2025 IEEE/SICE International Symposium on System Integration (SII)
January 21-24, 2025, Munich, Germany

PuzMaty: Supporting Puzzle Mats Design Creation

Sarii Yamamoto[1] Jiajun Wang[2] Liwei Chan[3] and Yuta Sugiura[4]

***Abstract*— Puzzle mats made of cushioned material are widely used in environments like homes and playrooms to prevent injuries from infants and toddlers falling. The mats feature puzzle-like edges, allowing users to freely adjust their size and shape to fit the space where the mat is placed. This study proposes "PuzMaty," a design interface for drawing patterns of animals, numbers, letters, etc. using puzzle mats of different colors. This interface is expected to make the puzzle mat function not only as a safety measure but also as an interior decoration. It is also likely to reduce the burden of childcare when placing mats because it makes the number of mats required for a particular space more intuitive.**

I. INTRODUCTION

Many traumatic brain injuries in infants and toddlers are caused by falls in the home, often due to the child's behavior, such as running and jumping [1]. However, it is not easy to control infant behavior, and children's ability to move around freely is crucial for healthy development. For this reason, families with small children and children's rooms often place cushioned puzzle mats on the floor of living rooms and children's rooms. Puzzle mats are made of resilient materials like Ethylene Vinyl Acetate (EVA) or polyethylene, with each mat surrounded by edges that fit together like puzzle pieces, and they measure approximately 30 cm to 1 m on each side. Due to their high cushioning properties, they absorb shock and sound, preventing injuries from falls and reducing noise. The puzzle-like edges allow the mats to be connected, so their size can be freely adjusted to fit the room's dimensions and shape.

In general, most puzzle mats on the market are colorful, with two or three colors, intended for use in children's rooms. However, due to the emphasis on safety, design options are limited and tend to feature simple patterns.

Therefore, this study aims to develop a design interface called "PuzMaty," which allows children and caregivers to easily and enjoyably simulate puzzle mat patterns 1. By doing so, puzzle mats, traditionally used for children's safety, can be repurposed as tools for freely designing floors. Users can create their drawings freely or refer to websites like DOTOWN[1] to draw patterns that match the room's dimensions, seasonal themes, or educational designs (e.g., letters and numbers) to support children's learning. Additionally, since the number and colors of mats required can be intuitively determined based on the room's size, caregivers do not need to measure the room dimensions and calculate the number of mats required, thereby reducing the burden of childcare.

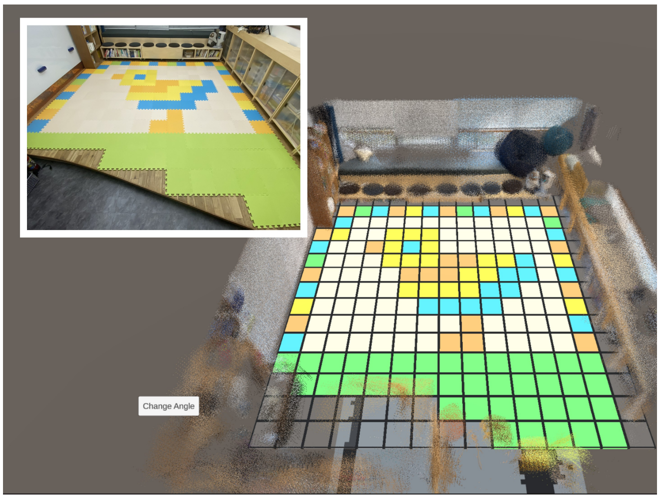

Fig. 1. Systems Overview

II. RELATED WORK

A. Design Support Tool

Handcrafting and garment creation usually require manual design schematics and structural planning during the creation process. However, these tasks can be challenging for children and beginners and time-consuming even for experienced individuals. Therefore, simulating design schematics via computer tools can offer several benefits, such as improved efficiency and support for beginners' learning. Tools exist for designing not only 2 Dimensions (2D) works like wire wrapping [2], stenciling [3], rhinestone embellishments [4], and paper piecing [5], but also for creating 3 Dimensions (3D) handcrafts like plush toys [6], beadwork [7], and pouches [8]. There are numerous studies on embroidery [9], knitting [10], [11], and garment design [12], including sketch-based systems that create e-textile patterns incorporating electronic components like sensors and LEDs [13] as well as programming-based tools that promote programming education through the creation of embroidery patterns [14]. In addition to creating and simulating designs, some studies have focused on optimal design and support during the creation process. For example, there is research on the

[1]Sarii Yamamoto is with Faculty of Information and Computer Science, Keio University, Kanagawa, Japan sarii429@keio.jp

[2]Jiajun Wang is with the Department of Computer Science and Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan shigurewg.cs10@nycu.edu.tw

[3]Liwei Chan is with the Department of Computer Science and Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan liweichan@cs.nycu.edu.tw

[4]Yuta Sugiura is with Faculty of Information and Computer Science, Keio University, Kanagawa, Japan sugiura@keio.jp

[1]https://dotown.maeda-design-room.net/

application of pixel art to handicrafts, where images are converted into knitting, cross-stitch, and beadwork patterns, and patterns are corrected when errors such as pixel skipping or duplication occur during creation [15]. Legolization [16] generates Lego assembly patterns based on 3D models, suggesting stable structures to prevent collapse during assembly. While many design interfaces use images, sketches, or 3D models as input, sketch-based design interfaces are simple to operate, allowing even novices to easily realize their ideas.

In comparison, PuzMaty aims to create a tool that supports pattern generation for puzzle mats, enabling users to design floor layouts easily before placing the mats without requiring complex operations. Users can scan a 3D model of the environment in which they want to place the mats, select the mat size, and automatically simulate mat placement. They can then design the floor like pixel art, adjusting to the room and mat sizes. This tool is expected to eliminate the need to calculate the number of mats required for the space before purchase, thereby reducing the burden of mat placement tasks.

B. Interaction with Floor Surfaces

The floor is a particularly important area in living spaces, with its materials and design significantly impacting the overall ambiance and style of the space. Using carpets and rugs not only improves comfort through insulation and thermal effects but also harmonizes the entire space, creating a cozy environment. There are several studies in the field of Human-Computer Interaction (HCI) that use floor surfaces. For example, TapTiles[17] embeds LED lights in the floor to present information, while other studies have investigated the impact of floor-based interface design on decision-making [18]. In addition, there are studies on developing interactive children's games that project images in response to human movements [19], [20]. However, installing displays or embedding LEDs across the entire floor presents challenges, such as financial costs and space requirements. In contrast, there are studies that use carpets or mats such as PI Floor [21] and those aimed at rehabilitation for children with disabilities [22], [23], [24]. These studies utilize paper with printed letters or carpets embedded with sensors and LEDs, which are more cost-effective and portable compared to large-scale displays.

Related research on floor design includes studies on AI Carpet [25], generating patterns for jacquard woven carpets [27], and Graffiti Fur [26]. AI Carpet creates carpet designs that match the room's ambiance based on user preferences and room images. Graffiti Fur is a technology that uses raised fur fibers to display designs on carpets. This allows ordinary carpets to function as rewritable displays, with no running costs to maintain the image. Puzzle mats are also available with designs or numbers and letters embedded like puzzles [28], offering aesthetic appeal and educational value for young children. However, these mats often have fixed designs that are difficult to change.

This study aims to design floors using flexible puzzle mats traditionally used for safety purposes. This approach eliminates the need for new devices or special spaces, allowing children to safely draw and play in their everyday living spaces. The use of multiple mats to create a single design in a room allows for easy redesign by rearranging the mats, facilitating room redecoration with educational letters and numbers or seasonal designs, thus contributing to children's education and making it easier to change the room's appearance.

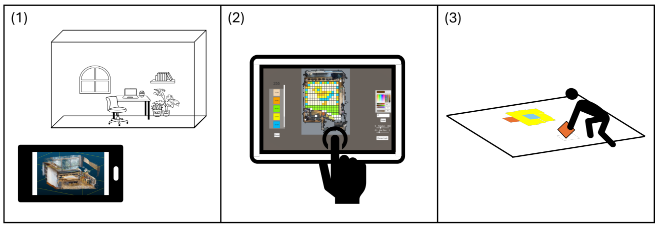

Fig. 2. System flow: (1) 3D model scanning; (2) drawing; (3) mat placement

III. Systems Scenario

The scenario for this system is shown in Figure 2. The target users are (a) those who already own puzzle mats and want to change the pattern using a limited number of mats they own and (b) those who are considering purchasing puzzle mats and want to buy the necessary amount based on patterns that match the room's atmosphere or patterns drawn by their children.

1). 3D model scanning and importing into the system: Users use tablets like iPhones or iPads to scan a 3D model of the environment in which they want to place the mats and import it into the system.
   a) Enter the colors and numbers of the mats users own in advance, and create a new pattern while ensuring that the number of mats used for each color does not exceed the number of mats owned.
   b) Create patterns while freely adjusting the colors. After deciding on a pattern, check the list of colors and numbers used in the simulation, and purchase the necessary mats.
2). Drawing: The 3D model of the room is displayed by the system, allowing users to rotate the model, adjust the area where the mats will be placed, and set the size of the mats.
3). Mat placement: Arrange the mats in the actual environment while referring to the created pattern, either by printing it out or viewing it on a display.

IV. Design Interface "PuzMaty"

In this study, a design interface is created using Unity to simulate the placement of the puzzle mat. The interface is shown in Figure 3 below.

A. Scanning 3D Models

First, scan the 3D model of the environment in which the user wants to place the puzzle mats and import it into

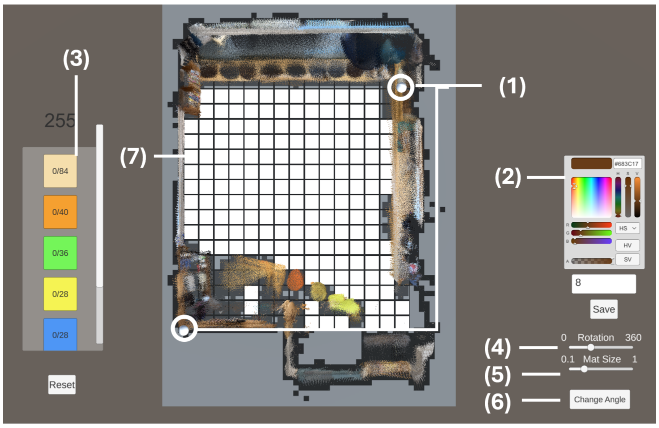

Fig. 3. PuzMaty

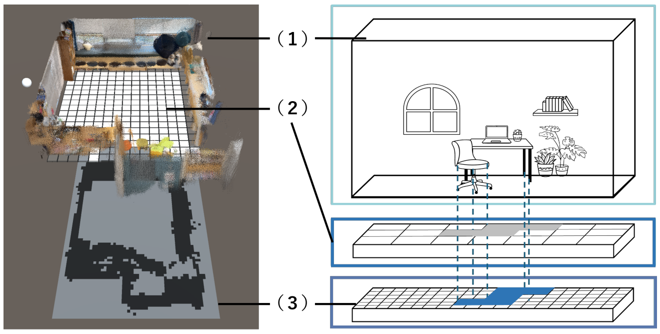

Fig. 4. System configuration: (1) 3D model; (2) mat layer; (3) point cloud detection layer

PuzMaty. In this study, we use the iPhone's built-in LiDAR sensor to capture the actual environment and convert the files for import into Unity using Meshlab[2]. The 3D model is displayed in the center of the screen within the interface, and mats are placed in areas excluding furniture and walls. The detection of obstacles like furniture and walls is described in detail in Section IV-C. Before drawing the pattern, the user can use the slider at the bottom right of the screen to rotate the model and adjust the mat size, thereby adjusting the angle. Additionally, users can set the area where they want to place the mats by moving the spheres located at the top right and bottom left of the 3D model.

B. Functional Description of the Interface

As described in Section III, this system targets users (a) who already own puzzle mats and those (b) who are considering purchasing them. Therefore, the system has two nodes to serve both purposes. The basic interface and operation instructions are the same, but during color selection users (a) adjust the size of the mats in the interface to match the mats they own, register the colors and quantities, and create patterns within the limits of their available mats. In contrast, when selecting the second option, users (b) can freely choose the size and color of the mats, create patterns and then purchase the mats based on the colors and quantities used in the simulation. Users considering the purchase of puzzle mats traditionally need to measure the area where the mats will be placed and calculate the required mat size and number of pieces. However, with the use of this system, it becomes possible to simulate the placement of mats and their sizes on a 3D model, thereby eliminating the need for this cumbersome process in a real environment.

1). Setting the placement area: Adjust the placement area of the mats by moving the spheres located at the top right and bottom left of the 3D model in the simulation.
2). Color Palette: Select the color of the mats from the color palette. Specify the color using RGBA, HSB, or HEX color codes.
   a) Create a color that closely matches the mats you already own, enter the quantity in the text field below the color palette, and press the save button.
   b) Create the colors needed for the pattern you want to draw.
3). Color preview: Check the colors used and the number of each.
   a) The initially created colors using the color palette, the quantity of each color owned, and the quantity used in the simulation are displayed.
   b) The colors and quantities used in the simulation are displayed.
4). Rotation slider: Rotate the 3D model.
5). Mat size adjustment slider: Adjust the mat size on a scale from 0.1 m to 1 m.
6). Angle change button: Change the camera position. Initially, the model is projected from directly above (Figure 3), but pressing the button changes the camera position to a 45-degree angle. You can further adjust the camera position forward, backward, left, and right using the WASD keys and up and down using the arrow keys to replicate a human's view in the actual environment and check the mat placement.
7). Mat simulation: Apply the selected color to the mat area by left-clicking on it, and erase the color by right-clicking.

C. System Implementation

This system consists of a 3D model (Figure 4(1)), a mat layer (Figure 4(2)), and a point cloud detection layer (Figure 4(3)). The 3D model is captured by the user and imported into Unity. To remove the floor portion of the 3D model, pre-crop the bottom 10% of the model's point cloud and create a mat layer in place of the floor. The size of the puzzle mats in the mat layer can be adjusted on a scale from 0.1 m to 1 m. Users can change the color of the mats and draw patterns by clicking on them. The point cloud detection layer consists of a collection of smaller mats (point cloud detection mats) and is used to detect objects such as furniture and walls within the 3D model. When the scale of the 3D model is set to 1 and point clouds exist up to a height of 0.6, the point cloud detection mat directly below these point clouds

[2]https://www.meshlab.net/

becomes active. If 60% or more of the area of a single puzzle mat contains active point cloud detection mats, the area where the puzzle mat is placed is considered to contain furniture or walls and is grayed out. Initially, the point cloud detection mats are one-fifth the size of the default puzzle mats, so each puzzle mat contains 25 point cloud detection mats ($5 \times 5 = 25$). If 60%, or 15 or more, of these point cloud detection mats are active, the area where the mat is placed is recognized as containing furniture.

V. Results

We conducted a workshop and recruited ten participants (6 males, 4 females, average age 23.8 ± 2.23 years) to evaluate the system by simulating patterns and arranging mats in the actual environment. Participants first received explanations of the system's functions and practiced operating it. Then, they registered the colors and quantities of mats prepared in advance, drew patterns, and arranged mats based on the patterns. There was no time limit for drawing or arranging mats. All experiments were conducted in the same environment to arrange mats in the actual environment, and mats were prepared in advance to fit the room dimensions. A total of 224 mats were prepared in six colors (beige: 84, orange: 40, green: 36, yellow: 28, blue: 28, brown: 8)

Participants were not given specific tasks and were free to draw animals, plants, characters, etc. They arranged the puzzle mats using a printout of their designs as a reference. Eight out of ten participants searched for images and pixel art on the Internet for reference. On average, participants spent about 20 minutes on drawing and 30 minutes on arranging mats. Figure 5 shows the patterns created by the participants and the actual arrangement in the room. Additionally, the System Usability Scale (SUS) [29] was used to evaluate the interface, resulting in a score of 82.5. In post-experiment interviews, participants were surveyed about their satisfaction with the designs created and suggestions for improving the interface. While participants enjoyed designing and arranging mats, they noted that it was difficult to create colors without explanations for HSV or RGB values and highlighted the need for a feature to bulk draw mats by dragging the mouse, as currently, each mat needs to be clicked individually for coloring. Regarding satisfaction, many participants felt that the simulated and arranged designs met their expectations. However, one participant mentioned that his impression of the simulated patterns and those in the real environment differed because he registered colors different from the actual mat colors during registration.

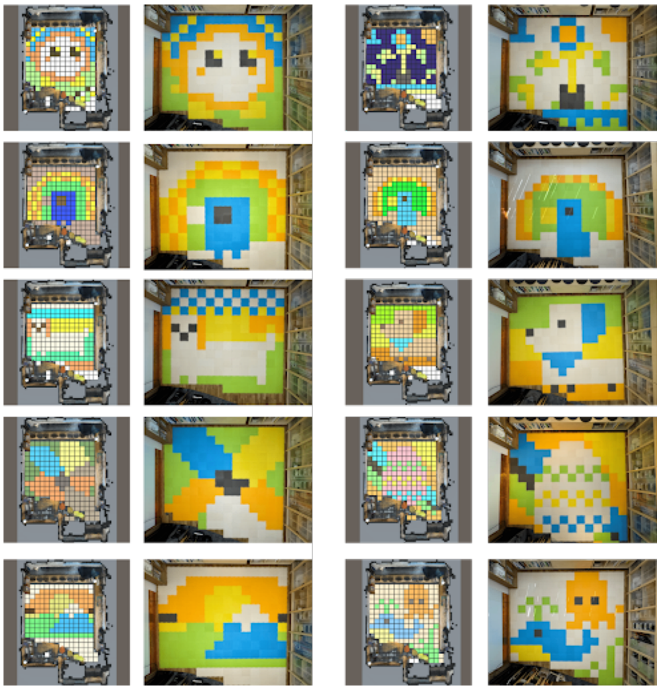

Fig. 5. Patterns Created by Participants

VI. Future Work

One constraint of this system is that users need to scan a 3D model of the room using an iPhone or iPad, followed by converting files and removing unnecessary parts to import them into PuzMaty. Furthermore, mastering the technology to scan more accurate 3D models takes time, which raises concerns that creating 3D models could be a barrier to using this system. In this experiment, we scanned and pre-processed the room's 3D model in advance, and the participants' tasks were limited to registering the colors and quantities of mats, drawing patterns, and arranging mats. In the future, we plan to consider the practicality of the system and implement features to easily incorporate 3D models into PuzMaty. Additionally, this experiment only involved adult participants, excluding the intended users: children and parents. Therefore, we plan to organize workshops with children to evaluate the system's usefulness. Moreover, considering that children will use the interface, there is a need to simplify the functions for ease of use. In this study, a tool was developed to allow users to freely create designs. However, it is acknowledged that some users may find it difficult to come up with ideas and draw them on their own. Therefore, it is necessary to build a system that suggests appropriate designs based on images or keywords. After the experiment, a function was added to load the image and convert it into pixel art with a resolution of 2 x 2 to 20 x 20 pixels. In future experiments, this functionality will be used and evaluated for design tasks, and if necessary, we envision implementing a function to create designs from keywords by preparing a design data set as a simpler design method. Implementing these features would lead to the development of a more user-friendly tool, even for those who find the design process challenging.

VII. Conclusion

In this study, we developed a design creation tool using cushioned puzzle mats, which are commonly used to prevent injuries and noise due to falls by infants and toddlers. Our aim was not only to enhance safety measures but also to foster children's creativity by allowing them to draw patterns with puzzle mats and to reduce the childcare burden by intuitively calculating the required number and colors of mats during placement. Through user studies, we evaluated the usefulness of the system and considered improvements to the interface. Moving forward, we plan to conduct experiments involving children and their parents, who are actual users of the puzzle mats, to build a more practical system.

ACKNOWLEDGMENT

Part of this research was supported by JSPS KAKENHI (Grant Number: JP23H01046).

REFERENCES

[1] J. Haarbauer-Krupa, T. Haileyesus, J. Gilchrist, K. A. Mack, C. S. Law, and A. Joseph, Fall-related traumatic brain injury in children ages 0-4 years, J. Safety Res., vol. 70, pp. 127-133, 2019.

[2] E. Iarussi, W. Li, and A. Bousseau, WrapIt: computer-assisted crafting of wire wrapped jewelry, ACM Trans. Graph, vol. 34, no. 6, Article 221, pp. 1-8, November. 2015.

[3] Y. Igarashi and T. Igarashi, Holly: A Drawing Editor for Designing Stencils, IEEE Computer Graphics and Applications, vol. 30, no. 4, pp. 8-14, July-August. 2010.

[4] Y. Igarashi, Deco: A Design Editor for Rhinestone Decorations, IEEE Computer Graphics and Applications, vol. 31, no. 5, pp. 90-94, September-October. 2011.

[5] M. Leake, G. Bernstein, and M. Agrawala, Sketch-Based Design of Foundation Paper Pieceable Quilts, in Proc. 35th Annu. ACM Symp. User Interface Software and Technology (UIST '22), New York, NY, USA, Article 21, pp. 1-11, 2022,.

[6] Y. Igarashi and T. Igarashi, Designing plush toys with a computer, Commun. ACM, vol. 52, no. 12, pp. 81-88, December. 2009.

[7] Y. Igarashi, T. Igarashi, and J. Mitani, Beady: interactive beadwork design and construction, ACM Trans. Graph, vol. 31, no. 4, Article 49, pp. 1-9, July 2012.

[8] Y. Ikeda and Y. Igarashi, Podiy: A System for Design and Production of Pouches by Novices, IEEE Computer Graphics and Applications, vol. 42, no. 2, pp. 81-88, 2022.

[9] Y.-C. Lee and L. Albaugh, Hybrid Embroidery Games: Playing with Materials, Machines, and People, in Proc. 2021 ACM Designing Interactive Systems Conf. (DIS '21), New York, NY, USA, pp. 749-762, 2021.

[10] B. Jones, Y. Mei, H. Zhao, T. Gotfrid, J. Mankoff, and A. Schulz, Computational Design of Knit Templates, ACM Trans. Graph, vol. 41, no. 2, Article 16, pp. 1-16, April. 2022.

[11] A. Kaspar, L. Makatura, and W. Matusik, Knitting Skeletons: A Computer-Aided Design Tool for Shaping and Patterning of Knitted Garments, in Proc. 32nd Annu. ACM Symp. User Interface Software and Technology (UIST '19), New York, NY, USA, pp. 53-65, 2019.

[12] A. Bartle, A. Sheffer, V. G. Kim, D. M. Kaufman, N. Vining, and F. Berthouzoz, Physics-driven pattern adjustment for direct 3D garment editing, ACM Trans. Graph, vol. 35, no. 4, Article 50, pp. 1-11, July 2016.

[13] N. A. Hamdan, S. Voelker, and J. Borchers, Sketch&Stitch: Interactive Embroidery for E-textiles, in Proc. 2018 CHI Conf. Human Factors Comput. Syst. (CHI '18), New York, NY, USA, Paper 82, pp. 1-13, 2018.

[14] B. Spieler and V. Krnjic, Creative, Engaging, and Playful Making-Activities with Smartphones and Embroidery Machines, in FabLearn Europe / MakeEd 2021 - An Int. Conf. Computing, Design and Making in Education, New York, NY, USA, Article 20, pp. 1-4, 2021.

[15] Y. Igarashi and T. Igarashi, Pixel Art Adaptation for Handicraft Fabrication, Comput. Graph. Forum, vol. 41, no. 7, pp. 489-494, 2022

[16] S.-J. Luo, Y. Yue, C.-K. Huang, Y.-H. Chung, S. Imai, T. Nishita, and B.-Y. Chen, Legolization: optimizing LEGO designs, ACM Trans. Graph, vol. 34, no. 6, Article 222, pp. 1-12, November. 2015.

[17] N. S. Dalton, TapTiles: LED-based floor interaction, in Proc. 2013 ACM Int. Conf. Interactive Tabletops and Surfaces (ITS '13), New York, NY, USA, pp. 165-174, 2013.

[18] L. Albarrak, O. Metatla, and A. Roudaut, Exploring the Design of History-Enriched Floor Interfaces for Asynchronous Navigation Support, in Proc. 2020 ACM Designing Interactive Systems Conf. (DIS '20), New York, NY, USA, pp. 1391-1403, 2020.

[19] O. S. Iversen, K. J. Kortbek, K. R. Nielsen, and L. Aagaard, Stepstone: an interactive floor application for hearing impaired children with a cochlear implant, in Proc. 6th Int. Conf. Interaction Design and Children (IDC '07), New York, NY, USA, pp. 117-124, 2007.

[20] K. Moriya, T. Iio, Y. Shingai, T. Morita, F. Kusunoki, S. Inagaki, and H. Mizoguchi, Playing with invisible animals: An interactive system of floor-projected footprints to encourage children's imagination, Int. J. Child-Computer Interact., vol. 32, No. C, 2022.

[21] A. H. Mahmoud, Y. Abdullatif, and S. Lazem, PI Floor: Portable Interactive Floor with High Resilience and Minimal Setup for Edutainment, in Proc. 17th Int. Conf. Mobile and Ubiquitous Multimedia (MUM '18), New York, NY, USA, pp. 419-423, 2018.

[22] Y. An, Q. Bu, J. Sun, E. G. Lim, L. Kong, Z. Chen, and R. Devaraj, Interactive Rehabilitation Carpet for Children with Cerebral Palsy, in Proc. 17th Int. Conf. Tangible, Embedded, and Embodied Interaction (TEI '23), New York, NY, USA, Article 40, pp. 1-5, 2023.

[23] C. O'Bryan, A. Parvez, and D. Pawluk, An interactive play mat for deaf-blind infants, in Proc. 14th Int. ACM SIGACCESS Conf. Computers and Accessibility (ASSETS '12), New York, NY, USA, pp. 239-240, 2012.

[24] Y. Zhiglova, The Interactive Carpet - Smart Textile Interface for Children on Autism Spectrum Disorder, in Proc. 12th Int. Conf. Tangible, Embedded, and Embodied Interaction (TEI '18), New York, NY, USA, pp. 712–714, 2018.

[25] Z. Wang, X. Wang, Z. Jin, X. Li, S. Sun, and J. Jia, AI Carpet: Automatic Generation of Aesthetic Carpet Pattern, in Proc. 30th ACM Int. Conf. Multimedia (MM '22), New York, NY, USA, pp. 6958-6960, 2022.

[26] Y. Sugiura, K. Toda, T. Hoshi, Y. Kamiyama, T. Igarashi, and M. Inami, Graffiti fur: turning your carpet into a computer display, in Proc. 27th Annu. ACM Symp. User Interface Software and Technology (UIST '14), New York, NY, USA, pp. 149-156, 2014.

[27] C. Guangfeng, Z. Yawei, J. Zhilei, X. Yang, and M. Zhuo, Study on Pattern Preparing System for Three-Level Loop Tufting Carpet, in Proc. 2009 IITA Int. Conf. Control, Automation and Systems Engineering (CASE '09), Zhangjiajie, China, pp. 363-366, 2009.

[28] WONDERFOAM® LETTERS & NUMBERS PUZZLE MAT, available: `https://pacon.com/puzzle-mats/wonderfoam-puzzle-mat-ac4390.html`, last accessed: August 19, 2024.

[29] J. Brooke, SUS: A quick and dirty usability scale, Usability Eval. Ind., vol. 189, 1995.