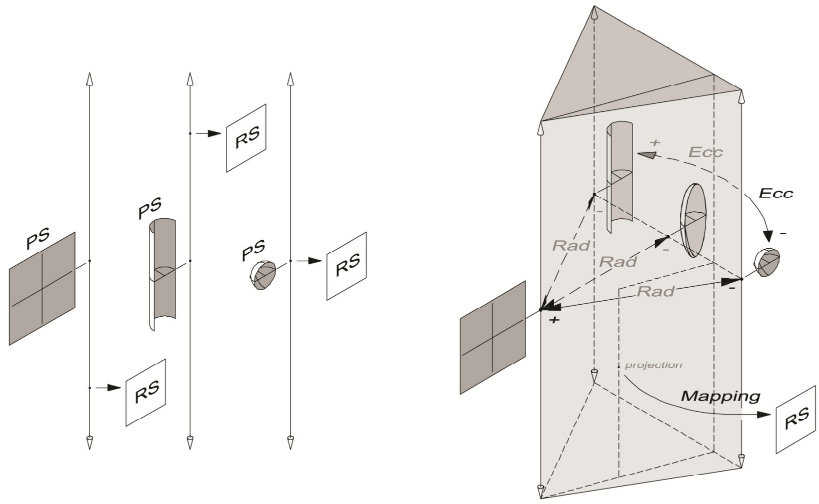

Fig. 1. The three referential perspective systems: planar, cylindrical, spherical – separated, at left, and gathered by the EPS concept, at right.

5 The EPS depictions

The use of the new parameters Rad and Ecc in combination with the already established variables, like 'distance' or 'zoom', turns perspective depiction of an object into a choice made from a much wider range of possibilities. In Figure 2, a set of 16 images, resulting from variations of Rad, Ecc and Field of View (zooming effect), exemplifies that diversity.

On the lower left corner, the EPS depiction turns into current spherical perspective. On the upper left corner, the EPS depiction nearly turns into current cylindrical perspective. On the upper right corner, the EPS depiction resembles current linear perspective, with a narrow field of view. In the middle, we find EPS hybrid depictions.

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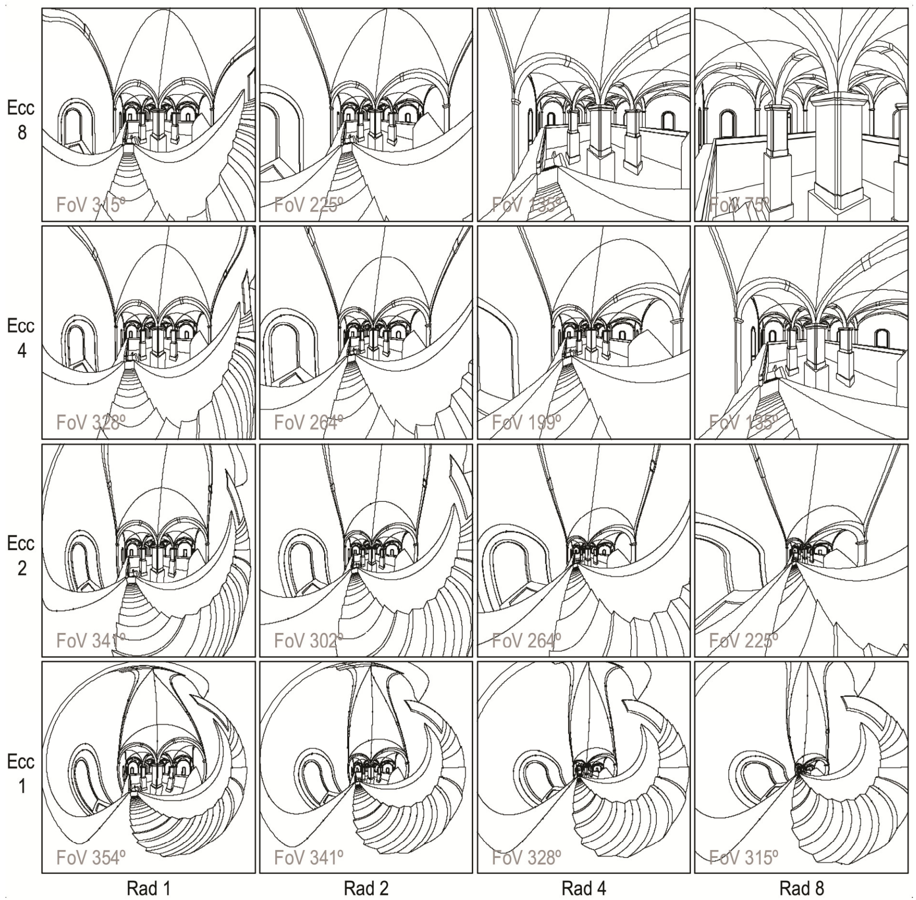

Fig. 2. A table of diverse EPS depictions of an architectural scene

It is noticeable that a full range (0-360º) of field of view is attainable, despite the eventual anamorphic character of the image or some of its parts. We believe it shall depend on the EPS user to evaluate and decide on the appropriateness of the depiction, regarding the specific representation purposes or intents of visual analysis.

6 The EPS Visualizer

Previous work on implementing non-linear projection in computer graphics has taken varied approaches, including the use of ray tracing techniques [7-10] and both singular [11] and multiple cameras [12-16].

In [17] the authors presented an approach to generating non-planar projection in real time. It used the capabilities already found in most modern graphics cards to produce dynamic environment maps and then applied projections to them. Their solution is applied to only a few types of projection. John Brosz et al. [18] introduced a flexible projection framework capable of modeling a wide variety of linear, non-linear and custom artistic projections using a single camera by introducing the concept of a flexible viewing volume defined by parameters. It uses ray tracing for rendering but can use scanline rendering for a limited set of projections. For all its flexibility, this solution seems too unwieldy and potentially inefficient for practical use by architects.

To validate the EPS concept, it was implemented in an interactive application, the EPS Visualizer, which allows the user to visualize 3D scenes. By controlling a single camera and the parameters (Rad, Ecc, FoV), the user can gain a better understanding of the spatial characteristics of the model.

The EPS Visualizer has four viewports, one larger than the others, as seen in Figure 3. Each can be set to display the model from the point of view of a controlled camera using the EPS or classical perspective, or can be set to display orthogonal or classical perspective axis-aligned views of the model from the top, bottom, left, right, front or back.

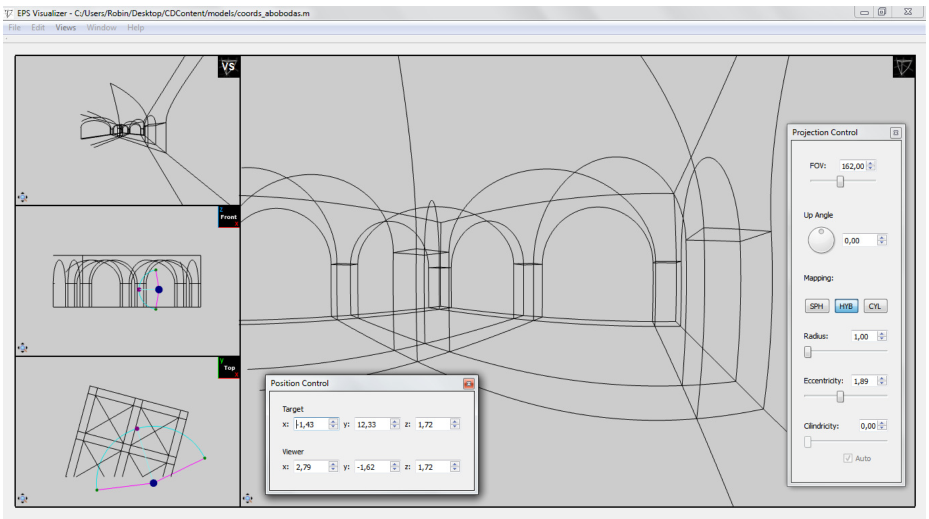

Fig. 3. The EPS Visualizer interface: the four viewports and the parameter control windows

The camera position and rotation are defined by two points (viewer and target) and an angle (up angle). The viewer point defines the location of the camera, the target point defines the location of what the camera is looking at and the up angle defines the camera's rotation along the axis that contains the target and viewer point. The camera and target positions, as well as the field of view, are marked on the axis-aligned views with a special cursor. It is a 2D cursor marking the camera position with a blue circle, the target with a smaller magenta circle and the field with an arc. The camera and target positions can be altered by clicking and dragging over the cursor in the axis-aligned views and the up angle can be set with a dial.

The camera projection can be controlled using the radius, eccentricity and field of view variables by dragging sliders in the projection control window (Figure 3). The field of view can also be controlled with the mouse wheel. The mapping of the projection surface on to the representation surface can be switched between the spherical, cylindrical or hybrid modes. All values can also be inputted directly as numeric values.

The user can also pan the views by dragging with the middle mouse button and zoom in on side-views with the mouse wheel. The views can then be returned to a default position by clicking on a small icon of a magnifying glass on the bottom left corner of the viewport.

The visualizer also allows the user to activate a two dimensional grid on the XoY plane, a ground plane. It is possible to visualize the 3D model superimposing the grid, or just the grid which can be printed and then used as a visual guide to perform free-hand drawing. Finally, the software allows users to export projections as images in both bitmap and vector formats.

7 Evaluation as a Tool for Architectural Design

An evaluation of the EPS concept and visualizer was carried out to determine their perceived usefulness and usability as a tool for the design process in architecture. It took place as a two-session workshop in the context of a project course of the 3rd year of the Architecture degree at Faculty of Architecture, University of Lisbon. The software was presented as a potential aid in the development of the project challenge defined for the workshop, where the students had to design a living space based on a given volume and determine an arrangement of those volumes to produce a final building.

Method: In the first session, the students built an architectural 3D model using a CAD tool. In the second session, after a brief introduction and demo of the EPS Visualizer, the students worked on their 3D model using the Visualizer for about one hour, and were then asked to fill in a questionnaire with 16 questions focusing on: previous experience, how the Visualizer was used and helped in their design, the EPS concept itself and the tool usability.

The answers were mostly in the form of a 1-5 scale ('never' to 'always'; or 'very weak' to 'very good' and NA for 'not applicable'), with some open ones, allowing the students to express their opinions more freely.

Results: Even with a relatively small number of users (eleven, aged 19-23) trialing the tool just during the workshop, the collected data was analyzed allowing to find a tendency in perceived usefulness and satisfaction with the tool, to assess main usability aspects, and to get feedback from target users. The main results are presented next as (Mean; Standard deviation).

Use of 3D Modeling Software, Curvilinear Perspective and Free-hand Perspective Drawings: All students indicated at least some prior experience with 3D modeling software, sometimes using perspective visualization mode. All but one was already familiar with the concept of curvilinear perspective, mostly from photography and classes, and all do free-hand perspective drawing in their design processes.

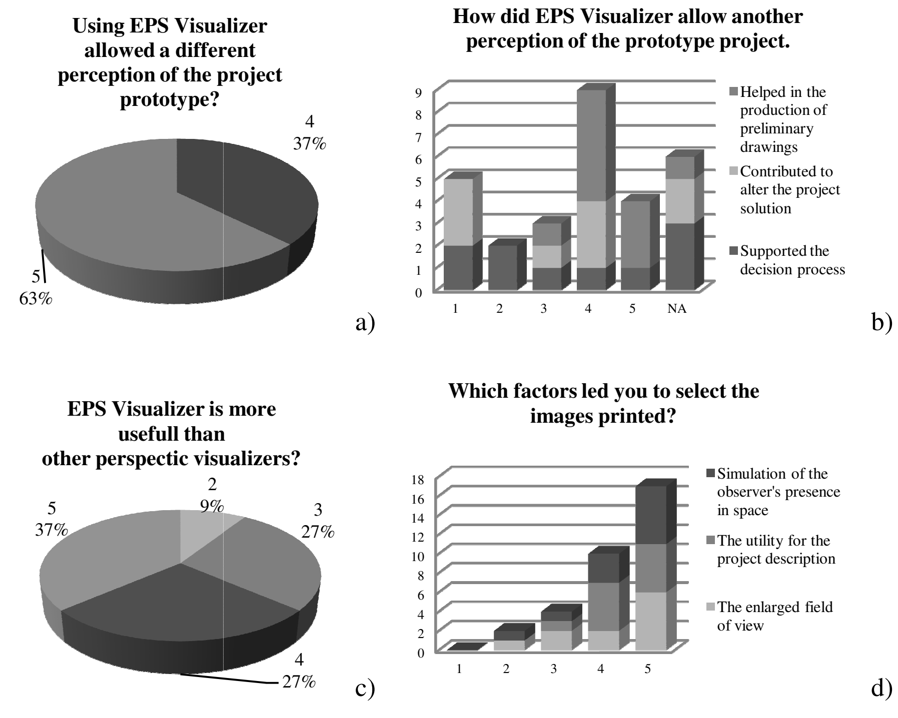

Fig. 4. Main evaluation results

EPS Visualizer Supporting the Architecture Design Project: Students indicated that it gave them a new perception, or view, of their work (4.63;0.48), (Figure 4a,b). While it seems to have helped them produce study drawings (4.22;0.63), less often they felt it helped them making decisions in the design process (2.57;1.40) or alterations to their solution (2.5;1.32), possibly because they used the Visualizer when the design was already near completion and for a relatively short time. Anyway, student comments mentioned "it allowed to understand the interior and exterior simultaneously", "good light/surface drawing", and "gave a better perception of the problem". For the decision of printing an image (Fig.4d), the factors suggested received similar importance: utility for project's description (4.36;0.64), simulation of the observer's presence in space (4.27;0.96), and enlarged field of view (4.18;1.03).

Students would use EPS fairly often in the initial study and development phases of the project (3.2;1.4), more often during the final presentation stage (3.9;0.7), one of these "would use it to study the light on the surface", and another one found "it would help through the whole process". The EPS was considered a good complement to free-hand perspective drawing (4.09;0.79), could help learning and drawing (4.18;0.72), and was considered advantageous compared to conventional perspective visualizers (3.91;1). They reported: "it created an interesting exterior-interior relation", "helped visualize 3D objects in new ways" and "a way of approaching reality". About the usefulness of the EPS in contrast with other perspective modes, the answers were mostly positive (Fig.4c) showing interest in the new ways of viewing allowed, e.g. "interesting and innovative relation between inside and outside space" and "different 3D objects visualization". Improvements were also suggested such as the implementation of solid surfaces and lighting.

Usability of the EPS Visualizer: users found the EPS Visualizer easy to use (4;0.43); the experience satisfactory (4.36;0.64); they appreciated the layout (3.1;0.54), the commands (3.55;0.66); the images produced (4.18;0.57); the interface flexibility (3.9;0.94), and consistency (3.9;0.83). It "helped them understand their project better", "it was simple and intuitive", "it was fast when changing parameters and easy to choose and print images".

Overall: the most important aspects were the interface flexibility and the final images obtained. A majority of students showed interest in having the EPS concept integrated in to 3D modeling software (4.45;0.66). Students commented that the EPS could be useful in design, in scenery creation, for working details and to have a wider framing view of a scene. There were also suggestions of it having applications in video games.

8 Conclusions

This paper presented a new perspective representation system, called Extended Perspective System, which gathers linear, spherical and cylindrical perspectives in a unified and expanded theoretical build. The conceptual dissociation of Representation Surface from Projection Surface and the mutability of the latter are the key properties that provide this new perspectograph with greater versatility in generating depictions of the space surrounding a viewer.

A software tool – the EPS Visualizer – implemented this representational system. The preliminary evaluation suggests a favorable assessment of the EPS Visualizer, considering the interface flexibility and the final images obtained as the most important aspects. Overall we had 36% of answers being "very frequent"/"good" and 31% being "always"/"very good" meaning that the general impression garnered from the evaluation is very positive, validating the work done thus far and encouraging future work, namely on the outline of new didactical approaches to observational and conceptual drawing.

One aspect to emphasize is that the EPS Visualizer was not envisaged as standalone software. We foresee its integration into existing 3D modeling software, as part of the visualization modules. This way, the EPS depictions could be utilized together with editing and throughout all the design process. Also, further image rendering features shall be added.

Priority was given to the use in architectural design, which delimited the options considered. However, this framework is an open concept, as it is able to incorporate other kinds of projection surfaces and mapping methods. Therefore, the main goals of the project were reached and several lines of investigation could start from here. This tool provides new ways to see the world, and communicate it. The team expects other applications to be considered beyond architectural drawing.

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