ITU A|Z • Vol 22 No 2 • July 2025 • 411-425

Robotic technology and artificial intelligence in the process of creating artworks from waste materials: The role of circular design

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Received: January 2024 • Final Acceptance: September 2024

Abstract
In recent years, the application areas and techniques of robotic mechanisms have been gaining significance within design disciplines and various branches of art. This study aims to investigate the hardware and software development of a robotic model that assembles portrait images out of waste material. The primary objective of this research is to demonstrate the feasibility of using robotics to create works of art made out of recycled materials. This research method discovered that it is possible to carry out a production process in which artificial intelligence and robots manage all stages—from generating portrait images, to detecting waste materials to assembling the final artwork. By exploring the possibility of converting waste materials into art objects, this study aims to investigate the potential of technological advancements in robotics to establish a new realm of possibilities in the field of art, design, and waste management. This study will explore the intersections of technology, environmental sustainability and artistic expression and add a new perspective to the existing literature of robotic assemblages.

doi: 10.58278/0.2025.74

Keywords
Computer vision, Diffusion model, Machine learning, Robotics, Waste art.

1. Introduction

During the construction of the Hagia Sophia in the sixth century, Emperor Justinian acquired spolia from all corners of the Roman Empire to compose his masterpiece in Istanbul. Spolia were architectural components taken from older unused structures repurposed for new construction or decoration. This method was quite common even for ordinary buildings. It was easier and cheaper, but it also built on the circularity of building materials, in which materials from unused structures in the vicinity were repurposed for new housing projects, city walls and churches. Even today, some architects are finding creative ways to reuse materials from old structures, such as turning old steel shipping containers into homes, (Clark, 2023) or using pieces of old infrastructure to build unique and vibrant houses (Cala, 2010). While these are inspiring examples, they are outliers in the overall scheme of architectural production. They are not scalable enough to exhaust the immense amount of building waste continuously accumulating around the globe. The scale of the waste problem is immense: According to the United States (US) Environmental Protection Agency (EPA), the US alone produced more than 600 million tons of construction and demolition waste in one year (Demetriou et al., 2023). And, only 25% of that waste underwent reuse or recycling, while the rest ended up in ever-growing landfills (EPA, 2017) and caused severe environmental harm (Duan et al., 2011).

Finding new ways to reuse materials has become crucial to the building industry today. Studies show that 95% of non-hazardous waste could be reused or recycled (Ma et al., 2020). Instead of throwing away materials, we could reuse them to make new buildings or other artifacts. In circular economies (CEs) waste is recaptured as a resource to manufacture new materials and products (Demetriou et al., 2023), i.e., material resources are reused over and over as much as possible to limit the amount of waste. This reuse helps reduce waste and gives materials a longer lifespan, which aligns with the United Nation`s (UN) sustainability development goals on responsible consumption and production (Biermann et al., 2017; Senem & As, 2022).

There has been ongoing research on the role artificial intelligence (AI) and robotics can play in supporting CEs in architecture. For example, recent studies focus on 'Buildings as Material Banks (BAMB)' (BAMB, 2016). One such study investigates using AI to identify the material stock of entire cities in order to predict the amount of stone, brick, metal and glass stocks in existing building inventory via Google Street Views (Raghu et al., 2022). Others investigate how robots can automate construction processes with as-found materials to create walls and various landscape formations (Gramazio Kohler Research, 2023). Yet, these studies do little to address the immense potential of innovative technologies to automate and compose waste into new and multi-layered designs. Indeed, the genuine capacity of waste repurposing resides within the intersection of artistic creativity, new technologies and sustainability. Through the use of AI for the conception and development of designs, combined with the precision of robotic engineering for waste sorting and assembly, we offer a particular answer towards *artistic sustainability* (Scalera et al., 2019a; 2019b).

Our literature review does not include fully automated art generation and production by AI and robots, or related works; this study aims to address that gap. . This paper will showcase a multi-faceted project that repurposes and assembles household waste into two-dimensional artwork. It involves AI-generated visuals, machine learning-driven color spectrum adjustments, object detection, preparation of waste materials, and the assembly of material pieces into artwork with the help of a robotic arm. However, our approach may extend past the confines of two-dimensional space. At the end of the paper, we will discuss a home remodeling project for Deniz Sagdic, a contemporary artist who creates ready-made art with waste materials (Figure 1). Through this architecture project we will elaborate on how some of our ideas can be transferred to three-dimensional space. With new technologies, robots and creativity we can transform waste into something new, acting as a testbed for bigger and more impactful projects in the future.

2. Background

In an era where artistic innovation and technological advancement overlap, we can create a synergy at the intersection of art, architecture, AI-driven robotics, and waste repurposing. The convergence of artistic vision, automation, and responsible resource utilization offers a glimpse into a future where waste is transformed into habitable structures, paving the way for a more sustainable world running on CEs. Through the lens of manual and automated assembly, the utilization of AI, and the symbiosis of creative artistry and technological advancement, we start exploring how these elements shape the landscape of architecture, sustainability, and artistic expression.

2.1. Manual assembly

Today, several artists repurpose materials for their artwork. For example, Sagdic is using household waste as a medium in her work to explore the social and environmental significance of recycling. She repurposed over two tons of waste for her expressive portraits, using 13,000 buttons, 34,000 plastic clamp bands, jeans, and expired medical tablets (Oru, 2021; Figure 1).

Like Sagdic, other artists make ready-made art from old clothing material, sculptures from plastic forks and spoons, furniture and buildings from scrap foam, reused cross-laminated timber, scrap windows, salvaged building elements, recycled and other repurposed building materials (Figure 2).

These projects prove that remarkable outcomes can come from simple assembly operations. Nonetheless, new technologies can help automate such manual operations. In the following section we will give an overview of the state-of-the-art uses of robotics and AI in architecture, and discuss their use in our research.

2.2. Automated assembly

Robots have been widely used in many architectural applications, such as pick-and-place operations (Gawel et al., 2019; Gharbia et al., 2020; Vähä et al., 2013), drilling, welding, laser cutting, and 3D printing (Evans, 2012; Tay et al. 2017; Zhang et al., 2019). Robots are versatile and have been known for their ability to adapt to different tasks and environments, from laying brick walls to 3D printing entire homes to fabricating smaller-scale objects, such as urban furniture or product designs (Bonwetsch, 2012; Abdalla et al., 2021; Sakin & Kiroglu, 2017; Oberti & Plantamura, 2015). For example, in the 'Circularity Park' project researchers used robots to construct a retaining wall and terraced landscape. They worked on autonomous construction processes, using recycled building materials, and investigated the design, control and computational tools needed for on-site construction with as-found building materials and local excavations (Gramazio Kohler Research, 2023).

Figure 1. *Ready-made art from waste materials by Deniz Sagdic, left: blow-up view, right: entire canvas 140cm x 140cm (Sagdic, 2022).*

Figure 2. *1- Jane Perkins' Girl with a Pearl Earring (after Vermeer), made from clothing buttons (Perkins, 2024); 2- Sayaka Ganz's sculptures of horses made from plastic forks and spoons (Liarostathi, 2012); 3- Douglas & Company's furniture made from scrap foam and reused cross-laminated timber (Douglas, 2021); 4- Hirushi Nakamura's Zero-Waste Center assembled from 700 scrap windows (Iype, 2022); 5- S+PS Architects' Collage House upcycled salvaged building elements into its façade (Grozdanic, 2016.); 6- Lundberg Design's Breuer Cabin made from leftover materials of their earlier projects (Lisa, 2014); 7- James & Mau's Manifesto House made from recycled and repurposed building materials (James & Mau, 2023).*

2.3. Use of AI

Within the realm of architecture, AI has been extensively explored for a range of purposes including design generation, analysis, optimization, and as a wellspring of inspiration. It has shown promise in generating basic design concepts, predicting energy efficiency, maintenance needs, and risk assessment (Theis et al., 2015; Goodfellow et al., 2020; Dhariwal & Nichol, 2021; Yang et al., 2023), and developing optimized topologies for structural systems (Bernhard et al., 2021). A noteworthy illustration of AI's ingenuity in CE studies can be found in the Building As Material Bank's (BAMB) project. This project adeptly utilizes AI to predict material stock within urban settings and explores the feasibility of repurposing components from existing structures. Employing Google Street View, BAMB discerns facade materials and reusable elements such as windows, doors, and shutters, to produce classification maps and protocols facilitating urban mining, i.e., the extraction of urban materials for potential reuse in new building projects (Raghu et al., 2022). The landscape of AI-driven design generation is equally vibrant, consisting of various generative models including variational autoencoders, generative adversarial networks (GANs), normalizing flows, autoregressive, energy-based, and diffusion models. Exemples such as Midjourney (Borji, 2022), DALL-E (Kapelyukh et al., 2023), DeepDreamGenerator (Lyu et al., 2022), DreamStudio (Zhou & Shimada, 2023), as well as platforms like FreewayML, NightCafe, and DeepAI, stand out for their capacity to automate design concepts and ideas through text-to-image or image-to-image AI protocols.

2.4. Synergy of AI and robots

AI-driven robotics spans a spectrum of tasks, including autonomous navigation, precise object recognition, and collaborative undertakings (Wright et al., 2010; Klette, 2014). These technologies extend to diverse activities, such as trash sorting and recycling (Zhou et al., 2022; Ingle & Phute, 2016), the transformation of plastic waste into functional tiles, and the creation of 3D-printed metal structures using recycled materials (Tobi et al., 2017; Oberti & Plantamura, 2015; Abdalla et al., 2021). While research converging AI and robotics within the architectural realm remains relatively sparse, there are a few notable examples, such as machine learning's role in forecasting adjustments for robot toolpaths (Nicholas, 2021) or the implementation of reinforcement learning to orchestrate the assembly of discrete components through action, reward, and observation protocols (Wibranek & Tessmann, 2021). However, research on the integrated use of robots and AI to assemble and repurpose waste into habitable structures is a relatively new area of investigation.

The remarkable journeys of artists, like Sagdic, who sculpt their visions from discarded materials, stand as living testaments to the potential that emerges from such synergy, i.e., robotics and AI in architecture is built on innovation, from robots skillfully constructing retaining walls and terraced landscapes with recycled materials to AI algorithms mapping the urban landscape to salvage and repurpose architectural components. The intersection of robots, AI, and visionary art has the potential to transform waste into habitable structures and can open a path for a more sustainable and circular future in the building industry.

3. Methods and tools

Our work makes use of a. AI diffusion models for generating expressive portrait images; b. the application of unsupervised machine learning to distill and organize color spectrums; c. the preparation of repurposed materials; and, d. the careful setup of a robotic arm to detect, sort, pick and place waste materials (Figure 3). We used open-source resources and created customized solutions to develop a prototype. The exploration of AI diffusion models, particularly the effectiveness of Midjourney, underscores the potential of crafting AI artwork tailored for robotic assembly. We used K-means clustering, spatial adjustments in image preparation, and computer vision for object detection and sorting (Dhanachandra et al., 2015). We also undertook precise coordination of the robot arm's intricate pick-and-place operations. Integrating a six-axis robotic arm within a modified control cabinet represents a practical approach to assembly. In this synthesis of technology and artistry, we present a pathway toward a fusion of AI, robotics, and sustainability within artistic architectural expression.

3.1. AI diffusion models

Since its emergence in late 2022, AI diffusion models have profoundly impacted architecture, prompting architects and designers to delve into potential applications (Epstein et al., 2023; Leach, 2022; Fernberg & Chamberlain, 2023). We surveyed Dream ML, Deep Dream Generator, Dall-E, and Midjourney for our research. The latter produced the best results for our research, i.e., generating AI artwork that a robot arm can effectively assemble. AI diffusion models provide stability and high-resolution results, which make them particularly apt for art and graphic design. They are also increasingly integrated into architectural practice with plugins that work with common software tools in the industry. AI diffusion models are built on a two-step process: a forward and a reverse diffusion process. Their neural network is trained to apply conditional distribution probabilities via text or image prompts, and to reverse the noise diffusion into discernable imagery (Dhariwal & Nichol, 2021).

3.2. Image preparation

After generating an image with Midjourney, we used computer vision for both K-means clustering to reduce the image's color spectrum and object

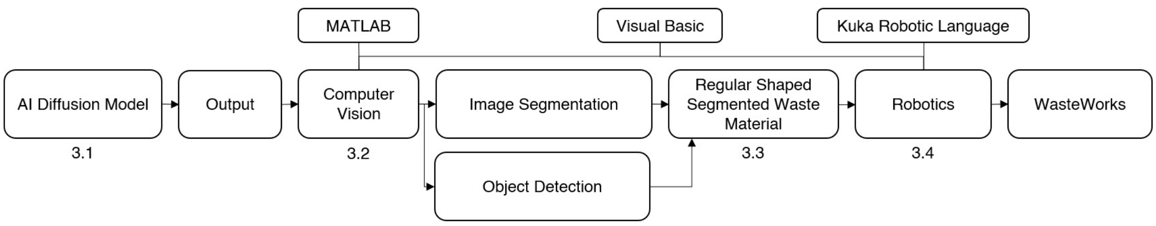

Figure 3. *Workflow of WasteWorks: AI-generated image (3.1) is segmented into color shades (3.2) through K-means clustering and material waste is identified with computer vision. Waste material is then prepared and assembled (3.3) into artwork with a robot arm (3.4).*

detection to sort and identify materials. These colors are linked to a particular material slot on the robot cabinet. While the image has red, green, and blue color channels (RGB), we set the robot arm to recognize a single greyscale channel, and converted the color images into grayscale shades. In addition, we adjusted the spatial and radiometric resolution of the source image, which is an important step in the segmentation process (Schabenberger & Gotway, 2017). The system is then able to produce an image with precise coordinates for the pick-and-place operations of the robot arm.

The use of computer vision for object detection has become indispensable in numerous fields, including remote sensing (Fritsch, 2023; Nurkarim & Wijayanto, 2023; Büyükkanber et al., 2023), autonomous vehicles (Prakash et al., 2023; Gharge et al., 2023), and even healthcare (Liu et al., 2023; Kesana et al., 2023). In the field of architecture and robotics, research on image processing and object detection is increasingly becoming more popular (Demetriou et al., 2023; Figure 3).

Within the scope of this research, we used computer vision for extracting data from the physical world. The data obtained in the image segmentation stage and the color values encoded have been used in the object detection task. Our setup achieved an accuracy rate of 90% in picking and placing materials at the desired points. With an inbuilt camera, an '8-megapixel iSight camera with 1.5μ pixels' the robot arm was able to detect and identify waste materials as target objects and perform pick-and-place operation. We mounted a plane service area, equivalent to an A2 paper, to the robot arm cage to provide a space for object detection, as shown in Figure 4.

3.3. Waste material preparation

The waste material for our project came from a printing facility. They were cut into 1.2" x 1.2" (3cm x 3cm) pieces, which took 3 hours of preparation. The production of a 4'7"x4'7" (140cm x 140cm) canvas took 38 hours of runtime. However, we had to reduce the speed of the robot arm by half for security reasons. At full speed, the robot arm would have been able to assemble all the pieces onto the canvas in only 12 hours.

3.4. Robot-arm setup

We used a six-axis robotic arm housed in a custom-made control cabinet (Figure 4). The robot arm has a maximum reach of 3' (90cm), which limits the size of the canvas to a maximum of 4'7" x 4'7" (140cm x 140cm). We placed the robot arm

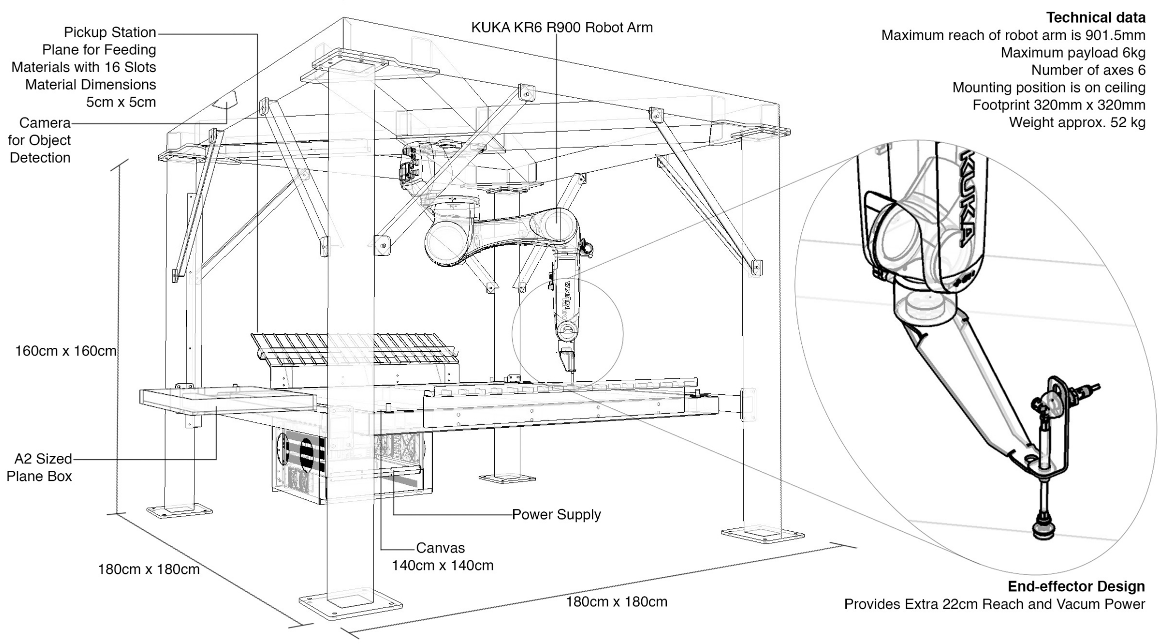

Figure 4. Diagram of the robot-arm cabinet, camera location, pickup station, cage dimensions, design of the end-effector, robot-arm specs and cabinet components.

upside down onto the ceiling of the cage so it has maximum flexibility to reach every point on the canvas. The head nozzle uses vacuum suction to collect waste material from the slots and transfers them to specific locations on the canvas. With the help of a local coordinate system, the robot arm picks up materials from the physical slots and places them onto the canvas.

The project workflow consists of the following steps: applying AI diffusion models, preparing images through K-means clustering, detecting and sorting material with computer vision, arranging waste materials, and setting up the robot arm to create a prototype. The utilization of AI diffusion models underscores the potential for generating AI artwork fit for robotic assembly. The image preparation phase's employment of K-means clustering and resolution adjustments, coupled with object detection capabilities provides the robot arm with precise coordinates. It enables the proper execution of pick-and-place operations.

4. Case study: The canvas

We fused AI, robotics, and sustainability to turn discarded household items into captivating art forms. Our project transforms waste, e.g., paper cards, glass, and textiles, by harnessing AI's creative potential and robotics' precision, into intricate artworks, aligning with the CE ethos. The project's core lies in computer vision, where RGB colors are translated into 4-bit grayscale compositions and stitched together via a robot arm. The pixel tapestry takes shape through careful hardware and software orchestration - a new way of fusing art, technology, and sustainability.

4.1. K-Means clustering

For the prototype, we generated a portrait image using Midjourney. We used various machine learning operations, such as pixelization, segmentation, and reduction of RGB colors to a single grayscale band in MATLAB. The resulting 4-bit grayscale data comprising 16 segments was fed to the robot arm's native software environment (Figure 5).

4.2. Object detection

We developed a customized camera setup to use computer vision to detect and sort waste material, i.e., we assembled a mainboard, graphics card, data storage, and camera system to process image data in real-time. We trained a neural network and created an efficient model to predict material type, color, shape and size, i.e., 'WasteMaterialType, R, G, B, Shape, Size' (Figure 6). The robot arm then automatically picks a material piece closest to the grey-scale shade set in the

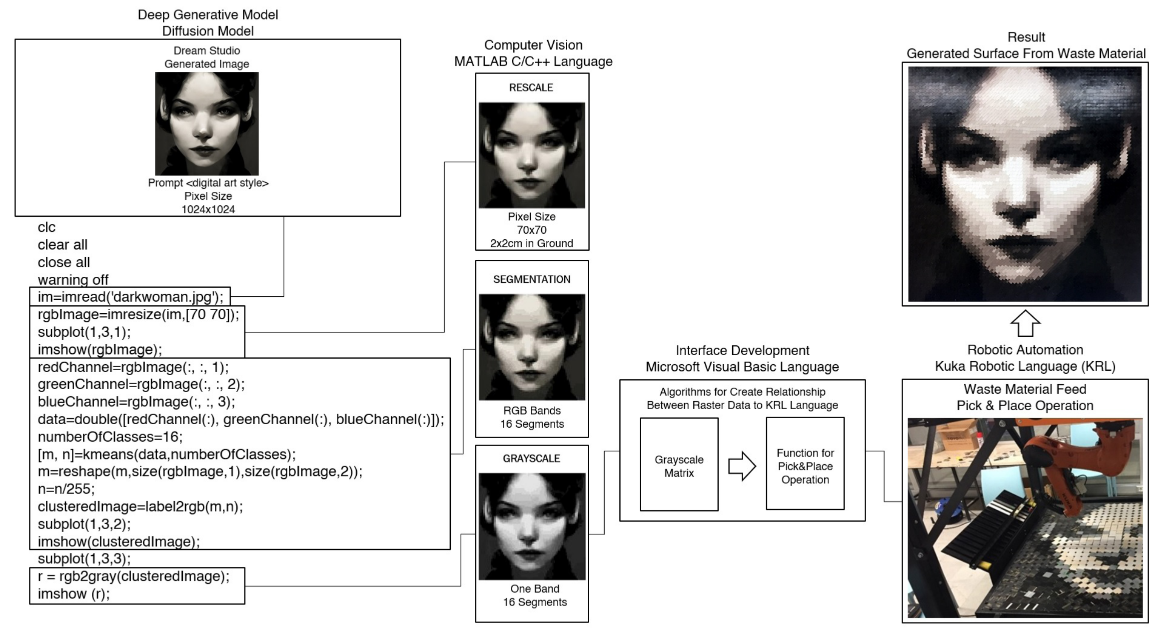

Figure 5. *Image preparation – script with corresponding image translations to turn an AI generated image into ready-made artwork.*

previous step, in 4.1, and places it onto the proper coordinates on the canvas.

4.3. Resolution and scale

We first conducted a test sample with larger pieces measuring 2”x2” (5cm x 5cm) to evaluate the software and hardware architecture. We limited them to only five color segments - as shown at the bottom right in Figure 5. The results showed that the system can effectively handle various materials and surfaces across various spatial resolutions. We subsequently increased the spatial and radiometric resolution of the image. Ultimately, the system functioned best at a ¾” x ¾” (2cm x 2cm) pixel resolution with 1 1/8” x 1 1/8” (3cm x 3cm) material pieces, allowing for a 3/16” (0.5cm) overlap on each side. We employed a 4-bit radiometric resolution, enabling the robot arm to detect 16 distinct color shades.

4.4. Material selection

Figure 7 shows the application-plan based on material types, shapes, overlapping ratios, and surface qualities. The robot arm utilizes

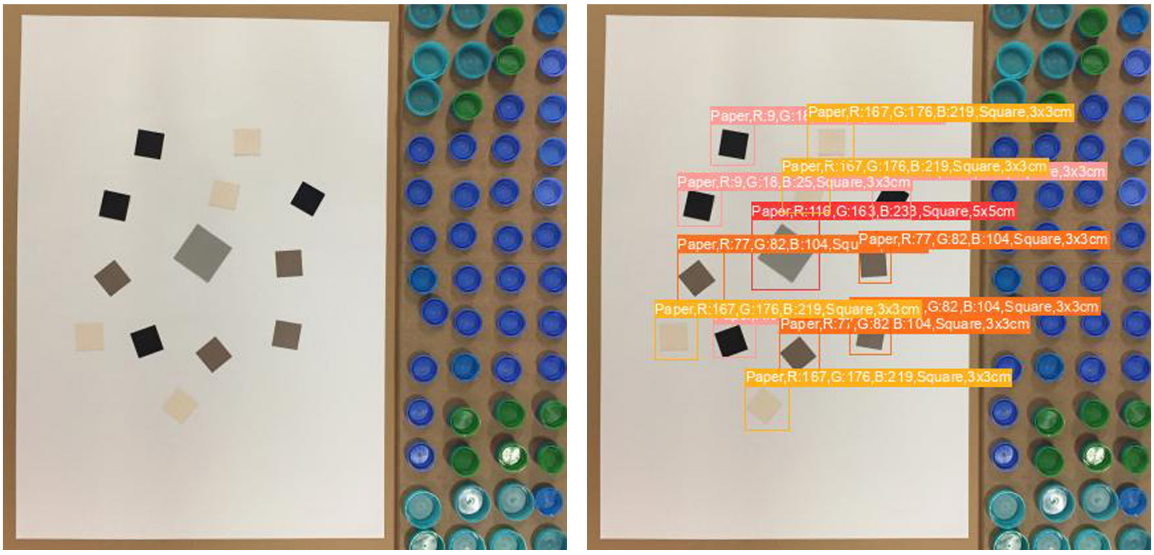

Figure 6. *Object Detection Process for Waste Material Detection, top left: randomly placed waste material pieces, top right: predicting material types, colors, shapes and scale.*

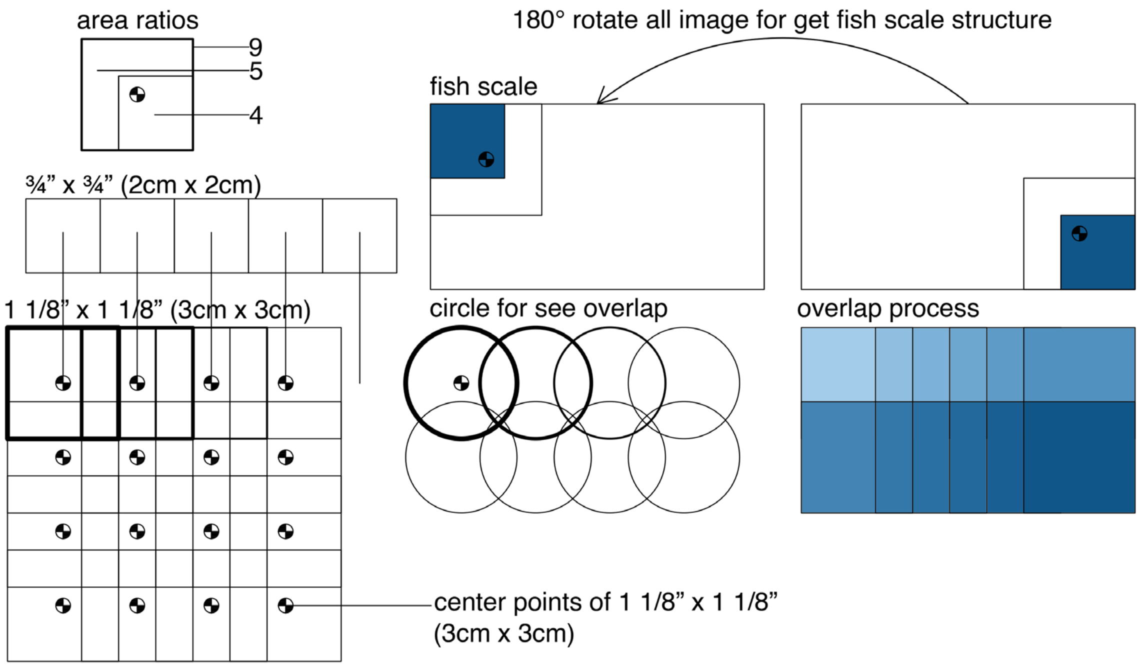

Figure 7. *Application plan for a 4’7”x4’7” (140cm x 140cm) canvas.*

vacuum suction to pick and place waste materials; therefore, choosing the proper material was critical. The materials we used had to possess specific properties, such as rigidity, to ensure successful handling by the robot arm. While we used waste paper cards, the robot arm can also work function with various other rigid materials, including glass, plastics, and metals. To ensure that the pieces remained fixed in place at the specified coordinates, we used a two-sided adhesive tape mounted on a 10mm-thick photo-block canvas. Figure 8 shows our first ready-made artwork - an automated assembly of waste material illustrating a striking synthetic image.

To test the set-up's performance and replicability, we produced additional examples with different paper-based materials, as seen in Figure 9.

4.5. Limitations

During the production of the initial few portraits, we experienced some limitations regarding material selection, resolution, and scale of the artwork.

First, the use of vacuum suction limits the type of material that can be handled. For instance, cotton, fine fabric, thin paper, and cardboard could not withstand the power of the vacuum nozzle. We found that stiff, impermeable paper, thicker cardboard, plastic-coated waste, and various plastics worked better with the robot arm's end-effector. Thus, further work with different types of nozzles is needed. For example, three-finger grippers or manipulators may allow exploring other softer materials, like plastic bags and delicate fabrics.

Second, reducing the size of material pieces would result in more pixels, thus increasing the spatial resolution from 70x70 to 140x140 or 280x280 pixels, producing finer and more detailed results. This, however, would, in turn, require more time for the robot arm to complete the tasks of object detection, sorting and placing material onto the canvas.

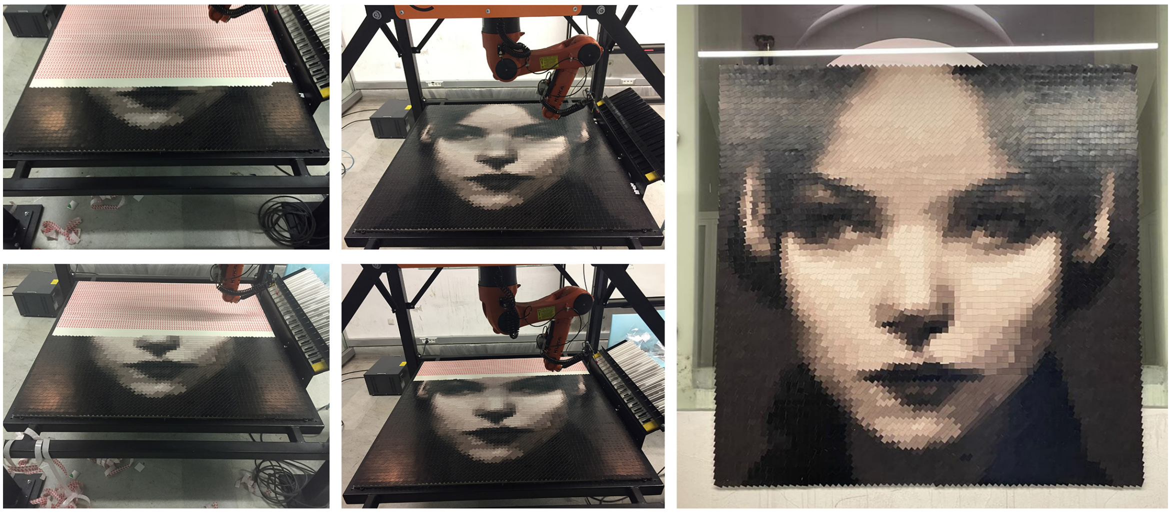

Figure 8. *WasteWorks – Assembling AI-generated art with a robot arm using waste material, e.g., old paper cards received from a printing manufacturer.*

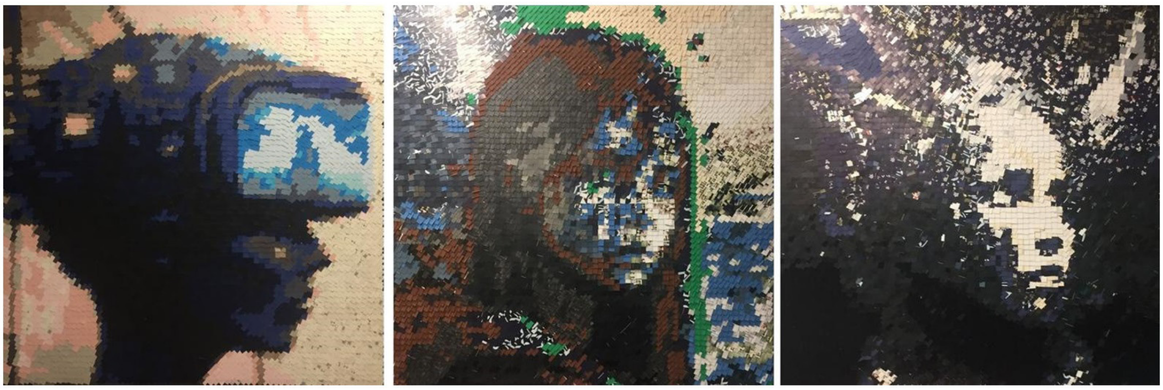

Figure 9. *Various AI-generated portraits assembled with waste materials on 140cmx140cm canvases.*

Third, the robot cabinet setup was limited to work on a two-dimensional surface – the canvas. Extending our methodology to three-dimensional space may not be feasible without adjustments. There are physical size limitations, and it may not work for the design of objects beyond the physical reach of the robot arm. This may be overcome by developing a trial system for the robot arm, using robots with wider reach, and/or multiple robots working in tandem.

In sum, this case study is an example of repurposing waste at the intersection of artistic vision, cutting-edge technology, and environmental stewardship. By converging AI's creative capacities with the precision of robotics, the project repurposes discarded household items, infusing them with new uses in captivating art forms. From the inception of generating portrait images through Midjourney to the detailed orchestration of machine learning processes for image segmentation and material detection, the project achieves a synthesis of form and function. While material selection, resolution, and scale limitations posed various challenges, the interplay of hardware and software produced pixel artistry, symbolizing the fusion of art, technology, and sustainability.

5. Discussion

The concept of *artistic sustainability* offers a creative response to the challenges of waste accumulation and environmental impact. We outlined an exploration of this concept, spanning historical precedents, contemporary artistic endeavors, technological advancements, and practical implementations. The following discussion section will delve into the broader implications, potential future developments, and the significance of the research findings.

5.1. Advancing circular design and resource management

Integrating robotics and AI into waste repurposing projects presents a paradigm shift in how we perceive and manage resources. By leveraging the principles of CEs, where waste becomes a valuable resource, this research highlights the potential to reduce the environmental burden of construction and artistic production. The examples above, such as the use of old shipping containers and repurposed infrastructure elements in creating new artifacts, underscore that creative solutions exist. However, we argue that the true scalability and impact lie in the interplay of AI, robotics, and artistic creativity.

5.2. Transforming artistic expression

The convergence of technology and artistry has the power to redefine artistic expression. Our work demonstrates how AI-generated visuals, machine learning-driven color adjustments, and robotic sorting and assembly can collaboratively produce captivating art forms. This transcends traditional artistic processes, blurring the lines between human creativity and technological innovation. The result is a fusion of human intentionality and precision, pushing the boundaries of what can be achieved through artistic endeavors.

Ethical issues and questions of authorship are critical concerns, e.g., privacy of data. Also who is the author, the person who chooses the dataset, the developer of the generative AI model, the end user who creates the output, or the AI model itself. Potentially no one can claim authorship, as such the generative result may stay anonymous (Avrahami & Tamir, 2021). The use of cultural objects, styles, and the styles of significant figures further complicates the ethical debate. Some solutions, such as assigning specific weights to these components, have been proposed, but ethical discussions around Generative AI are likely to continue.

5.3. Overcoming challenges and future directions

The paper acknowledges the challenges and limitations of the work, such as material selection, resolution considerations, and the confinement to two-dimensional canvases. These challenges, however, open the door for future exploration and refinement, such as extending the methodology to three-dimensional applications. There is a potential to translate our modus operandi to the built environment and to augment existing workflows, i.e, to incorporate circular design principles in architectural practice that may prove a helpful step towards achieving Turkey's ambitious zero-carbon emission goals by 2053. Undoubtedly, more rigorous and comprehensive research in this area is much needed.

5.4. Impact on sustainability goals

The research aligns with the UN's global sustainability development goals, particularly those related to responsible consumption and production. By reimagining waste as a resource and leveraging AI-driven robotics potentially at scale, the study has the potential to highlight the need for resource efficiency and environmental protection. These outcomes have far-reaching implications beyond artistic expression, resonating with broader efforts to address climate change, reduce pollution, and create a more sustainable future.

In short, *artistic sustainability* can offer a particular response, albeit minute, to the challenges posed by waste accumulation and environmental degradation. We show a creative example of waste repurposing and challenge us to reimagine how art, architecture, and technology intersect to shape a future where waste is transformed into an opportunity. By starting a dialogue around innovative solutions, we want to pave a way for further exploration, collaboration, and a broader shift towards circular design and responsible waste management.

6. Conclusion

This paper illustrates waste as a valuable resource in creating automated artwork - through the convergence of robotics, AI, and creative ingenuity. Our exploration is driven by the urgency of addressing the escalating environmental impact of waste accumulation and the imperative to transition towards CEs.

The fusion of robotics and AI in architecture has presented us with remarkable opportunities. From the use of spolia in constructing the Hagia Sophia to the intricate assembly of modern structures, technology has consistently advanced the boundaries of what is possible. However, the true potential of waste repurposing lies in the intersection of artistic creativity, new technologies and sustainability. We have forged a path towards artistic sustainability by utilizing computer vision to detect and sort waste material and robotic precision to assemble striking arty compositions. The project's multidimensional workflow, encompassing AI-generated images, machine learning-based color spectrum reduction, waste material detection and preparation, and robotic arm assembly, illustrates a new era of waste transformation.

The project was not without its challenges and limitations. The selection of appropriate waste materials, the intricacies of resolution and scale, and the confinement to two-dimensional canvases underscore the evolving nature of our work. As the robot's vacuum suction determined the materials that could be used in our study, our search for diverse materials and more delicate substances has opened new opportunities for recycling waste material. Resolution and scale, intricately linked to physical constraints, serve as an impetus for future improvements. The prospect of extending our methodology to three-dimensional space, introduces opportunities for innovation, collaboration, and pioneering solutions.

In conclusion, this paper represents a creative step towards waste repurposing. Using technology imaginatively, we explored sustainable artistic expression, circular resource utilization, and environmental stewardship. The limitations we encounter will guide us towards continuous refinement and evolution. As we stand at the crossroads of tradition and innovation, we aim to contribute to a world where waste is transformed into new designs, and innovation reshapes the built environment. Through the synergy of robotics, AI, and human ingenuity, we discussed redefining waste as an opportunity to create works of art. The examples we have discussed stand as proof that creativity, new technologies and recycled resources hold the potential to catalyze real change. We hope that our work ignites inspiration, and prompts a wider discussion of CEs - paving the way towards a future of *artistic sustainability*.

References

Abdalla, H., Fattah, K. P., Abdallah, M., & Tamimi, A. K. (2021). Environmental footprint and economics of a full-scale 3D-printed house. *Sustainability, 13*(21), 11978. https://doi.org/10.3390/su132111978

Avrahami, O., & Tamir, B. (2021). Ownership and creativity in generative models. *arXiv preprint*, https://doi.org/10.48550/arXiv.2112.01516

BAMB. (2016). Synthesis report on the state of the art (Report No. D1). *Buildings as Material Banks Project.* Retrieved from https://www.bamb2020.eu/wp-content/uploads/2016/03/D1_Synthesis-report-on-State-of-the-art_20161129_FINAL.pdf

Bernhard, M., Smigielska, M., & Dillenburger, B. (2021). Augmented intuition. In A. Koumoutsou, D. Venanzoni, & A. Andia (Eds.), *The Routledge Companion to Artificial Intelligence in Architecture* (p. 405). New York: Routledge.

Biermann, F., Kanie, N., & Kim, R. E. (2017). Global governance by goal-setting: The novel approach of the UN Sustainable Development Goals. *Current Opinion in Environmental Sustainability, 26-27,* 26–31. https://doi.org/10.1016/j.cosust.2017.01.010

Bonwetsch, T. (2012). Robotic assembly processes as a driver in architectural design. *Nexus Network Journal, 14,* 483–494. https://doi.org/10.1007/s00004-012-0134-4

Borji, A. (2022). Generated faces in the wild: Quantitative comparison of stable diffusion, MidJourney, and DALL-E 2. *arXiv preprint,* arXiv:2210.00586. https://doi.org/10.48550/arXiv.2210.00586

Büyükkanber, F., Yanalak, M., & Musaoğlu, N. (2023, June). *Vessel detection from optical remote sensing images with deep learning methods.* In 2023 10th International Conference on Recent Advances in Air and Space Technologies (RAST) (pp. 1–5). IEEE. Istanbul. https://doi.org/10.1109/RAST59485.2023.10147456

Cala, A. (2010, November 10). *Raise high the bridge beam for a house in Spain. The New York Times.* https://www.nytimes.com/2010/11/11/greathomesanddestinations/11location.html

Clark, P. (2023, February 24). *History of the shipping container*. Inbox Projects. https://inboxprojects.com/history-shipping-container/1472

Demetriou, D., Mavromatidis, P., Robert, P. M., Papadopoulos, H., Petrou, M. F., & Nicolaides, D. (2023). Real-time construction demolition waste detection using state-of-the-art deep learning methods: Single-stage vs two-stage detectors. *Waste Management, 167,* 194–203. https://doi.org/DOI:%2010.1016/j.wasman.2023.05.039

Dhariwal, P., & Nichol, A. (2021). Diffusion models beat GANs on image synthesis. *Advances in Neural Information Processing Systems, 34,* 8780–8794. https://doi.org/10.48550/arXiv.2105.05233

Dhanachandra, N., Manglem, K., & Chanu, Y. J. (2015). Image segmentation using K-means clustering algorithm and subtractive clustering algorithm. *Procedia Computer Science, 54,* 764–771. https://doi.org/10.1016/j.procs.2015.06.090

Douglas, L. (2021, June 17). *Pipedreams*. Visi. Retrieved January 20, 2025 from https://visi.co.za/pipedreams-by-douglas-company/

Duan, H., Hou, K., Li, J., & Zhu, X. (2011). Examining the technology acceptance for dismantling of waste printed circuit boards in light of recycling and environmental concerns. *Journal of Environmental Management, 92*(3), 392–399. https://doi.org/10.1016/j.jenvman.2010.10.057

EPA. (2017). Building decontamination: Building design for reuse (EPA Publication No. 600/R-17/137). *U.S. Environmental Protection Agency.* Retrieved from https://www.epa.gov/sites/default/files/2017-06/documents/building_decon_design_reuse.pdf

Epstein, Z., Hertzmann, A., Investigators of Human Creativity, Akten, M., Farid, H., Fjeld, J., ... & Smith, A. (2023). Art and the science of generative AI. *Science, 380*(6650), 1110–1111. https://doi.org/10.1126/science.adh4451

Evans, B. (2012). *Practical 3D printers: The science and art of 3D printing.* Apress Berkeley, CA: Apress.

Fernberg, P., & Chamberlain, B. (2023). Artificial intelligence in landscape architecture: A literature review. *Landscape Journal, 42*(1), 13–35. https://doi.org/10.3368/lj.42.1.13

Fritsch, F. (2023). *Deep neural networks for object detection in satellite imagery* (Master's thesis). Department of Information Technology, Uppsala University, Sweden.

Liarostathi, P. (2012, October 18). *Animal sculptures made of salvaged plastic*. Yatzer. https://www.yatzer.com/Sayaka-Ganz-Animal-Sculptures-Made-of-Salvaged-Plastic

Gawel, A., Blum, H., Pankert, J., Krämer, K., Bartolomei, L., Ercan, S., ... & Sandy, T. (2019). *A fully-integrated sensing and control system for high-accuracy mobile robotic building construction.* In 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (pp. 2300–2307). IEEE. Macau, China.

Gharbia, M., Chang-Richards, A., Lu, Y., Zhong, R. Y., & Li, H. (2020). Robotic technologies for on-site building construction: A systematic review. *Journal of Building Engineering, 32,* 101584. https://doi.org/10.1016/j.jobe.2020.101584

Gharge, S., Patil, A., Patel, S., Shetty, V., & Mundhada, N. (2023). *Real-Time Object Detection Using Haar Cascade Classifier for Robot Cars.* In 2023 4th International Conference on Electronics and Sustainable Communication Systems (ICESC) (pp. 64-70). IEEE. Tamil Nadu, India.

Goodfellow, I., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S., ... & Bengio, Y. (2020). Generative adversarial networks. *Communications of the ACM, 63*(11), 139–144. https://doi.org/10.1145/3422622

Ingle, S., & Phute, M. (2016). Tesla autopilot: Semi-autonomous driving, an uptick for future autonomy. *International Research Journal of Engineering and Technology, 3*(9), 369–372.

James & Mau. (2023). *Infiniski Manifesto House* [Website]. Retrieved from https://jamesandmau.com/projects/infiniski-manifesto-house/#info

Kapelyukh, I., Vosylius, V., & Johns, E. (2023). Dall-e-bot: Introducing web-scale diffusion models to robotics. *IEEE Robotics and Automation Letters, 8*(7), 3956-3963.

Kesana, A., Nallola, J., Bootapally, R. T., Amaraneni, S., & Reddy, G. S. (2023, May). *Brain tumor detection using YOLOv5 and Faster R-CNN.* In 2023 2nd International Conference on Vision Towards Emerging Trends in Communication and Networking Technologies (ViTECoN) (pp. 1–6). IEEE. Vellore, India.

Klette, R. (2014). *Concise Computer Vision: An Introduction into Theory and Algorithms*. London: Springer.

Gramazio Kohler Research (2023, November 30). *Circularity park - ETH Zürich.* Archdaily.

https://www.archdaily.com/1010430/circularity-park-gramazio-kohler-research-plus-robotic-systems-lab-plus-chair-of-landscape-architecture-eth-zurich

Leach, N. (2022). From deconstruction to artificial intelligence: The new theoretical paradigm. In *The Contested Territory of Architectural Theory* (pp. 229–241). Newyork: Routledge.

Liu, Z., Zhang, J., Wang, N., Feng, Y. A., Tang, F., Li, T., ... & Liu, Y. (2023). Enhanced YOLOv5 network-based object detection (BALFilter Reader) promotes PERFECT filter-enabled liquid biopsy of lung cancer from bronchoalveolar lavage fluid (BALF). *Microsystems & Nanoengineering, 9*(1), 121. https://doi.org/10.1038/s41378-023-00580-6

Lisa, A. (2014, July 18). *Breuer Cabin made from leftover materials of their earlier projects.* Inhabitat. https://inhabitat.com/lundberg-design-custom-built-this-striking-breur-cabin-using-leftover-materials-from-five-past-projects-in-california/

Lyu, Y., Wang, X., Lin, R., & Wu, J. (2022). Communication in human–AI co-creation: Perceptual analysis of paintings generated by text-to-image system. *Applied Sciences, 12*(22), 11312. https://doi.org/10.3390/app122211312

Ma, M., Tam, V. W., Le, K. N., & Li, W. (2020). Challenges in current construction and demolition waste recycling: A China study. *Waste Management, 118,* 610–625. https://doi.org/10.1016/j.wasman.2020.09.030

Iype, J. (2022, February 17). *700 donated windows and salvaged waste form the Kamikatsu Zero Waste Center*. Stir World. https://www.stirworld.com/see-features-700-donated-windows-and-salvaged-waste-form-the-kamikatsu-zero-waste-center

Nicholas, P. (2021). Machining and

machine learning. In *The Routledge Companion to Artificial Intelligence in Architecture* (p. 394). London: Routledge.

Nurkarim, W., & Wijayanto, A. W. (2023). Building footprint extraction and counting on very high-resolution satellite imagery using object detection deep learning framework. *Earth Science Informatics, 16*(1), 515–532. https://doi.org/10.1007/s12145-022-00895-4

Oberti, I., & Plantamura, F. (2015). *Is 3D printed house sustainable?* In Proceedings of International Conference CISBAT 2015 Future Buildings and Districts Sustainability from Nano to Urban Scale (No. CONF, pp. 173–178). LESO-PB, EPFL. Lausanne, Switzerland.

Oru, B. (2021, September 10). *Pantolona değil tabloya bak. InBusiness.* https://www.inbusiness.com.tr/in-business/2021/09/10/pantolona-degil-tabloya-bak

Perkins, J. (2024, June 30). *Jane Perkins Art.* Janeperkins.wordpress. https://janeperkins.wordpress.com/2024/06/30/angel-with-honesty/

Prakash, M., Janarthanan, M., & Devi, D. (2023). Multiple objects identification for autonomous car using YOLO and CNN. In *2023 7th International Conference on Intelligent Computing and Control Systems (ICICCS)* (pp. 597–601). IEEE. Madurai,India.

Raghu, D., Markopoulou, A., Marengo, M., Neri, I., Chronis, A., & De Wolf, C. (2022). Enabling component reuse from existing buildings using machine learning: Using Google Street View to enhance building databases. In Proceedings of the 27th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2022) (Vol. 2, pp. 577–586). Singapore.

Sagdıc, D. (2022, January 29). *Deniz Sağdıç Art*. Facebook. https://www.facebook.com/denizsagdicart/photos/207520000./4752167854832086/?-type=3

Sakin, M., & Kiroglu, Y. C. (2017). 3D printing of buildings: Construction of the sustainable houses of the future by BIM. *Energy Procedia, 134,* 702–711. https://doi.org/10.1016/j.egypro.2017.09.562

Scalera, L., Seriani, S., Gasparetto, A., & Gallina, P. (2019a). Watercolour robotic painting: A novel automatic system for artistic rendering. *Journal of Intelligent & Robotic Systems, 95,* 871–886. https://doi.org/10.1007/s10846-018-0937-y

Scalera, L., Seriani, S., Gasparetto, A., & Gallina, P. (2019b). Non-photorealistic rendering techniques for artistic robotic painting. *Robotics, 8*(1), 10. https://doi.org/10.3390/robotics8010010

Schabenberger, O., & Gotway, C. A. (2017). *Statistical methods for spatial data analysis.* New York: CRC Press.

Senem, M. O., & As, I. (2022). Esenler the city of the future: Nar innovation district zero waste target. In *Zero Waste.* 153–173. Ankara: Republic of Türkiye, Ministry of Environment, Urbanization and Climate Change.

Grozdanic, L. (2016, April 29). *A colorful facade of recycled doors and windows adorns this unique Mumbai residence*. Inhabitat. https://inhabitat.com/a-colorful-facade-of-recycled-doors-and-windows-for-this-unique-mumbai-residence/collage-house-by-sps-architects-1/

Tay, Y. W. D., Panda, B., Paul, S. C., Noor Mohamed, N. A., Tan, M. J., & Leong, K. F. (2017). 3D printing trends in building and construction industry: A review. *Virtual and Physical Prototyping, 12*(3), 261–276. https://doi.org/10.1080/17452759.2017.1326724

Theis, L., van den Oord, A., & Bethge, M. (2015). A note on the evaluation of generative models [*arXiv preprint*]. https://doi.org/10.48550/arXiv.1511.01844

Tobi, A. M., Omar, S., Yehia, Z., Al-Ojaili, S., Hashim, A., & Orhan, O., (2017). *Cost viability of 3D printed house in UK.* 4th Asia Pacific Conference on Manufacturing Systems and the 3rd International Manufacturing Engineering Conference, APCOMS-iMEC 2017, Yogyakarta, Indonesia.

Vähä, P., Heikkilä, T., Kilpeläinen, P., Järviluoma, M., & Gambao, E. (2013). Extending automation of building construction: Survey on potential sensor technologies and robotic applications. *Automation in Construction, 36,* 168-178. https://doi.org/10.1016/j.autcon.2013.08.002

Wibranek, B., & Tessmann, O. (2021). Interfacing architecture and artificial intelligence: Machine learning for architectural design and fabrication. In A. Koumoutsou, D. Venanzoni, & A. Andia (Eds.), *The Contested Territory of Architectural Theory* (pp. 380–393). Routledge, New York, NY.

Wright, J., Ma, Y., Mairal, J., Sapiro, G., Huang, T. S., & Yan, S. (2010). Sparse representation for computer vision and pattern recognition. *Proceedings of the IEEE, 98*(6), 1031–1044. https://doi.org/10.1109/JPROC.2010.2044470

Yang, L., Zhang, Z., Song, Y., Hong, S., Xu, R., Zhao, Y., ... & Yang, M. H. (2023). Diffusion models: A comprehensive survey of methods and applications. *ACM Computing Surveys, 56*(4), 1–39. https://doi.org/10.48550/arXiv.2209.00796

Zhang, J., Wang, J., Dong, S., Yu, X., & Han, B. (2019). A review of the current progress and application of 3D printed concrete. *Composites Part A: Applied Science and Manufacturing, 125,* 105533. https://doi.org/10.1016/j.compositesa.2019.105533

Zhou, J., Zou, X., & Wong, W. K. (2022). Computer vision-based color sorting for waste textile recycling. *International Journal of Clothing Science and Technology, 34*(1), 29–40. https://doi.org/10.1108/IJCST-12-2019-0190

Zhou, Y., & Shimada, N. (2023). *Vision+ language applications: A survey.* In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (pp. 826–842). Vancouver, BC, Canada.