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ColorTracker

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With the work-in-progress research project ColorTracker we explore color as a formal design tool. This project-based paper describes a novel software application that processes color composition of a place and transcribes the data into three-dimensional geometries for architectural design. The research comprises two parallel trajectories: a theoretical survey and the software application design. The theoretical survey presents the historical background of color. The project-based research seeks to develop digital methods and techniques that analyze the color compositions of the environment. Subsequently the objective is a novel application software for smart mobile devices in order to demonstrate the potentials of examining the color composition and chromatic parameters of a given environment and how it can contribute to the design.

Keywords: color, architecture, urbanism, tracking, form-generation

As the cities become denser, competition for visibility between buildings and businesses increase. With densification, we also find more and more spaces that fall out of the desirable visual perception. Another compelling problem stems from the leftover or in-between urban places where no one cares to go. On paper, these places may not be seen problematic. But from the pedestrians' point of view, they may stand out as dark spots that appear undesirable and thus avoided. This research is motivated by the desire to use new encoding technology to translate the contextual color combinations for architectural and urban design. **ColorTracker** (hereafter CT) envisions a unique tool to augment the simulation and development of chromatic formal composition for architectural design.

Digital technologies have greatly augmented architectural work. They help increase quality and precision, as well as efficiency and performance. With

the computer technologies in architecture and design becoming increasingly sophisticated, the discipline has transitioned from simply emphasizing productivity toward generative design experimentation and simulation. Now we use digital tools and techniques to simulate, explore, organize, and solve problems with enhanced visual or structural complexity. With the ongoing parametric design research project ColorTracker we aim to explore one specific element of environmental variables in architectural and urban design: **Color**.

With the preceding points in mind, this ongoing research project consists of two continuous phases: the theory-based research and the project-based one. While the theory-based research aims to establish the conceptual framework, the project-based research, based on the scientific yet theoretical premises of the first phase, directly engages the advanced inquiries in software development and de-

sign application. In the following section, though not a comprehensive summary, we will start with illustrating the complexity of the historical precedents on color research.

Theory

Two people might agree about the color of the objects surrounding them but the perception of color is actually a highly subjective experience. Physiological as well as cultural factors play an important role. The potential disjunction between the human perception of color and the physical composition of an object that exhibits color has been argued since the ancient Greek philosophy. In "Color for the Sciences," Jan J. Koenderink explains the dispute as follows: "The pessimistic notion that colors are 'mere mental paint' and have no relation to the physical and chemical constitution of things at all is popular in science and (especially) in philosophy, but it has no basis in fact" (Quoted in Kuehni 2013:3). Thus, color concerns a large body of research ranging from natural sciences, to engineering and to metaphysics.

Definition. *Color: Attribute of visual perception consisting of any combination of chromatic and achromatic content. This attribute can be described by chromatic color names such as yellow or brown, red, pink, green, blue purple, etc. or by achromatic color names such as white, gray, black, etc., and qualified by bright, dim, light, dark, etc., or by combinations of such names* (Kuehni 2013:3).

Color Values. The modern understanding of color began with Isaac Newton. His observation of light passing through a prism led to the discovery that white light is a mixture of distinct color rays. Newton also states, "*For the rays, to speak properly, are not colored. In them there is nothing else than a certain power and disposition to stir up a sensation of this or that color*" (Quoted in Kuehni 2013:3).

Thomas Young (1773-1829) most notably contributed the wave theory of light and brought insight into the nature of light. He related color to wavelength and calculated the approximate wavelengths of the seven colors Newton recognized. Fur-

thermore, Young and Hermann von Helmholtz (1821-1894) postulated that the human eye has three different types of color receptors with different spectral sensitivities, specifying that those photoreceptors (cones) roughly correspond to red, green and blue (RGB). Based on this trichromatic vision theory the RGB color space was developed in the 1920. Subsequent experiments proved that the RGB primaries could indeed match all visual colors within a certain range of color spectrum. To this day we use the RGB color-space model and represent colors in terms of the tri-stimulus values.

Kurt Nassau (1927-2010) contributed to how matter alters the composition of light and causes diverse effects of color. He describes fourteen category of causes, "[...] *four dealing with geometry and physical objects, and those remaining dealing with various effects involving electrons in atoms or molecules of materials and causing absorption or emission of light at selected wavebands*" (Kuehni 2013:4). Nassau also states that " [...] *perceived color is merely the eyes' measure and the brain's interpretation of the dominant wavelength or frequency or energy of a light wave*" (Byrne & Hilbert 1997:3).

Cultural Preferences and Color Connotations.

Color conveys information and affects our perception and response to our environment and what we see. Depending on the environmental circumstances one color may convey different meaning from one place to the other. A color seen alone might hold a different meaning than when it is seen along with another color. When working with color we also have to recognize the cultural, personal and emotional disposition colors carry. Colors have different meaning in different cultures for example: in Russia the color red is associated with communism while in South Africa it is the color of mourning. Likewise, the color blue in India is associated with Krishna while in the Western culture in general it is seen as a cool, masculine color (Livingston 2014:133).

Goethe conducted one of the earliest formal explorations of color theory. Derived by the poet's intuition (later corroborated in part by science) he pro-

vided the first catalogue of how color is perceived under different circumstances. Goethe observes:

"Green: If yellow and blue, which we consider as the most fundamental and simple colors, are united as they first appear, in the first state of their action, the color which we call green is the result. The eye experiences a distinctly grateful impression from this color. If the two elementary colors are mixed in perfect equality so that neither predominates, the eye and the mind repose on the result of this junction as upon a simple color. The beholder has neither the wish nor the power to imagine a state beyond it. Hence for rooms to live in constantly, the green color is most generally selected" (Goethe 1840:316).

Following Goethe's lead, Johannes Itten further explored the psychological aspects of color. Itten's *The Art of Color* is a synopsis of his studies and teachings where he describes among other aspects his subjective association of particular colors with specific emotions. Itten *"represented colors as expressive moods and descriptions over the importance of different types of color contrast: hue, light-dark, cold-warm, complementary, simultaneously, extension and saturation"* (Opara & Cantwell 2014:172). In his writings Itten describes the impact of colors on the viewer: *"Colors are forces, radiant energies that affect us positively or negatively, whether we are aware of it or not"* (Itten 1970:12). Most of all, *"Color is life; for a world without color appears to us as dead... Colors are the children of light, and light of their mother"* (Itten 1997:8).

Project

How do we embody the cultural significance of color connotations and include the scientific parameters of visible light in architectural design? CT tackles this question through geometry. CT grows out of the research work on apparatus-centricity (Lee 2016). One facet of the theory posits that the cultural construct is largely driven by implementation and use of perceptual and cognitive apparatuses that are designed to augment and sometimes to replace human capacities. The CT research aims to develop an architectural and environmental instrument to analyze, map and

transcribe the color palette of a given urban place at the eye level for architectural analysis and form-giving. CT approaches the topic of *colorscape* from a numerical point of view. (Here the term *colorscape* indicates a combination of colors that characterize a specified environment. It will also be referred to in video recording as creating the sensation of experiencing the colors of a particular environment or as compositions created using the found color ensemble of a particular environment, either exclusively or in combination with visual performances.) It keeps track of chromatic parameters such as brightness, contrast, hue and saturation that can be organized as data, not the perceptual and emotional *interpretation*.

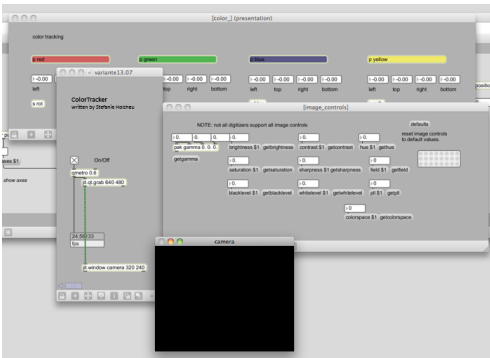
Within this framework, CT aims to develop a way to track color compositions of cities and landscapes, and utilize the information as a form-making tool. In addition, the extended capabilities and application may very well include the potential as an analysis tool to diagnose and evaluate the color palette, saturation and balance of a given architectural and/or urban environment. Therefore the application may be used in mapping and studying the color composition of cities and its in-between spaces. CT makes a tool for both data visualization and form-making.

Iteration 1. In the first series of exercises, CT was used to analyze colorscales and map them in 2D in the vocabulary of lines, shapes and materials. This process defines spatial relations and expressions that correspond to different arrangements of color in the formal vocabulary.

Iteration 2. During the second series of exercises, the colorscales are treated as a design tool where the 3D shapes generated represent the colorscales. While architects usually describe spatial relations in terms of form, CT allows to describe the relations in terms of the color qualities, which can also inform about light or material. The CT app outputs a series of 3-d data-forms in the .obj file format that can be easily used by common modeling and design applications. The .obj file from the CT application can then be modified and elaborated on using various additional parameters.

CT.1.4. In the current iteration *CT.1.4* consists of a custom application that can read from real-time video camera feed or a prerecorded video file from a video camera or mobile device. Here we apply digital programming methods to create a new design application. The resulting custom CT application translates the color composition and chromatic parameters of a given video input to inform and manipulate a three-dimensional geometry and surface.

As mentioned before algorithmic processes are used in the actual color analysis and form making process. The program seen in Figure 1 was written in Max/Msp/Jitter. Max/Msp/Jitter has been used by performers, artists, and composers extensively in order to customize applications for use in computer music, interactive media and sound design. It is comparable to Grasshopper for Rhino in architecture as it also follows a graphic approach rather than the more traditional coding. It offers a unique and diverse collection of tools so called objects that are visual boxes containing singular instructions to perform specific functions. Some create noises, some other make video effects or perform simple calculations. These objects are added to a visual canvas and connected with patch cords (virtual wires). By combining objects, one can design an interactive, unique software application.



The patch consists of three segments. The first segment contains the main components for the color

tracking and the shape generator. The second section are the sub-components that are necessary to execute each function, such as the timer and the four individual shape components for each color range. The third section finally consists of the components necessary to generate, save and export a shape as an .obj file.

Analyzing the contents of the video input. Even though the basic algorithms for tracking motion and color have been around for a while (such as those in animated movies), the dynamic nature of the technology has been hardly put to use in architecture. Therefore CT takes advantage of such dynamic, real-time algorithms in the analysis and signification of colorsapes. This part of the application is designed to define and track a particular color range in a video as its position changes from frame to frame. This technique helps locate a particular color within a given scene. First the video is captured and displayed in a separate window. It is possible to adjust upfront the image quality, saturation, hue, contrast, and so forth within the image control function of the program. The Max MSP Jitter object *suckah* is positioned over the window of the video and will output, after simply clicking on the display window, the color of choice as RGB color value. This value is used to alter the video to a preferred color range. In the second step, the altered video is channeled through a *jit.chroma* object. This object takes two inputs: the video on the left and a reference color, in this case, black, on the right input. This object measures the chromatic distance between each of the left input's cells (pixels) and the reference black. This step was performed to achieve a "green screening" effect. A second *suckah* object over the new picture is used to define the final color value for the tracking function. The output value is then routed through a small sub-patch that defines a specific color range. Using only one definite value would not allow any light ergo color changes in the input live video and therefore not deliver accurate data.

The object used to locate a particular color in an image is *jit.findbounds*. It tracks the previously de-

Figure 1
Custom
Max/Msp/Jitter
color tracking
software; Aleatorix.

defined color range in the video using the min and max attributes. When *jit.findbounds* receives a video input, it looks through the entire input for values that fall within the specified range. It then outputs the cell indices (coordinates) that describe the region where it located the designated values. In effect, it outputs the indices of the bounding region within which the values fall. The bounding region is a rectangle, so *jit.findbounds* will output the indices for the left-top and bottom-right cells of the region in which it found the specified values.

The process described here is executed for each color range individually and the coordinates are send to the corresponding part of the form generator as well as the sound output component for further use.

Figure 2
NURBS display
window; Aleatorix.

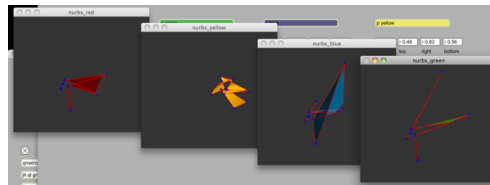


Figure 3
NURBS with four
control points as
flat plan; Aleatorix.

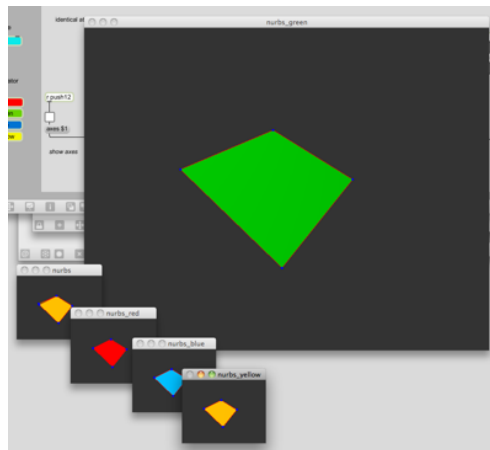
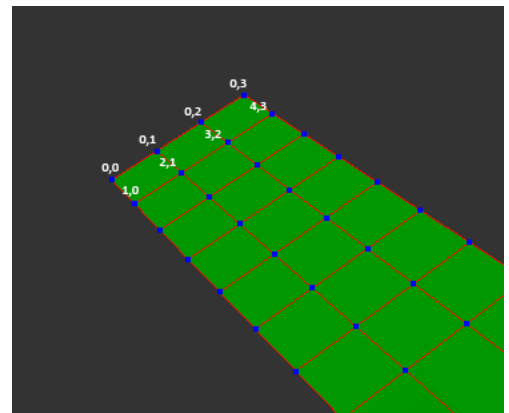


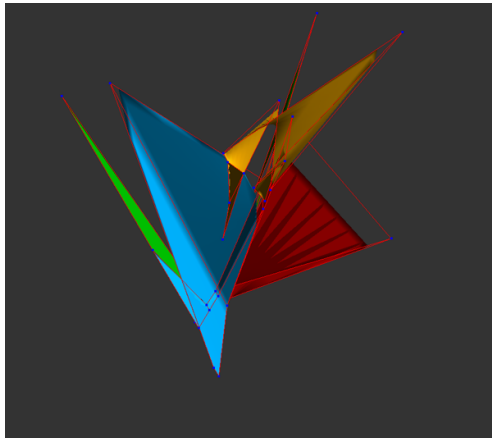
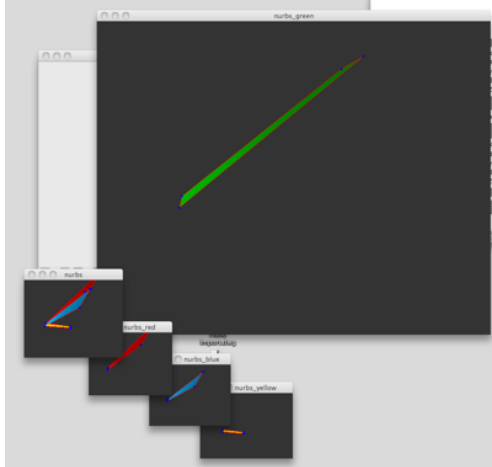
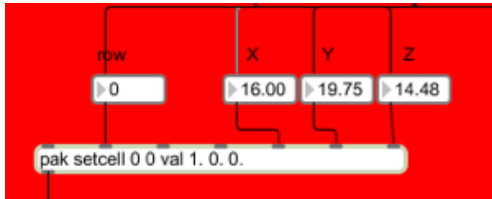
Figure 4
coordinate system;
Aleatorix.

Sound Output (alternative way to express the collected data). This section transforms the received values into audible sound. A *makenote* object outputs MIDI sound information paired with a velocity

value which can be adjusted. With the *pgmaout* object a specific color is assigned to a specific sound type. This component executes four times in total, one for each color range. The result is a unique sound *montage* based on the urban colorscape samples.

Form Generator. Starting point of the actual form generation process is the *jit.gl.nurbs* object, which renders a NURBS surface. Displaying the NURBS requires a *jit.gl.render* object that renders the shape. In total there are four NURBS displayed as there are four different color ranges in the current iteration of the application and each color range generates its own shape as part of the final composition (Figure 2). Through various control points defined in a *jit.matrix*, the shape of the NURBS surfaces can be altered. In the specific case here, the *jit.matrix* object specifies the amount of control points to 40 x 40 points, which describes the maximum amount of points in X and Y direction. In the *dimension* component, the order and initial position of these control points is predefined to a regular grid. Several attributes can be added to the *jit.gl.nurbs* object. On one hand there are attributes equal for all four NURBS surfaces such as position, rotation, predefined viewports and scale. On the other hand there are the attributes specific to each individual NURBS surface such as appearance and color. At the start of the run-cycle the grid is set to display four control points as a flat plane (Figure 3).





The values obtained from the color tracking process are then used to alter the location of these control points and therefore the geometry of the NURBS sur-

face (Figure 4).

To manipulate the location of a single control point, 3 values X,Y and Z are needed. Figure 5 shows which points are altered and how the values for these points are registered to X,Y and Z coordinates. In this case the point in column 0 (first column) and row 0 (first row) is altered. The initial location was X= 1.0, Y= 0.0, Z= 0.0 which was altered to X= 16.0, Y= 19.75, Z= 14.48 (Figure 6). Y and Z coordinates are defined through the color tracking process. To the X coordinate equals duration, a time length set by the user. The X coordinate therefore changes as the user changes the time settings. Every time a sequence is completed the column value will increase as there will be one more control point added to each row, while the row value itself stays constant, set to 2 rows. This technique can be describes as a mono-directional (or linear) growth process. At a given time, 2 control points will be manipulated simultaneously.

The values of a given set of control points are stored in the sub-matrix. In the next sequence the consequent set of control points will be transformed. This entire process can be repeated at least 4 times but beyond that as many times as needed (Figure 7).

Once the video input has ended it is possible to save the shape in the .obj file format that for example can be read in AutoCAD or Rhino (Figure 8). The shape will be exported in a rectangular grid mesh. Therefore the amount of control points must be a multiple of 4. A sub-patch monitors the amount of control points. If the user chooses to save the shape it will check if the value is in multiples of 4. If it mismatches, it will set the amount of control points to the next smaller multiple of four.

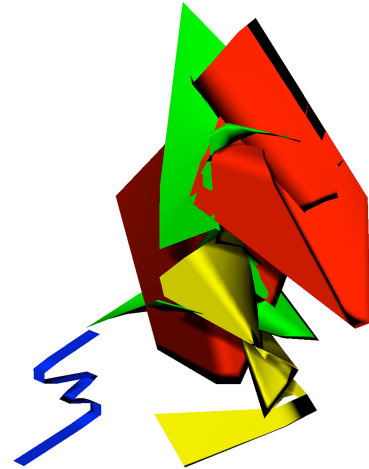
Calibration. The visual performance of the camera sensor presents a series of complexity in calibration. The settings to produce equal images throughout different cameras vary from one to the next and do not remain consistent throughout. For the sake of clarity, we will adopt the *zone system* and color temperature based on the existing conventions of photography. The zones indicate the brightness range of light and dark, and the color temperatures, the light

Figure 5
NURBS point and
X-Y-Z coordinates;
Aleatorix

Figure 6
NURBS with four
altered control
points; Aleatorix.

Figure 7
shape example;
Aleatorix

Figure 8
input/ output
example; Aleatorix.



source that directly affects the color rendition. The zone 0 indicates pure white and the zone 10 pure black when printed on white paper. The zone gradients are measured using the neutral photo grey (80% grey). The color temperatures refer to three main reference points: 2700K (incandescent light), 3200K (tungsten photo light) and 5500-6500K (sunlight). The white balance on the video camera input is calibrated according to the three color temperature references. The exception to the color temperature references include fluorescent lights (greenish tint) and sodium vapor street lights (orange). For these two kinds of lights, we will rely on the automatic white balance function of the camera.

CT Mobile App (Work in Progress)

The CT Mobile App will take advantage of the photo- and video-capturing capabilities of today's mobile

devices. The app is aimed at an architectural and urban use for color-to-geometry conversion with a mobile device. The CT Mobile App utilizes hand-held devices such as smartphones or tablets equipped with a camera for site analysis and design. Here the app is intended to work as location-based mobile application that translates color disposition of architectural and urban places immediately at the scene into three-dimensional data-geometry. Such hand-held mobile devices may also be networked; exchange the visualized color data; and superimpose the information on different locations.

Application & Use

CT can be used to assess and evaluate colorscales and identify the perceptual *black holes* as well as to evaluate how they can be improved in order to restore the chromatic balance and composition of the

place. Furthermore CT enables its users to compare the color palettes of different architectural and urban places.

Complexity behind the Making of Simplicity

The application that drives CT has a simple interface design to deliver *pure forms* that are free of the cultural and enculturating baggage human constructs always carry. But those forms are derived from the complex combination of hardware and software. A kit of hardware (e.g. smartphone, webcam, computer, etc.) requires a complex string of existing, mass-produced parts and assemblies. A piece of software is often a behemoth of conflicting algorithms that have accumulated and become too complex to fix but too expensive to be abandoned. In essence, CT embodies such contradictions of science versus culture and a never-ending pursuit of creating something simple from a warehouse-full of complex bits and pieces of technology.

In Closing

The significance and contribution of the overall research can be summarized as the development of an easy-to-use, portable application. It enables architectural and landscape professionals to analyze the color disposition of a place and experiment with the formal expression by means of color composition. The value of the research output can be summarized as a tool for documenting and visualizing the complex urban conditions in terms of color and providing the effective means to express the combination of urban colors in 3D-shapes.

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