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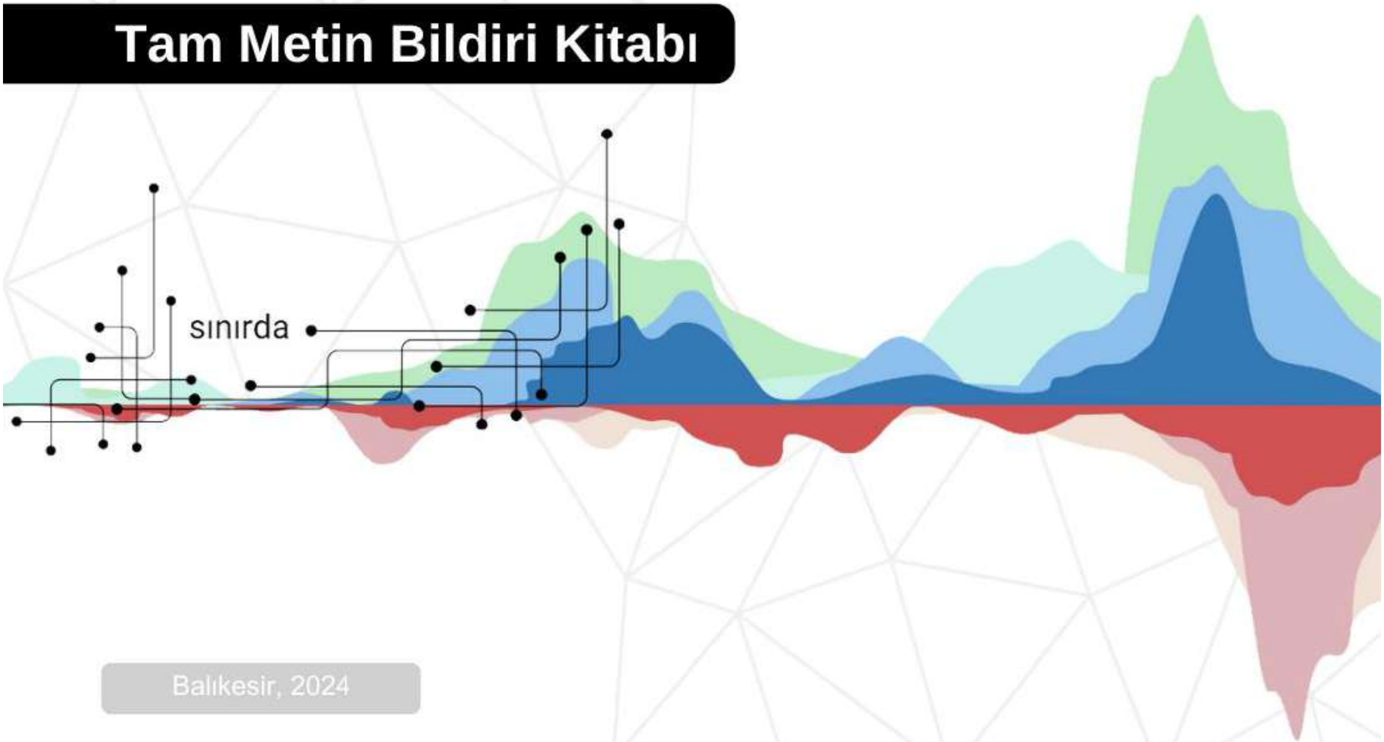
MSTAS

Mimarlıkta Sayısal Tasarım XVIII. Ulusal Sempozyumu

1- 2 Temmuz 2024

Tam Metin Bildiri Kitabı



Balıkesir, 2024

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Reimagining Pixels: Exploring Data-driven Panels to Enhance Human-Machine Interaction

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Abstract

Introduction *- Technological advancements have redefined the pixel from a basic visual unit to a key element in digital imagery. Understanding pixels involves exploring their perception by the human eye and mind and recognizing visual cues like color, intensity, spatial arrangement, and composition. These cues are essential for interpreting visual information which has been studied across psychology, neuroscience, design, visual arts, and computer science within various contexts. AI developments have enhanced methods for image processing, making pixel knowledge a prominent research topic. This shift in image perception, from mere visuals to numerical data, has influenced how artists and scientists explore interaction. This study aims to examine elements of image perception and explore the potentials of the data-driven mechanical panels to enhance human-machine interaction through reproduction and prototyping within an experimental learning environment.*

Design/Methodology/approach *- An experimental research method is used in this study to create a prototype based on a kinetic art installation done by Daniel Rozin to comprehend all of the necessary elements needed to achieve basic data-driven panels. The learning outcomes from this reproduction stage are used to integrate AI with architecture in a later stage of a broader study. The first step of this study is to define the main elements that would turn any array of objects into an image. After thorough understanding, a prototype of data-driven panels is designed through four stages: (1) Image capturing, (2) Image processing, (3) Image data remapping, (4) prototype building. The expected outcome of this study is a prototype that reflects the image of the subject interacting with it and reacts to sounds and music in the surrounding environment.*

Discussion *- The rise of artificial intelligence has strengthened the human-machine relationship, making AI more of a personal companion. Data-driven mechanical panels aim to enhance this interaction by transforming a wall, ceiling or any other architectural element into a dynamic, interactive medium. These panels would have the potential of optimizing light, controlling temperature, and adjusting acoustic performances, significantly impacting interactive architecture. They could revolutionize various industries, such as retail, healthcare, and education, by adapting to user needs in real-time. Integrating AI with architectural elements elevates user experience and interaction. The development of these panels represents a step towards dynamic and responsive environments, merging technology and architecture to improve daily life and occupant comfort. In this context, the production of new knowledge and the discovery of potentials through experiential learning environments also come to the fore within reproduction and prototyping domains.*

Keywords: *Human-Machine Interaction (HMI), Image Recognition, Object-Oriented Programming, Perception Psychology, Visual Abstraction*

Pikselleri Yeniden Tasarlamak: İnsan-Makine Etkileşimini Geliştirmek İçin Veri Odaklı Panelleri Keşfetmek

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Özet

Giriş *- Teknolojik gelişmeler, pikseli temel bir görsel birimden sayısal görüntülemenin anahtar bir öğesine dönüştürmüştür. Pikselleri anlamak için insan gözü ve zihninin algılama üzerinden araştırılması gerekir. Bu bağlamda renk, yoğunluk, mekansal düzenleme ve kompozisyon gibi görsel ipuçlarını tanımlamak önemlidir. Bu ipuçları, psikoloji, nörobilim, tasarım, görsel sanatlar ve bilgisayar bilimi gibi birçok alanda görsel bilgiyi yorumlamak için kullanılmaktadır. Yapay zeka gelişmeleri, görüntü işleme yöntemlerini geliştirerek piksel bilgisini önemli bir araştırma konusu haline getirmiştir. Görüntü algısındaki bu değişim, görsellerden kod-tabanlı temsil formlarına doğru kayarak sanatçıların ve bilim insanlarının etkileşimi keşfetme şeklini etkilemiştir. Bu çalışma, görüntü algısının unsurlarını incelemeyi amaçlamakta ve insan-makine etkileşimini artırmak için veri odaklı mekanik panellerin yeniden üretimi üzerinden deneysel bir öğrenme ortamı oluşturmayı hedeflemektedir.*

Tasarım/Yöntem *- Bu çalışmada, Daniel Rozin tarafından tasarlanan sanatsal kinetik bir kurulumun prototipini yeniden üretmek için deneysel bir araştırma yöntemi kullanılmıştır.. Bu, geniş çaplı bir çalışmanın ileriki aşamalarında yapay zekayı mimari ile entegre etme girişimi için gerekli temel veri odaklı panelleri anlamayı amaçlamaktadır. Bu çalışmanın ilk adımı, herhangi bir nesne dizisini bir görüntüye dönüştürecek ana unsurları tanımlamaktır. Tam bir anlayış elde edildikten sonra, veri odaklı panellerin prototipi dört aşamada tasarlanacaktır: (1) Görüntü yakalama, (2) Görüntü işleme, (3) Görüntü verilerini yeniden eşleme, (4) Prototip oluşturma. Bu çalışmanın beklenen sonucu, etkileşimde bulunan kişinin görüntüsünü yansıtan ve çevredeki seslere ve müziğe tepki veren bir prototip olacaktır.*

Tartışma *- Yapay zekanın yükselişi, insan-makine ilişkisini güçlendirerek yapay zekayı daha kişisel bir yardımcı haline getirmiştir. Veri odaklı mekanik paneller, bir duvarı, tavanı veya başka bir mimari unsuru dinamik, etkileşimli bir ortama dönüştürerek bu etkileşimi artırmayı hedeflemektedir. Bu paneller, ışığı optimize etme, sıcaklığı kontrol etme ve akustik performansları ayarlama potansiyeline sahip olup, etkileşimli mimariyi önemli ölçüde etkileyebilir. Bu paneller, perakende, sağlık ve eğitim gibi çeşitli endüstrileri gerçek zamanlı kullanıcı ihtiyaçlarına uyum sağlayarak dönüştürebilir. Yapay zekanın mimari unsurlarla entegrasyonu, kullanıcı deneyimini ve etkileşimini yükseltir. Bu panellerin geliştirilmesi, teknolojiyi ve mimariyi birleştirerek günlük yaşamı ve kullanıcı konforunu iyileştiren dinamik ve duyarlı ortamlara doğru bir adımı temsil etmektedir. Bu bağlamda, yeniden üretim ve prototip oluşturma alanlarında deneyimsel öğrenme ortamları aracılığıyla yeni bilginin üretilmesi ve potansiyellerin keşfedilmesi de ön plana çıkmaktadır.*

Anahtar Kelimeler: *İnsan-Makine Etkileşimi (HMI), Görüntü Tanıma, Nesne Yönelimli Programlama, Algı Psikolojisi, Görsel Soyutlama*

1. Introduction

In its core state, the pixel has crossed the theoretical boundaries that restricted its conception as just a basic visual unit of an image with technological developments. It is the essence of how we interact with the digital world, where it forms the building block of digital imagery. Understanding pixels necessitates exploring how the human eye and mind perceive them. While it contains the visual representation information of an image which is color and intensity (brightness), its recognition also occurs through visual cues like spatial arrangement and composition. These cues form the core of interpreting visual information and recognizing objects, patterns, and scenes. From various aspects, these interpretations have been studied within the intersection of multiple research domains like psychology, neuroscience, design, visual arts and computer science. As the technological developments in AI-enhanced novel methods to read and elaborate the use of the pixels via image processing, the embedded knowledge in the idea of what a pixel has been made of has started to be at the forefront as a research subject matter as it has been during the first decade of the 2000s (Mitchell, 1984). The transformation of the perception of the image from being a mere visual to being a form based on digits/numbers gathered through the resolution grid affected the ways of questioning its perception through interaction especially by artists and scientists (Reas et al., 2010). While some studies concentrated on the screen-based projections (Reas & McWilliams, 2010), some tried experimenting with perceptual illusions through interactions (Freyer et al., 2011).

2. Related Works & Theoretical Background

In our daily lives, we typically see images reflected on TV screens and smartphones, where these images are constructed from LCD pixel units. Liquid Crystal Display (LCD) technology manipulates light through liquid crystals to produce images. However, while this is the most common method to see images on surfaces, many other media can be used to perceive images. According to Max Wertheimer, the scientist who developed Gestalt psychology, any array of objects can produce an image if arranged in a particular order and with specific characteristics (Wertheimer, 1945). Gestalt word in German is used as a way of placing or putting together a thing in modern language. Although there is no equivalent for direct translation in English, it is usually interpreted as shape, form, figure, configuration, appearance in psychology (Britannica, T. Editors of Encyclopaedia 2024;). According to this, Gestalt psychology is the theory of mind and brain that proposes that humans naturally perceive objects as organized patterns and unified wholes, rather than as separate components (Rock & Palmer, 1990). This approach originated in the early 20th century in Germany, with key figures including Max Wertheimer, Kurt Koffka, and Wolfgang Köhler.

2.1. Case Study: Weave Mirror In The Scope Of Gestalt Psychology

Several artists, including Daniel Rozin, have used Gestalt psychology principles to create images. Rozin is an artist, educator, and innovator known for his interactive digital art installations and sculptures. He is particularly famous for his "mechanical mirror" artworks, in which he uses materials such as wood, metal, and fabric combined with digital and mechanical components to create real-time reflections of viewers. Gestalt psychology includes seven principles of perceptual observations commonly implemented in visual design: Proximity, Similarity, Symmetry, Continuity, Closure, Common Movement, and Figure/Ground (MacNamara, 2017). This study showcases each principle of the seven principles of Gestalt psychology featured in Daniel Rozin’s installation "Weave Mirror" (2007) shown in figure (1), to interpret further how viewers get to see their reflected image in return. The identified principles and their contextual link with the “Weave Mirror” piece are as follows:

The Figure/Ground principle allows viewers to distinguish an object from its background. "Weave Mirror '' uses two primary colors, black and gold, and their gradients, with gold acting as the background and black acting as the foreground.

The Similarity principle involves grouping objects with visual characteristics, such as color or shape, to form a recognizable pattern. In "Weave Mirror," the installation is made of pixel units with identical C-ring shapes featuring typical gradients (Freyer et.al 2011). In this case, the similarity principle helps in grouping the pixel units to form the big picture of the installation.

The Proximity principle states that objects close to each other are perceived as part of the same group. "Weave Mirror" has all units almost touching each other, creating a coherent image based on their spatial arrangement. Figure (1) shows that the human eye perceives the gridded division of pixel units as a single visual output.

The Closure principle allows the mind to fill in missing parts of an image to create a whole, even if only some elements are present. In "Weave Mirror," the medium to represent an image consists of two main colors, merely representing foreground and background, resulting in the production of a highly pixelated silhouette image of the subject standing in front of it. After comprehending the image at first sight, the human mind begins to predict further details to fill in the perceptible gaps.

The Continuity principle guides the perception of smooth, continuous lines or patterns. Rozin designed the pattern in "Weave Mirror" so that each unit alternates from the one adjacent to it by a 90 degrees rotation, forming an uninterrupted pattern that allows the human mind to grasp an aggregate image.

The Symmetry principle, although not always present in Rozin's installations, helps the human mind distinguish an image by providing balance and regularity. In "Weave Mirror", aspects of symmetry can be seen within the display’s overall gridded structure and units.

The Common Fate principle refers to objects moving in the same direction being perceived as a group, creating a dynamic image based on motion. In "Weave Mirror", objects rotate either horizontally or vertically, dividing the movement into two directions which contributes to the final perception of the image. The movement of C-ring units is based on a 90-degree rotation depending on the axis of each unit, therefore forming the gradual shift in the gradient of the unit’s color which represents depth.

3. Methodology

The experimental research method used in this study encompasses four consecutive stages to build a prototype of data-driven panels to be later developed as an architectural feature promoting human-machine interaction (HMI). The stages to be taken into consideration are as follows: (1) Image capturing, (2) Image processing, (3) Image data remapping and motor controlling (4) Building of the prototype. The outcome of this study is a prototype informed by Daniel Rozin's "Weave Mirror", created in 2007 consisting of 768 laminated C-ring prints (Freyer et al., 2011). The prototype created in this study consists of 36-pixel units; the aim is to understand the main elements involved in Rozin’s workflow. The knowledge gained from building such a prototype will be used to create a more advanced installation that integrates AI and architecture. However, the approach taken to build the prototype is based merely on hypotheses that do not necessarily reflect the artist’s personal process. In other words, while the visual aspects of the piece are analyzed and adopted for reproduction in terms of form and kinetic behavior, the mechanical and computational design process of the prototype, along with interaction types, are redefined by the authors and collaborators of the project.

Figure 1. Right and left figures show “Weave Mirror” Installation done by Daniel Rozin in 2007 (Rozin, 2007).

1.1. Image Capturing

The first step of this project is to collect visual data of the subject standing in front of the prototype and start building up the dataset required to initiate the image capturing procedure. The prototype consists of 36 units each representing 1 pixel reflected on the data-driven panel, forming a highly pixelated image as an output. Moreover, an abstract image of the subject standing in front of the installation is displayed. In order to achieve a more precise visual output, a depth sensor is utilized. Depth sensors are devices used to measure the distance between the sensor and objects within a specific defined range. The depth sensor used in this case is Microsoft Kinect V2. The background and foreground are easily distinguished by creating a three-dimensional (3D) representation of the environment by capturing depth information. Units that form the prototype are hemicylindrical in shape featuring a gradient color degrading from white to black. White denotes negative visual values representing the background while black denotes positive visual values representing the foreground. The gradient from white to black signifies different distances. The subject standing within the range of the depth sensor is represented as a pixelated silhouette on the data-driven panel.

Figure 2. Left shows Microsoft Kinect V2 device (Basu, 2016) and right shows sensor's area coverage of Kinect's sensor (source: authors).

1.2. Image Processing

Microsoft Kinect is connected to an open source integrated development environment (Processing) as the second stage of the process for creating data-driven panels. Once the depth data is captured by Kinect, the same data is then fed into Processing. A custom code converts the live-recorded data into black and white values that make up pixels of the final image. The number of pixels in the code matches the number of units in the prototype. Each pixel in the code output corresponds to a specific value based on its grayscale number, which ranges from 0 to 255, with 0 representing black and 255 representing white. For further explanation, the closest objects to the sensor are depicted as black, while the furthest objects appear as white, ensuring that the depth information is accurately represented in the final visual output.

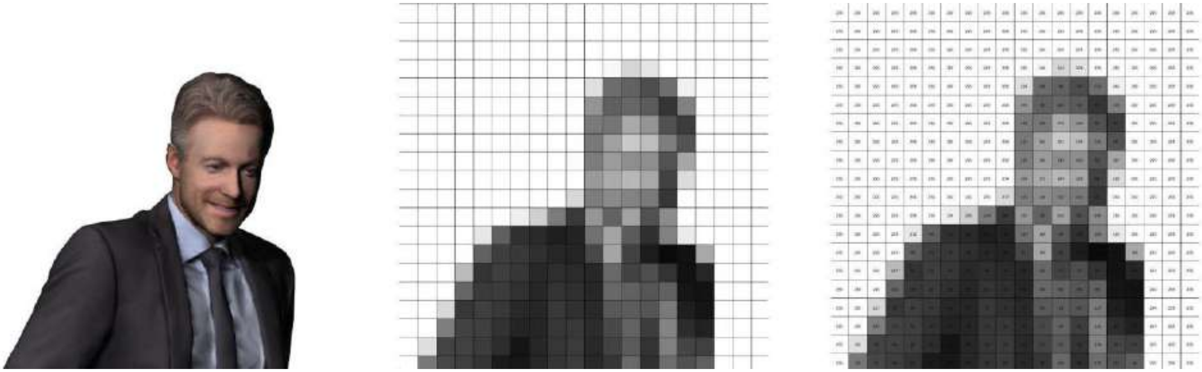

Figure 3. Left shows original input image, middle shows pixelated image, right shows grayscale numerical values displayed on each pixel (source: authors).

1.3. Image Data Remapping & Motor Controlling

Simultaneously, the grayscale numbers of each pixel is transferred in real time to Arduino, which is an open-source electronics platform used for building and programming interactive projects using microcontrollers. Given that the prototype consists of 36 pixels, Processing sends Arduino a sequence of 36 numbers for each frame in real time. Once the Arduino receives the sequences, it remaps them to control the servo motors attached behind each pixel unit. Servo motors are relatively small and simple motors capable of rotating 180 degrees, thus enabling only half-circle rotations. Therefore, the grayscale values, ranging from 0 to 255, are remapped to a range of 0 to 180 (**Figure 4**), defining the rotation degrees of the servo motors.

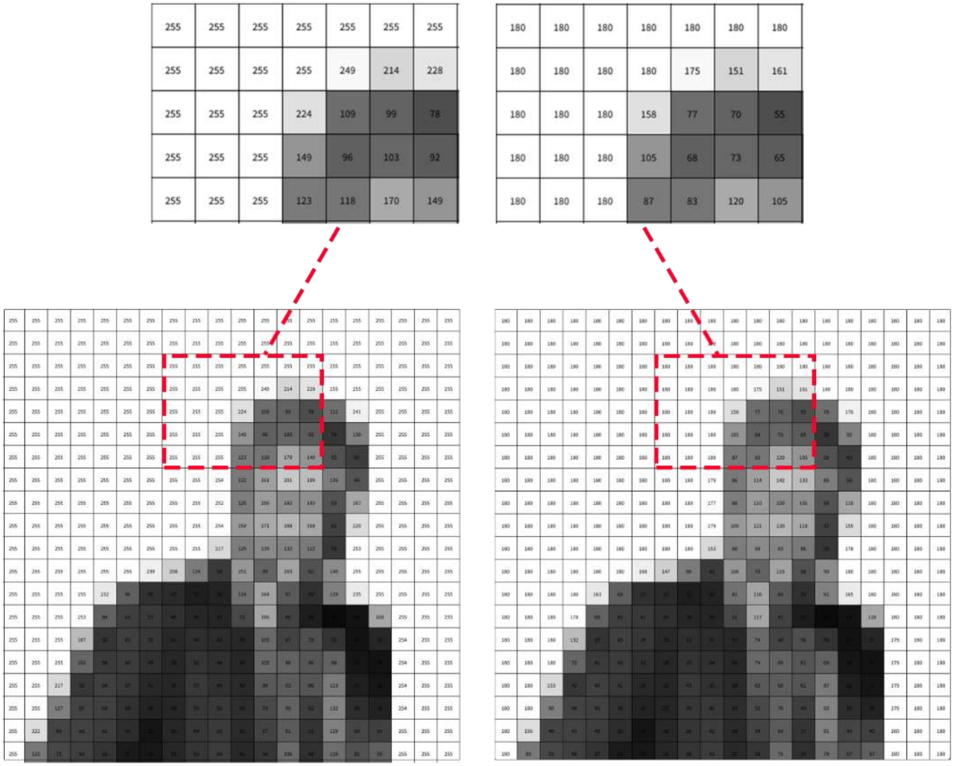

Figure 4. Shows data remapping of grayscale values to motor rotation movement values (left figure is grayscale values and right figure is motor rotation values) (source: authors).

1.4. Building of the Prototype

The C-ring display units in the data-driven panel are constructed from 3D-printed components. 3D printing is used to facilitate mechanical and design challenges that custom designs usually encounter, and to keep the prototype lightweight. The base of the prototype is made of a 2mm aluminum sheet, cut using a CNC machine, with custom voids used to fix each pixel unit and route each motor wire to the matching driver board in the back of the prototype. Additionally, the footing holding the prototype is 3D printed. Each pixel unit features a printed paper with a gray gradient glued to the 3D-printed part. On the back of the prototype, an Arduino board and three PCA9685 Driver boards are attached to distribute the data from the Arduino board to the servo motors.

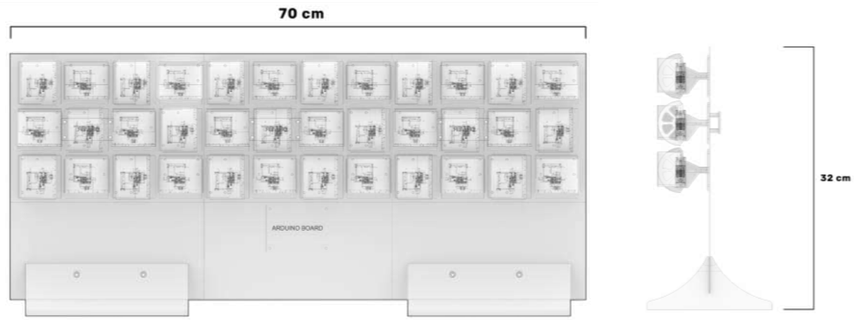

Figure 5. Shows elevation drawings of the prototype design (source: authors).

Figure 6. Left shows back of the prototype, middle shows aluminum base, right shows close up on pixel unit (source: author).

4. Findings and Discussion

The prototype of the data-driven mechanical panels was successfully developed and demonstrated effective performance across the four stages: image capturing, processing, data remapping, and prototype building. Utilizing Microsoft Kinect V2 depth sensor, Processing coding environment, and Arduino-controlled servo motors, the prototype accurately captured and translated depth data into mechanical rotations, forming a coherent, pixelated silhouette of the subject. The 3D-printed display units and footing as well as the aluminum base ensured mechanical stability and lightweight construction. The panels effectively reflect the sensed movement and respond to environmental stimuli, such as passers-by sound or music, showcasing their dynamic and interactive capabilities, and their potential as interactive architectural features informed by live data. This project lays a foundation for a future study to integrate AI with architectural elements, offering dynamic and responsive environments that enhance human-machine interaction (HMI) within the user experience.

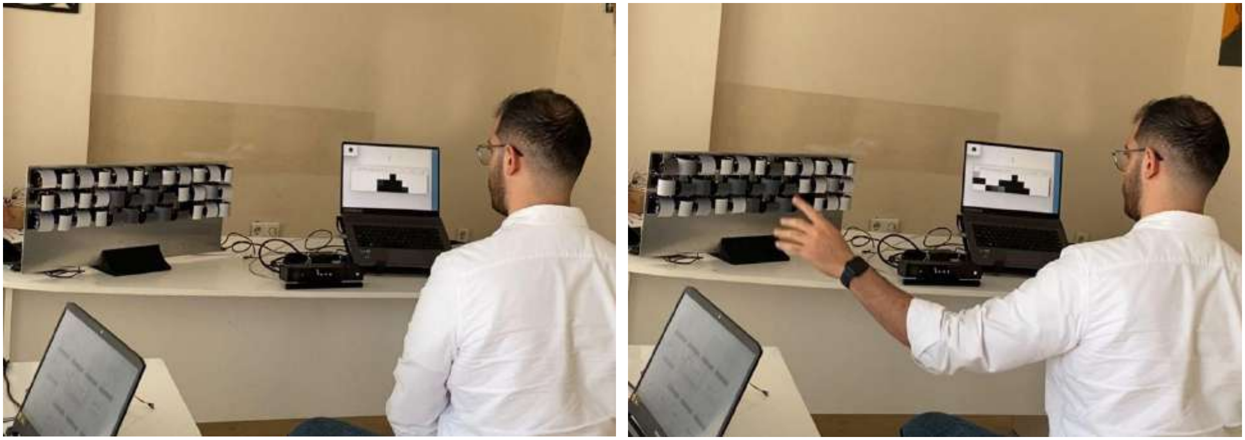

Figure 5. Shows image reflecting feature of Data-driven panel prototype (source: authors).

4.1. Limitations

The development and application of data-driven panels in interactive architecture encounter a number of limitations. Firstly, the complexity and cost of integrating AI and sensors like Kinect can be prohibitively high, particularly for large-scale implementations. Additionally, the prototype's reliance on precise mechanical and electronic components, such as 3D-printed parts and servo motors, presents durability and maintenance challenges and narrows down its potential setting mainly to indoor locations due to low resistance levels in outdoor environmental conditions. Over time, these components may wear out or require frequent maintenance, impacting the system's reliability and lifespan.

Moreover, while the panels effectively translate depth data into visual out-turn, the number of pixel units inherently limits the resolution. This can result in low resolution images, which may not be suitable for applications requiring high precision. Lastly, practically, adopting such interactive systems in real-world environments may encounter resistance due to their novelty and the need for specialized knowledge to operate and maintain them. This highlights the need for ongoing research and development to address these limitations and improve the feasibility of integrating AI-driven interactive panels into everyday architectural applications.

	Method	Integrated Development Environment (IDE)	Object-Oriented Programming (OOP) or Visual Programming (VP)	Device Used	Performance	Potential Improvements / Comments for AI Integration
Design Process	Image Capturing	Processing	OOP	PC + Microsoft Kinect V2	High	Kinect proved to be an effective and relatively inexpensive device for image capturing.
	Image Processing	Processing	OOP	PC	Mid	Processing is a simple and straight-forward tool for image processing. However, it is not optimal for AI integration. Therefore, TouchDesigner is planned to be used in upcoming studies.
	Data Remapping	Arduino	OOP	PC	High	Arduino proved to be an effective hardware and software tool to control servo motors.
	Motor Controlling	Arduino	OOP	Servo Motors + Arduino Board + PCA9685 Driver board	Low	Using Arduino boards and software with servo motors offered an easy experience to control the pixel units but servo motors are not high maintenance.
Data Collection	Depth Capturing	Processing	OOP	Microsoft Kinect V2	High	The method and device are appropriate for use in the final project.
	Motion Capturing	Processing	OOP	Microsoft Kinect V2	High	The method and device are appropriate for use in the final project.
	Voice Recognition	Processing	OOP	PC Built-in Microphone	Mid	A higher-quality microphone and sound filters, such as noise cancellation, can be used to achieve a clearer sound input, therefore enhancing the overall performance.
Materials / Components	Type	Usage	Characteristics	Cost Efficiency	Performance	Potential Improvements / Comments for AI Integration
	3D Printed Filament	Pixel Units + Footing	Highly Customizable + Lightweight	Mid	Mid	Other materials commonly found in architecture, such as wood, ceramics and concrete, can be utilized to establish a more cohesive relationship with the existing building's finishes.
	Aluminium sheets	Base	Relatively Strong + Lightweight	Mid	High	Aluminuim sheets proved high efficiency during the prototype, which increases its chance to be used in the final project.
	Servo Motors	Movement Generation	Affordable + Easy to Program	Mid	Low	Although servo motors are affordable and easy to program, they are prone to breakdowns and malfunctions. Therefore, stepper motors, which are more durable and cost-effective but harder to program and control, are planned for use in upcoming studies.

Figure 6. Table showing a breakdown of different sections in the project and potential improvements (source: authors).

4.2. Conclusion

The relationship between humans and machines is getting tighter, to the extent in which AI is now more of a personal companion. The main objective behind creating data-driven mechanical panels is to add an extended interaction layer between humans and machines within the architectural environment. The potential here lies in redefining the properties of a wall, making it a responsive and reciprocal layer rather than an isolating architectural element. Future developments of this project can leave an impact on the interactive design field. For example, future applications can be used to enhance occupant comfort through controlling factors within the built environment, such as temperature and ventilation, via opening and closing voids that penetrate light and air. Moreover, kinetic acoustic panels can be developed in further stages to be integrated in spaces such as concert halls and auditoriums to enhance the audio experience of attendees and performers alike. This experimental research focuses on the interaction between humans and machines in an effort to embed AI with architectural elements, therefore raising the standards and quality of spatial interaction.

Expanding on this concept of Human-Machine Interaction (HMI) , it's important to delve deeper into the implications and potential applications of such technologies. As technology becomes increasingly integrated in society, interactive architectural elements play a bigger role in shaping our environment. The vision is reaching a point in which buildings are dynamic entities that respond and adapt to human needs and interactions. With advancements in mechanical engineering and artificial intelligence, this vision is not far-fetched. In a future where mechanical panels are not only limited to static displays, but also seamlessly integrated into the fabric of our surroundings, new spatial experiences would shape our understanding of architecture. These interactive surfaces could add to the user experience when coming in touch with the built environment, blurring the lines between architecture and machines.

Furthermore, potential applications of such a technology extend beyond merely aesthetic installations. Data-driven panels could be utilized in various industries, from retail and advertising to healthcare and education. For instance, shopping experiences could be customized to display relevant products based on the customers' preferences and past purchases. Another example features interactive learning via displaying dynamic visual data in an immersive educational experience. The integration of AI into mechanical panels opens up a gate of possibilities for data-driven adaptive functionality. By collecting and analyzing user data, these panels can anticipate and respond to user needs in real-time, creating personalized experiences that enhance efficiency and convenience. In a smart home setting, the Internet of Things (IoT) technology could be merged with data-driven panels to adjust room temperature and lighting based on user preferences and daily routines, optimizing energy usage and occupant comfort.

In conclusion, this research focuses on the development of data-driven mechanical panels and their potential to unlock new levels of interaction within the architectural field. By seamlessly merging infocentric systems into the built environment, the limitations and boundaries are pushed further. This research is immersed in reimagining what is possible with AI and interactive architecture and unleashing new applications within this cross disciplinary field.

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