Augmented Reality Tools for the Creation of Physical Visual Arts.

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(a) Construction lines (b) Image analysis (c) Image synthesis

We ease the creation of physical drawings by interactively creating digital construction lines (a). It is also possible to draw from an image, which can be analyzed by touch (b). Finally we propose new uses of Non Photorealistic Rendering by combining multiple digital images to create one drawing.

ABSTRACT
We propose to empower the physical drawing creation with new spatial augmented reality tools. In order to do this, we created a projection mapping system with paper tracking and touch input from a depth camera. We created projection mapping tools to create drawings from an empty canvas, an image or a 3D scene.

Construction lines are thin pencil strokes used to structure a drawing. We push forward the limits of the use of construction lines by enabling the creation of digital construction lines which can be projected on any medium such as dark paper or wet paint. Moreover, we show how image analysis tools can be directly manipulated on paper to display the relevant informations for drawing. We also enable the visualization and manipulation of a cartoon shaded 3D scene. From these manipulations, the user extracts a few images with different lighting conditions. Each condition reveals relevant details, and they are combined by the artist in one drawing. We conducted a user study to verify the usability and quality of our user interface: it was found easy to use and led to higher quality perspective drawings.

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H.5.1 Information interfaces and presentation: Information interfaces and presentation

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Design, Human Factors

INTRODUCTION
The creation of visual art is part of all Human history and is present in every culture thorough history. It has a legacy of thousands of years of materials and styles. The purpose of visual arts can be very diverse such as religious, self-expression or for commercial interests.

Since the computer era, one can distinguish two types of visual art: physical (*e.g.* oil on canvas) and digital (*e.g.* jpeg file). The generation and edition of digital images significantly changed our living environments: most photos, newspapers and TV advertisements look “perfect”, every details are adjusted. This“perfection” is inherent with the tools that created them. Every error can be corrected with the undo-redo commands. Moreover, the rendering and image edition tools are extremely rich and they enable precise image creation. Conversely, with physical creation every mistake may leave a trace on the final result. Or at least it will require more work to cover it. There is no undo function in the physical world and the artist’s skills are tested on every step of the creation. However, the expression is direct and sensory rich: the paper's grain, the pencil's tip contact or the paint's odor are also part the creation experience.

In this paper, we propose to enrich physical creation with digital tools. These interactive tools are made to complement existing techniques for the creation of physical visual arts. We propose to use computers for what they are good at: image analysis and synthesis from line drawing to Non Photorealistic Rendering (NPR). And to use Humans for what they are good at: creativity, style and mistakes.

We identified some limitations of existing traditional techniques, such as the difficulty to trace guidelines over fresh paint or fragile mediums. Our first contribution is made to overcome this limitation. We propose a tool to create and edit virtual construction lines which can be projected onto any medium. They can be general purpose construction lines: such as lines curves and sketches. They can also be specialized such as construction lines for perspective drawings. The second contribution of this paper is the possibility to to analyse a projected image with a touch-based interface. Consequently, only the details relevant for drawing are displayed. The third contribution enables the manipulation of a 3D scene with NPR to create drawings. The user can capture the same view of a scene with different light conditions: each light condition will be used in different part of the final drawing. Finally, the last contribution of this paper is the evaluation of the interactive projection mapping system we created for drawing. We evaluated its ease of use, and verified if digital construction lines could replace physical construction lines.

In this paper we first describe previous works on projection for drawing and painting, and related works. Secondly, we describe the features of our projection mapping system. Then, we introduce the digital construction lines tools. After that, we show how one could use image analysis, and edition to ease the drawing from any image. The next section is about NPR techniques for drawing. Finally, we describe the user experiment we conducted and comment the results.

PREVIOUS AND RELATED WORK

Projection for physical creation

The camera obscura model has been used for centuries [7] as the first optical device to project a planar image onto the real world. Nowadays equivalent are the art projectors, which enables the projection of still images. They come with a wide variety of resolutions and intensities.

In Projector-guided painting [6], Flagg *et. al.* created a system dedicated to painting. They proposed solutions to assist novices during the whole painting process for: color mixing, brush stroke orientation, and layering of the painting. They demonstrated that their system successfully enabled novices to create high quality paintings. Our approach is much more generic and it focuses on the use of digital tools not only for guiding, but also as part of the creation process with the digital construction lines. It is also designed to be highly interactive.

In PapARt [12], the authors proposed to project photos to reproduce them on a paper with colored pencils and manipulate a virtual 3D scene as a basis for drawing. They tested it on a few subjects but did not provide any formal feedback. In this paper, we propose to extend this work on image projection with image processing, and virtual 3D scenes with complete examples. Furthermore, in this paper we propose a solution to trace digital construction lines and a formal evaluation of the projection mapping system and how it integrates with traditional tools.

Digital world integration

Paper is ubiquitous in our offices and homes and it may remain for a long time [17]. The integration of physical paper with computing started twenty years ago with the Digital Desk [21]. It was further explored by Rekimoto *et.al.* [15] and enriched with tangible interfaces [18].

Moreover, this continuity is not limited to planar surfaces, it can extend to any object: it is called Spatial Augmented Reality (SAR), firstly created by Raskar *et. al.* [14]. It enables to project various appearances on physical objects. Harrison *et. al.* pushed this integration forward to enable interactivity on self, or any surface with OmniTouch [11].

Our work is inscribed in the continuity of these works. Our goal is to add new features to the physical world through computing. In this paper we propose to use computing to overcome physical limitations and assist the drawing by the use of NPR techniques [8].

Non Photorealistic Rendering

The creation steps can be simulated from analysis of the geometry of a scene [9]. Many information can extracted from an image [10] or a 3D model [19] to create visually engaging NPR images. These rendering techniques can also be used during the creation process. An example is Shadow Draw [13] by Lee *et. al.*, which enables the rendering of probable strokes from a database.

In order to interactively create and project guidelines to assist physical drawings we designed our own projection mapping system.

PROJECTION MAPPING SYSTEM DESIGN

Design objectives

We had two main objectives for the creation of the projection mapping system. The first is the accuracy of the tracking-projection loop. Preliminary studies showed that accuracy is a critical issue: a small error in the calibration phase leads to projection errors. These errors lead to deformations of the projection *e.g.* a curve is drawn under the projection, and then the drawing support is moved and the projection does not match the curve any more.

The second objective is to enable direct interactions on the support without user instrumentation. Direct interaction is required because most of the physical tools are direct: the line appears where the stroke is done. It is an important factor for the perception of the system as an augmentation of reality. In order to enable any kind of drawing medium in terms of size

Figure 1. Projection mapping system.

and thickness we chose to use a vision-based touch detection. Hence, a depth camera such as Kinect enables any scale and provides enough precision for touch-based interactions.

The system illustrated in Figure 1 is completely vision-based: it is composed of a procam (projector-camera) to detect and project on paper and a Kinect to detect touch and hovering. This kind of vision system scales well: it can be used for very precise drawings as well as very large drawings with the same hardware configurations.

Additional tools

We integrated a key-based interfaces on a small numeric pad with icons projected on each key, as illustrated in Figure 4. It is used for menu selections. We also added an indirect pen input from a tablet. This input is used for digital sketching over the physical drawing.

IMPLEMENTATION DETAILS

The system uses consumer products for hardware: a Microsoft Kinect (depth camera), Sony Playstation Eye (tracking camera), Logitech C905 (capture camera) and Vivitek Qumi Q2 (projector). We used a Wacom Bamboo Pen and Touch for pen input. We used open-source software ProCamCalib [2] by Samuel Audet to calibrate the cameras and projector. It enables us to achieve sub-pixel accuracy in average for the procam calibration.

The touch and hovering detection are custom-made and is similar to Wilson's in [22]. The marker tracking relies on ARToolKitPlus [20] and most of the software uses OpenCV [3] and is coded with Processing [1] and its numerous libraries. The lens distortions are handled by OpenCV (camera) and a dedicated shader (projector). The image analysis and synthesis shaders are coded in GLSL. The softwares performed at cameras frame rates limits (30fps for touch, 60fps for tracking) on a powerful laptop: Alienware m18x 2010 (core i7, GeFore580). All the inputs (touch and paper) are filtered using the 1€ Filter [4]. The ARToolkitPlus data were additionally filtered to block any translation inferior to 2cm while drawing, thus filtering the normal changes.

DIGITAL CONSTRUCTION LINES

Construction lines are lightly drawn lines that aid to draw the final stroke. They are used mostly in pencil sketches, and are generally required during the first creation steps. They are mostly used in pencil sketches because it uses the same tool for trials and final strokes. Consequently, the construction lines can be artifacts of the creation and may be part of the style.

It is a advised to beginners to draw as much construction lines as needed in order to obtain a good structure and maintain valid proportions. The creation of these construction lines is strenuous and can be very difficult to erase. Furthermore, for some creations it is impossible to use construction lines because the paper will get bruised from erasing, or remaining lines could not be deleted afterwards such as for watercolor. For painting, the construction lines are drawn before painting. However, once it is covered it is impossible create new construction lines for the next layers.

We enable the creation and edition of construction lines on any support by projecting digital construction lines. They can either replace or complement physical construction lines.

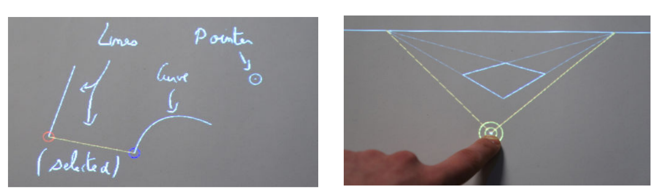
General purpose construction lines

The first set of construction lines tools are not specific to a type of drawing, they are illustrated in Figure 2 (a). The most simple structure we provide is a rectangular grid. The grid is commonly used in drawings to copy, scale or deform an image. It provides a regular discretization of the space. In our implementation, the user can change the grid size, position and intensity and the grid size is displayed in millimeters. A grid is visible in Figures 4 (a) and Figure 7 (d).

The second construction line tool is line and curve drawing. The user can set the position of the two ends of a line. He or she could add more lines, and snap the ends of lines together to fasten the creation of multiple lines or curves. A line can be converted to a bezier curve, and two control points are added and can their positions can be adjusted. The last construction line tool is free drawing with the pen tablet input. This input is important for the structure of a drawing: the artist can sketch new shapes and see how it looks like directly on the drawing. The pressure controls the size of the projected strokes. The users who tested it asked for more features, such as colors or layers. However, in this paper we focus on physical creation consequently we kept this interface very simple and raw.

Perspective construction lines

A perspective drawing can have multiple vanishing points (up to three) depending on the point of view of the desired scene.



(a) General construction lines (b) Perspective construction lines

Figure 2. General construction lines: lines, curves and sketches.

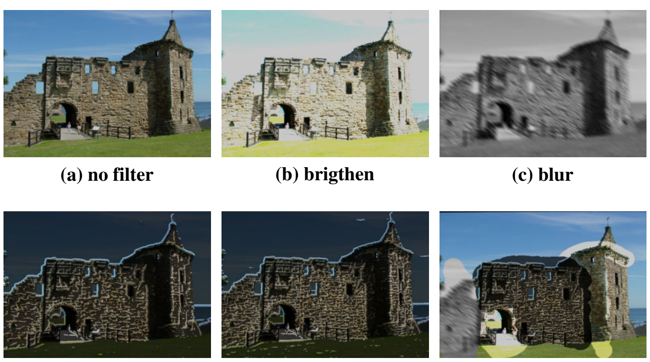
The user first sets the horizon and the vanishing points, then he or she can add new perspective points. From each point a line which goes to each vanishing point is also created, as shown in figure 2 (b). We extended this tool to perspective quad drawing for two-point perspective. From preleminary studies, this kind of automatic generation of construction lines seems to lead to faster drawings.

In this section we presented new tools to help the artists during their creation process. In the next section we propose new tools using image analysis, and image synthesis to assist the creation process.

DETAILS FROM IMAGE ANALYSIS

In this section we propose methods to assist the artist into deciding which parts are important to draw for the final result. He or she can adjust the algorithms and compose images to achieve the desired result.

In previous works [12], authors showed that the projection of a photo can lead to a compelling drawing. In these drawings, the user did copy the whole projected image. This lack of expression comes from the lack of interactivity. The insight on which details to draw or ignore requires training and experience. We propose to aid the artist on these decisions by the use of image analysis techniques.



(a) no filter (b) brigthen (c) blur

(d) coarse edges (e) fine edges (f) composition

Figure 3. From a photo (a), the artist can directly apply image filters: brighten (b), blur(c), edge detection (d)(e), or a combination of them (f).

We propose to use three image enhancement methods, as illustrated in Figure 3. The enhancements are applied directly on the projection using the touch interface. They are displayed as circles, the image (f) in Figure 3 shows a view during drawing.

The first filter (b) brightens the projection on a given zone. It is used to show more details from low-contrast zones. The second filter (c) blurs the image and makes it less bright. It is used to set regions which are less interesting at a given time. The last filter (d)(e) is a derivates of gaussians filter. This filter displays the edges (high gradient zones). The size of the analysis can be adjusted to display different gradient sizes. Moreover, the sensibility of the filter can also be adjusted to display more or less informations. These filters are complemented control of the projection's intensity. This set of tools provide different point of view on the same image; it is possible to use them to reveal details that are hard or impossible to see without filters.

We presented image analysis tools, in the next section we propose a new use of NPR for drawing.

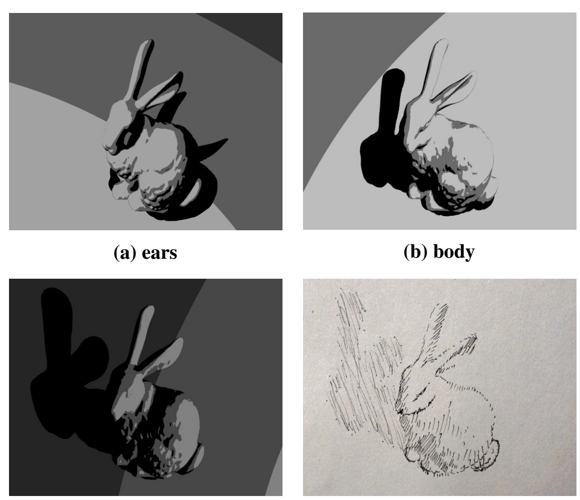
SHADING FROM IMAGE SYNTHESIS

The suppression of useless details from a 3D scene to obtain a simpler rendering is a difficult problem. It has been addressed in "Where do people draw Lines" by Cole *et. al.* [5]. Here we do not have the usual goals of NPR such as fully automatic and temporally coherent rendering. Our approach here is to use multiple renderings to create one drawing. Each rendered image highlight different details which are recombined by the artist.

Our example application is a hatching application using cartoon shading. The visualization metaphor we use is simple: the virtual object is put on paper as if it was a physical object and the point of view is fixed. The object can be moved, rotated and scaled using the multi-touch interface. Its position is linked to the tracked piece of paper, consequently the rendering is also controlled by the paper's position and orientation.

Once the model is placed, its lighting is adjusted to show the relevant details. The light's position is the user's hand position hovering over the paper. He or she can take screenshots of different ligthing conditions to create the drawing, as illustrated in Figure 5 (a)(b)(c). The user set 3 lighting conditions: one for each part of the body. Then, each captured image is reprojected for the hatching phase. In this example, we propose to use three colors for the cartoon shading, leading to three conditions : light hatching, heavy hatching and no hatching. A result is shown in Figure 5 (d).

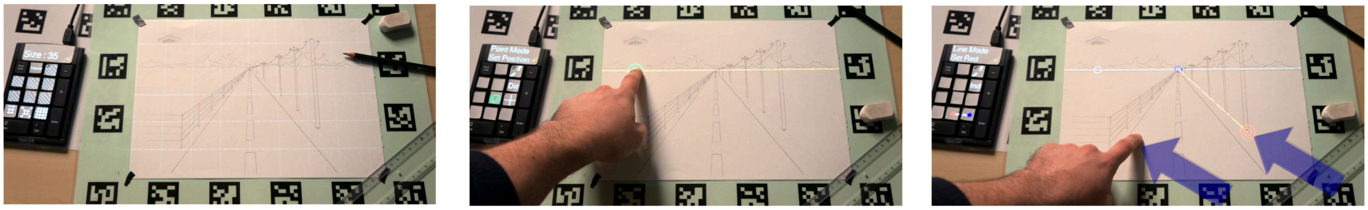
In the next section we evaluate the projection mapping system and some of the tools we created through a user study.



(a) ears (b) body

(c) shadow (d) result

Figure 5. The artist can choose different lighting conditions by hovering his or her hand over the scene. One for the ears (a), one for the head (b) and one for the body (c) to achieve one drawing (d).



(a) Grid **(b) Direct horizontal line** **(c) Indirect line**

Figure 4. User interface for the user study. The users could manipulate a grid (a), draw horizontal or vertical lines (b) and lines (c). The positioning of a line is either direct (b) or indirect (c).

USER EVALUATION

We conducted a user study to evaluate the usability of the system. The first goal was to validate the perceived precision and quality of the projection mapping system. The second goal was to check if our digital construction line tools could effectively complement or even replace physical construction lines. We did an independent measure evaluation on 28 subjets on a perspective drawing.

Application

The application enabled the users to draw simple digital construction lines. The complete construction line tool solution was too rich for new users (none of them used the system before). Consequently, we left only the most simple tools, which are more comparable to physical tools, consequently easier to learn. The set of construction lines is illustrated in Figure 4. The users could display a grid (a), move it and change its scale. Additionally, they could create horizontal and vertical lines (b), and lines by placing the two ends of it (c). The placement can be direct (b) or indirect (c). The users could switch between direct and indirect with a dedicated button. They could also be teleported to the closest point (with a .5cm threshold).

The user interface was displayed on a small numeric pad used by the non-dominant hand. Icons changed depending on the current mode and action, it is illustrated in Figure 4 on the left of each photo. We chose to use color codes to identify the ends of a line (red, blue), and the type of line (green). Each line could be selected, edited and deleted using “+”, “-” and “del” buttons of the numeric pad.

Task

We chose to use an exercise from a pedagogical book on drawing entitled “Dessiner pas a pas” [16] (p.370-372). The task consists in a step-by-step perspective drawing exercise of 17 construction lines which leads to a 11 lines house. It is made to be easy and it is extremely guided: each step contains a picture of the desired result and a short text describing how to achieve it. We chose this guided task so that the drawings would be comparable to each other. Moreover it did not require any expertise in drawing, consequently the user’s level in drawing did not interfere much during the experiment.

We divided the users in two groups, one group (BO: Book Only) uses the instructions, a H pencil, an eraser and a ruler. They had to follow the instructions, and we instructed them that all the lines that will be erased should be as light as possible to leave as less traces as possible. The BO group was composed of 6 male and 7 female participants. The second group (P: Projection) had the same tools, and our system with the application described above. They were instructed to avoid drawing construction lines as much as possible, in order to only draw the final strokes. The P group was composed of 7 female and 8 male participants.

Participants

The participants were volunteers aged from 22 to 59 (μ = 29.9). Most of them were novices in drawing, a few of them had a few drawing courses or draw at home, but none of them were trained professionals. We discarded two participants: one did not follow the instructions, and the second did not understood the concept of construction lines.

Apparatus

Both groups had to take questionnaires before and after the drawing task. They were instructed to do the exercise at their own pace, although they knew the exercise was timed.

The BO volunteers were alone or in small groups in well-lit rooms with a large space to draw. Each had their own pencil, eraser, ruler and instructions. Once they were all ready, we asked for silence and gave them the written and oral instructions.

The P volunteers were in a virtual reality room with controlled light conditions. These constant light conditions were required to provide the same projection experience for every user. The projection zone was 54cm by 34 cm with a 720p projector (5 pixels per mm^2). The projected image averaged a resolution of 650*460 pixels on a A4 paper sheet.

Each participant had to begin with a training exercise which we timed to 10 minutes. One user required more time to learn how to use the interface.

RESULTS

Drawing experience

The three first questions of the questionnaire were common to both groups. They were on a 1-7 Likert scale, with some space for comments. The questions and their results are displayed in Figure 6. The task was found easy (μ=1.6) and amusing (μ=2.07) by both groups. Furthermore the felt as confident with digital lines as with physical ones: BO μ=2.07, P μ=2.2. These similar results indicates that the experience

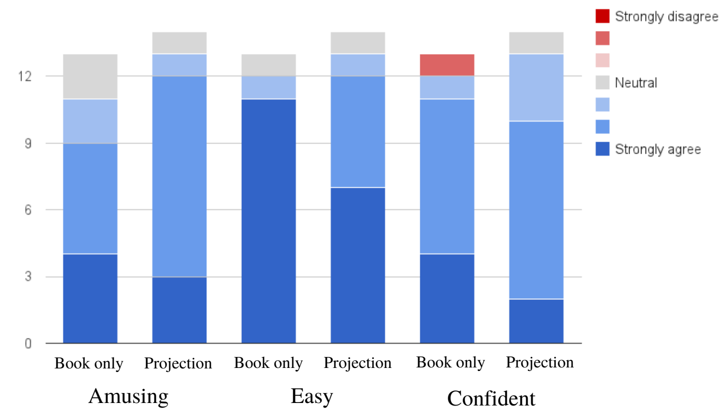


Figure 6. Subjective evaluation about the fun the users had, the ease of the task and their confident before tracing.

of drawing may not be altered, or at least that our system does not negatively impact the drawing experience.

Observations on the projection

The Projection group had five more questions about the user interface and the overall experience with the projection. They were stated as illustrated in Figure 8. The interface was designed to be simple and minimalist, so that the users could focus on the drawing task without a long training time. It was found easy to use by most users (μ=2.3).

We also colleced objective results on the interface use. They showed that the users did not make many mistakes. The average creation number of horizontal or vertical lines is 4.9 (SD=2.98) and standard line is 17.9 (SD=4.32). In the task they had to create 4 vertical lines and one horizontal, and instructions from the book indicated the creation of 17 lines. The average number of keys pressed on the key pad was 185 (SD=61), for 13.5 (SD=4.4) actions per minutes.

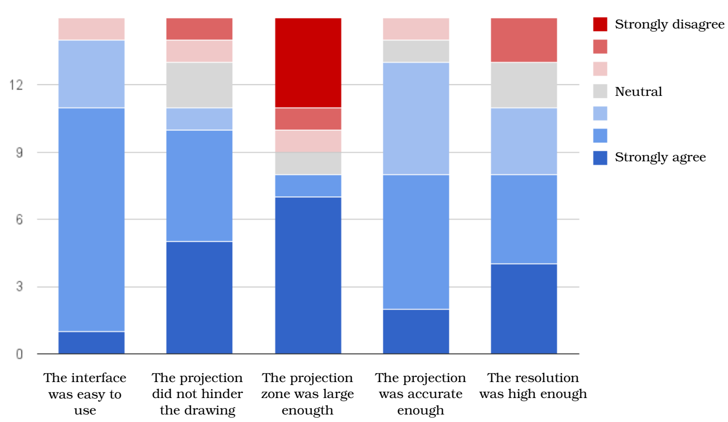


Figure 8. Subjective evaluation of the augmented reality system.

The question about the size of the projection zone divided the users in two groups. One group did not move the piece of paper, consequently they never had any trouble with the size (8 users). The other group changed their position more often and also the piece of paper. Consequently, they encountered the projection's limits (7 users).

The accuracy of the projection was found good enough (μ=2.5). However, some users reported that the definition of accuracy was not completely clear to them. It was mixed with the displayed size of construction lines. It is a positive point for us, it means that they did not encounter any projection error. The perception of errors seemed dependent of the user's drawing abilities (linear correlation coefficient : -0.395). The practice of drawing trains the visual system to see better and better understand the shapes of objects. It can be an explanation of the different perception of the imprecisions of the system. Trained users were also more sensible to the filtering we implemented.

The projection changes the perception of drawing, its intensity has to be adjusted to the current light conditions with dedicated controls. With our controlled light conditions we managed to set projection intensities that enabled a good visibility for both projection and drawing. Most users found the projection more usefull than harmful : μ=2.5, SD=1.6.

Drawing results

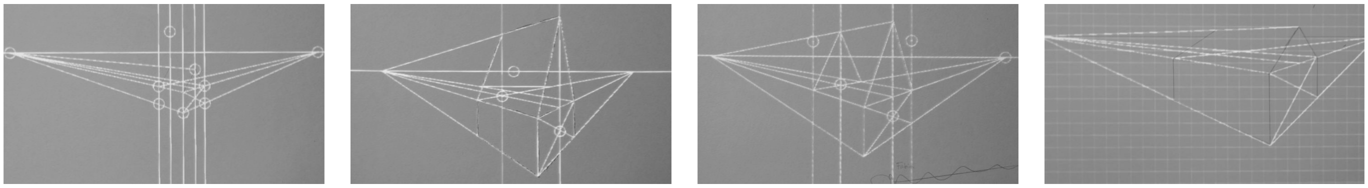
We monitored the drawing duration, as we mentionned before the users were instructed to draw at their own pace. The users without the projection were faster: 10 minutes in average (SD=2.5) compared to 14 minutes (SD=2.9) with the projection. The difference is statistically significant ($p<0.05$); it was expected because the user interface was not performance oriented but made to be easy to use. Moreover, the user had to take decisions on what kind of line to project or use use the grid. An example of the variety of the uses of the system is illustrated in Figure 7. Another important observation is that most users did more digital construction lines than instructed, *e.g.* in Figure 7 (c) a hidden part of the roof is projected.

With our system, the drawing did have a few or no traces of erased pencil. Moreover, we asked five persons in the lab to evaluate the drawings to find errors (traces impossible to erase). The BO group had a low number of errors: μ=1.09, SD=1.30, and the P group even less: mu=0.2 SD=0.38. The difference is statistically significant, the both values are very low and the P users had to think more before tracing, and they spent more time drawing. It would be interesting to evaluate more complex tasks to get a clear observation on the error ratio.

The overall results are good and they show that our system successfully replaced the physical construction lines. We managed to create a user interface to create digital construction lines easily. The drawings done without the projection were faster to do and most all them had many traces of the construction lines. The time performance was not an issue for this user study, it quite difficult to compare existing physical to new digital tools in terms of training time because of the past experience of every user.

FUTURE WORK

These tools are also well suited to teach the drawing: it is possible to project the drawing instructions directly on paper. Moreover, the Kinect and the tracking camera can monitor the artist while drawing. We could imagine a gamification of



(a) (b) (c) (d)

Figure 7. Projection at the end of four drawings.

drawing courses, where not only the result counts but also if the artist stayed still or moved a lot.

We presented one dedicated construction line tool for perspective. We started to develop more specific construction line tools for character drawing. This is much more ambitious because of the complexity of the human body. These construction line tools could bridge the current gap between the NPR techniques we used and the perspective tools. For example someone's pose is estimated using a Kinect. Then the estimated skeleton is rendered using NPR and placed at the right scale using the perspective construction lines.

CONCLUSION

In this paper we proposed three different techniques to ease the drawing using projection mapping. The techniques can start from an empty canvas, an image or a 3D scene. The first contribution is the use of digital construction lines to structure a drawing. We proposed and evaluated a simple construction lines tool and demonstrated an example of specific construction lines for perspective drawing. Our second contribution is the use of image analysis directly on the drawing medium. The artist can discard or enhance the different parts of an image to make it easier to draw.

The last method we proposed enables the creation of drawing from a 3D scene. The scene is manipulated using the touch and tangible interface and rendered with a NPR shading. The user can save screenshots of different ligthing conditions to create a drawing where each part of the model have a different illumination.

The user study we conducted showed that it is possible to use digital construction lines to replace the physical ones. It enables the creation of construction lines on any medium, such as dark or shiny paper and wet paint. Finally, the overall user experience was good with our projection mapping system and it encourages us to develop more complex and audacious drawing tools.

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