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Parametric Furniture Design in Promoting Circular Economy Principles

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ABSTRACT

The world is striving toward a sustainable future amid growing environmental challenges, requiring broad international cooperation. However, individuals also play a vital role by shifting consumer behaviours and adopting sustainable lifestyles. This collective effort supports sustainable development, which integrates economic, social, and environmental dimensions to ensure a better future for upcoming generations. IN this context, parametric furniture design emerges as a key solution, offering innovative, adaptable, and eco-conscious alternatives that merge function, aesthetics, and sustainability. This approach enables furniture to evolve over time, extending its lifespan and reducing waste. Moreover, it aligns with the principles of the circular economy, which emphasize minimizing waste and reusing materials. This research addresses core questions such as: What are the potentials of parametric furniture design in reducing waste and extending product lifespan? And how can it support the transition to a circular economy? The study proposes that parametric furniture is among the most effective sustainable solutions to reinforce the circular economy. It aims to develop techniques that ensure the furniture remains sustainable throughout its lifecycle and to create a model for assessing the economic feasibility of investing in such designs. Using both analytical-descriptive and practical methods, the research concludes that adopting circular economy practices in handling damaged furniture opens new horizons for creativity and innovation. At the same time, it offers environmentally and economically sustainable solutions.

1. Theoretical Studies

The world is witnessing a dramatic transition towards a new economic model which focuses on sustainability; this model is based on the principles of zero waste and continuously improved design; it aims to establish a more efficient system for production and consumption, in order to reduce loss and preserve natural resources, because the unsustainable utilization of resources is no longer an option, instead; it has become crucial to shift towards sustainable practices to ensure a better future for the upcoming generations. Furniture design is one of the vital aspects in the transition to circular economy; by rethinking the processes of furniture design, production, usage and disposal, in order to radically decrease the negative environmental impact of the furniture industry.

1.1 Manufacturing and Zero Waste Design Methodology

This is a comprehensive methodology which aims to eliminate any activity that does not add a value to the final product or service. This method; inspired from “Toyota” production system; focuses on improving efficiency, reducing costs and increasing the consumers’ overall satisfaction [4].
This methodology: with its tools and concepts which are applied on the design as well as the materials used in it; is utilized in a participatory approach, unlike the traditional method in which the user is the passive recipient of the product. [2] This participatory method provides the customer (or user) with an additional control side by side with the designers or engineers as it gives the customer a wide berth to participate in decision making because the user is the basis of the design process [8].

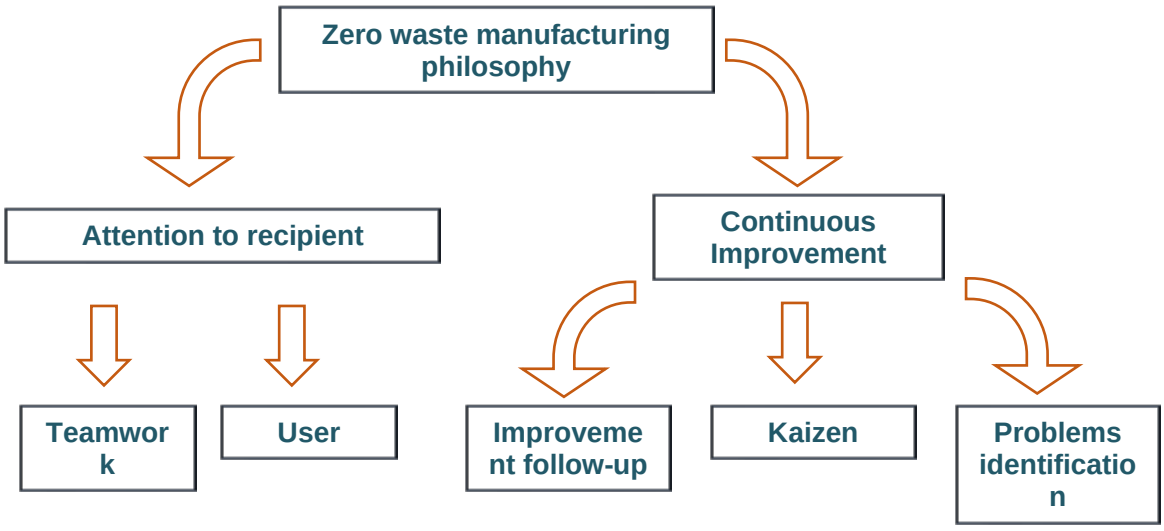


Fig.1: The philosophy of zero waste manufacturing philosophy

1.2 Kaizen System of Continuous Improvement

"Kaizen" is a Japanese term which means "continuous improvement"; and it is a Japanese philosophy which calls to apply continuous small improvements on all aspects of business; starting from the management and ending with the workers and resources. The main goal of Kaizen system is to establish a more efficient and productive work environment; and to provide higher quality products and services that meet the customer needs in a better way[9] .

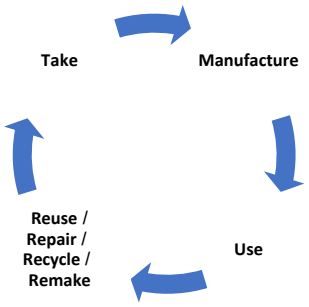
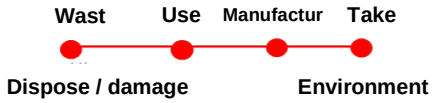
The continuous improvement system is a key element in the philosophy of circular economy, as it represents a continual process of evaluation and adjustment to gradually improve performance [9].

Fig.2: Kaizen main objectives

1.3 Circular Economy

Circular economy is an economic model which aims to eliminate waste and achieve optimum continuous utilization of the resources; it seeks to preserve the value of products and materials for the longest possible time, by reusing, repairing, renewing and recycling these products and materials; while the traditional model is based on the "take – make –consume – dispose" linear approach.[7].

TABLE 1

Comparison between Circular and Linear Economy		
Comparison	**Circular economy**	**Linear Economy**
Concept	It is an economic system which aims to improve resources utilization, reduce waste and decrease the negative impact on the environment [6]	It is the common economic system; it means to collect the resources to be manufactured and consumed, then to be disposed of after the need for them ends.
Origin	This economy is inspired from the environment bio-system; environmental wastes, such as manure; are nutrients to other living creatures. The environmental architect "Walter Stahel" is the first to talk about circular economy which he called "from cradle to cradle".	This economy has been used since the arise of industrial revolution; which was a huge burden on natural resources; in addition to the continuous huge production.
Implementation technique		
Impact	- Eliminates litter - Preserves natural resources - Limits environmental effects. [3]	- Drains natural resources - Produces huge amounts of litter

1.3.1 Implementation of circular economy on the product

The concept of circular economy can ideally be applied on products; instead of manufacturing new products from raw materials, old materials, e.g. organic textiles; can be recycled and used to design an assimilable and demountable product. This method extends the product lifespan and decreases the need for new production, thus; preserves natural resources and decreases waste; table (2) illustrates the application of circular economy on the product lifespan[6].

TABLE 2

The stages of circular economy implementation on a product		
Design stage	- Decrease the number of used materials - Choose sustainable materials - Follow a module network - Decrease production processes - Use assembly tools instead of adhesives	
Manufacturing stage	- Use recycled materials - Use microfabrication techniques	
Usage stage	- Apply optimal consumption rule - Maintain the product and follow instructions	

Post-use stage	- Provide spare parts - Repair - Reuse - Recycle - Remake	

Fig.3: Circular Economy

1.3.2 Implementation of circular economy on furniture design

The product design process is the first stage of its lifespan, thus; it is the foundation on which the primary plan for the next stages is set; the product depends on this plan to develop an economic method for its lifespan.
In order to implement circular economy on furniture design, there are some standards which may complicate the design process at the beginning; but shall positively affect sustainability, maximize resource utilization and minimize wastes of the used materials, as well as the manufacturing process[7]

1.3.3 Design determinants within the framework of the circular economy methodology

There are several determinants that should be considered when designing furniture within the circular economy framework; these determinants shall ensure the product sustainability and decrease its environmental impact [2] as shown in the following table:

TABLE 3

Furniture design determinants within circular economy framework		
Design Determinants	**Materials selection**	- **Recycled materials,** e.g. plastic, aluminium & glass; recycling revives such materials and decreases the need for new ones. - **Long life expectancy materials,** e.g. stainless steel; such materials last longer, thus; decrease the need to repeatedly replace the furniture. - **Avoid toxic materials,** e.g. paints, adhesives & varnishes; such materials contain chemical substances which harm health and environment.
	Modular design	- **Demountable Design;** furniture to be designed so that it can be easily taken apart into separate parts to facilitate repair and replacement. - **Simple joints;** plain and easy-to-use joints should be used to facilitate the demounting & assembly processes. - **Flexible design;** design adjustable furniture parts to meet the user variable needs.
	Product lifespan extension	- **Durable design;** use materials with high quality and solid construction to ensure a long lifespan for the furniture. - **Provide spare parts;** spare parts should be available to repair damaged parts. - **Promote the culture to repair;** provide repair materials with reasonable prices; and educate consumers about the importance of repairing furniture instead of replacing it.
	Design to reduce waste	- **Simple design;** avoid complicated designs which are hard to demount and recycle. - **Use compatible materials;** choose materials which can easily be recycled with other materials. - **Avoid complex materials;** exclude materials which components are hard to be separated and recycled.
	Aesthetic & functional determinants	- **Attractive design;** furniture should be appealing and contemporary in order to attract the consumers. - **Multifunction;** multifunctional furniture meets various needs. - **Compatibility with various spaces;** design furniture which can fit within different spaces and areas.

	Economic determinants	- **Balance between price & quality;** achieve high quality with reasonable prices. - **Reduce production costs;** simplify production processes and utilize locally available materials. - **Long term cost saving;** consider the costs of the product whole lifespan, including repair, maintenance & recycling costs.
	Social determinants	- **Job creation;** support local businesses and create job opportunities in the manufacturing, repairing & recycling processes. - **Contribute to society;** support social &environmental initiatives. - **Cooperate with local designers;** support local talents & encourage innovation.

1.4 Parametric Design

Parametric design is a powerful tool in the field of furniture design; it is a method based on mathematical equations and algorithms to develop complicated and flexible designs in the early stages when designing a piece of furniture. This type of design provides multiple design suggestions as well as multiple choices to solve the problems which face the designers, in addition to precise solutions and rapid production. The advantages of parametric design include endless formation alternatives which it can provide, as well as flexible design solutions which provide various substitutes according to the inputs determined by the designer, such as user needs, materials, dimension … etc [10] .

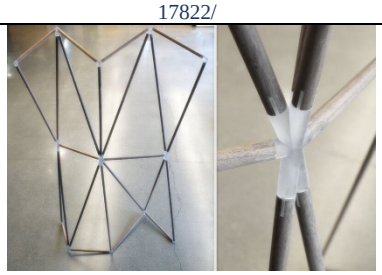
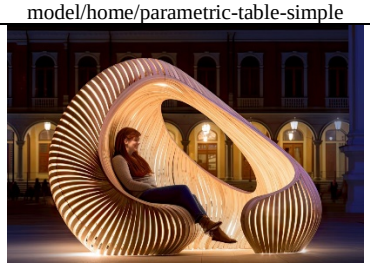
In regard to the determinants which support circular economy methodology, such as modular design and flexible design; these determinants are directly connected with the inputs which are controlled by the designer during the stage of setting the parameters for the furniture design process.

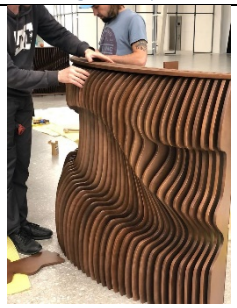
Circular economy methodology; supported by its principles; enables the designer to precisely control the design inputs of the targeted furniture unit, which ensures achieving both the sustainability and efficiency objectives; and results in a flexible and adaptable final product.

Fig.4: Parametrically designed reception desk

TABLE 4

Parametric furniture compatibility with circular economy determinants		
Furniture design determinants	**Parametric furniture Examples**	**Parametric furniture advantages**
Materials selection	 https://www.pinterest.com/pin/376754325087318544	- **Diversity and flexibility;** a wide group of materials can be integrated in one piece of furniture. - **Quantity control;** the quantity of each material used in the design is precisely calculated. - **Compatibility with the design;** select materials which suit the complicated geometric shape of the parametric furniture; as well as the materials suitable for the specific function of each part of the furniture piece.[10] - **Sustainability;** recycled materials can be used in parametric design, as well as natural materials, such as wood and bamboo; making the furniture more sustainable. Also, parametric furniture can be designed in a way that decreases its environmental impact throughout its lifespan.[5]

Modular design	 https://www.pinterest.com/pin/70437481017822/	- **High flexibility;** the design can be easily adjusted by changing the values used in the algorithms. - **Geometric complexity;** complicated untraditional geometric shapes can be created; such complexity is hard to achieve by traditional design methods. - **High efficiency;** parametric design programs can generate many different designs based on a specific group of data. - **High customization;** a parametric design can be customized to meet the user needs and location specifications.
Product lifespan extension	 https://parametrichouse.com/asterism	Modern joints are used to connect furniture parts as substitutes for adhesives and traditional fixed joints; this increases the design flexibility and extends the furniture lifespan, by allowing the change of the furniture damaged parts through demounting and assembly. On the other hand, joints are weak points in furniture, so suitable and sustainable joints should be carefully chosen. [11]
Design to reduce waste	 https://cults3d.com/en/3d-model/home/parametric-table-simple	- **Cost saving;** this can be achieved by careful planning of the of materials and design lines measures; a work sheet should be set prior to manufacturing, in order to reduce waste, thus; decrease the project overall costs. - **Increase efficiency;** optimal utilization of materials means achieving maximum benefit from them; which contributes to increase the design efficiency. - **Achieving multiple functions;** multifunctional furniture units can be designed through innovative thinking in regard to the utilization of available spaces and determination of suitable measures. - **Improve aesthetic appearance;** attention to small details, e.g. materials and design lines measures; helps to create a coherent and attractive design.
Aesthetic & functional determinants	 https://2u.pw/Vr4qZhwb/	- Functional values are achieved through multifunctional furniture which fits in all spaces and is easy to demount, assemble and store. - Aesthetic values are achieved based on innovation and uniqueness, as well as developing a vast number of shapes, sizes and patterns, by changing the data used in the design program. Also, parametric design can easily be created in smooth and organic shapes inspired from nature.

Economic determinants	 https://www.pinterest.com/pin/246297478 9712172/	**Long term profits.** - **Increased efficiency & productively;** thanks to specialized programs; time spent in the design process can be decreased as they can design complex furniture in record time. - **Improved manufacturing processes;** many manufacturing stages can be automated, which increase efficiency and accuracy. - **Customization & Individualization;** products can be specifically designed to better fulfil the customers individual needs, thus; increasing their loyalty to the furniture brand. - **Higher prices;** parametric furniture can be sold with higher prices due to its superior additional value[1] - **Increased sales;** a new category of customers; who seek innovative designs; can be gained.
Social determinants	 https://www.pinterest.com/pin/589760513 737829605	- Due to technological development and increased awareness of the importance of sustainable design; it is expected that parametric furniture will gain more acceptance within societies. Nevertheless, overcoming social challenges requires joint efforts among designers, manufacturers and consumers. - Support the creativity of emerging furniture designers and promote local furniture industry.

2. Practical Studies

2.1 Description of The Study Concept

A number of small sized elements were identified to be used as furniture accessories, in order to clarify the research concept in regard to applying the parametric design on furniture, while taking into consideration all design determinants mentioned in the theoretical and analytical framework. Designs were developed and implemented in scale models at first, then in actual size using recycled low-cost materials to achieve the highest economic and aesthetic value.

2.2 Examples of The Practical Study

The researchers selected eight design models; out of twenty designed and implemented models; due to the following considerations:
1- The functional and aesthetic added value of the recycled product.
2- Product total cost.
In addition to achieving the design determinants as shown in the following tables.

TABLE 5

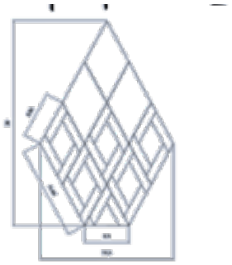
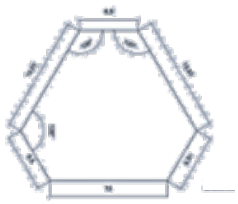
Practical model (1) – Lighting Lozenges			
Designed & implemented by:	Manar Al-Oufy	**Design & implementation supervised by:**	Dr. Marwa Hussein Dr. Dalia Khalil
  **Base**  - Cutting wood and acrylic - Smoothing  - Gluing wood & acrylic separately - Inserting the acrylic inside wood 			
Furniture Design Determinants			
Materials selection	Recycled wood - acrylic (factories residuals)		
Modular design	The design achieved the standard determinant through similar parts which have a module and are connected together for assembly.		
Product lifespan extension	Flexibility and different design positions.		
Design to reduce waste	Product parts can easily be replaced when damaged.		
Aesthetic & functional determinants	- The design is suitable for different functions. - Balanced aesthetic ratios.		
Economic determinants	The product was designed by AutoCAD and was exported for production by a CNC machine to save design and production time.		
Social determinants	The designed product is an office lighting fixture with a creative design inspired from the national heritage.		

TABLE 6

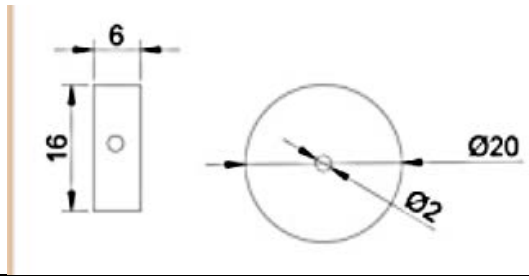
Practical model (2) – Table Lamp			
Designed & implemented by:	Rimas Saad Ibrahim	**Design & implementation supervised by:**	Dr. Marwa Hussein Dr. Dalia Khalil
 			
Furniture Design Determinants			
Materials selection	Recycled Lexan - metal tube - wooden base		
Modular design	Iterative rectangles coaxially piled.		
Product lifespan extension	Flexible design in which parts can be steered in various styles to create different innovative designs.		
Design to reduce waste	Product parts can be easily changed when damaged as they were assembled by compress.		
Aesthetic & functional determinants	- Multifunctional design. - Innovative lighting fixture.		
Economic determinants	Low-cost design due to using recycled Lexan in an economic simple design.		
Social determinants	An innovative design which supports the concept of sustainability.		

TABLE 7

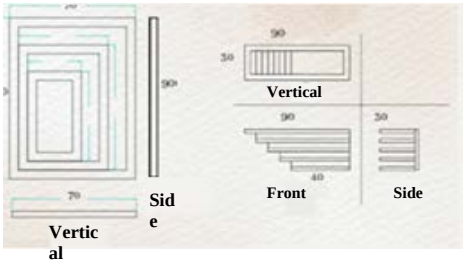
Practical model (3) – Alora entryway set			
Designed & implemented by:	Noura Al-Harby / Areej Tawfeek / Sara Al-Jahny	**Design & implementation supervised by:**	Dr. Marwa Hussein Dr. Dalia Khalil
			
Furniture Design Determinants			
Materials selection	Glass – recycled mirrors – wood residuals – wooden joints- wood adhesive		
Modular design	The design is based on ratio & proportion to create iterative rectangles with different design ratios.		
Product lifespan extension	The product consists of parts which can be easily replaced if damaged.		
Design to reduce waste	Product parts are reused materials from old products; the design was developed to suit the designed formation without any material waste.		
Aesthetic & functional determinants	- Multifunctional. - Harmonized iteration. - Natural wood colour.		
Economic determinants	The product cost is very low in comparison with its final shape.		
Social determinants	An innovative design that supports the concept of sustainability.		

TABLE 8

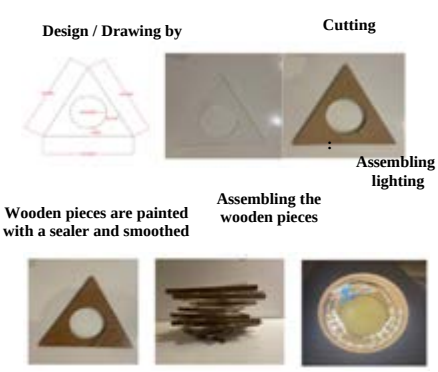
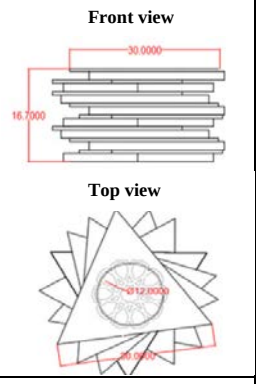
Practical model (4) – Zahra office lighting fixture			
Designed & implemented by:	Manar Mazen Zakour	**Design & implementation supervised by:**	Dr. Marwa Hussein Dr. Dalia Khalil
			
Furniture Design Determinants			
Materials selection	Reused wood – reused transparent acrylic – lighting cords – adhesive		
Modular design	Rectangular units in different materials.		
Product lifespan extension	Product parts are easy to replace.		
Design to reduce waste	Reused wood & acrylic are industrial residuals which are utilized as furniture accessories.		
Aesthetic & functional determinants	The lighting fixture is innovatively & parametrically designed.		
Economic determinants	The product cost is very low; as most of its components are reused materials.		
Social determinants	Laser was used to decorate the product with Islamic motifs to affirm identity.		

TABLE 9

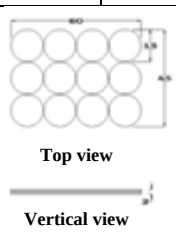
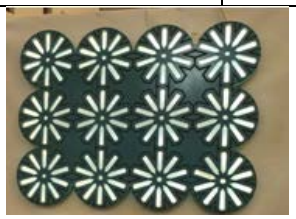
Practical model (5) – Arabesque lighting fixture			
Designed & implemented by:	Shaden Al-Anzy / Hoda Al-Nakhly	**Design & implementation supervised by:**	Dr. Marwa Hussein / Dr. Dalia Khalil
 **Top view** **Side view** **Vertical view**  			
Furniture Design Determinants			
Materials selection	Recycled wood – natural wood paints		
Modular design	Iterative units assembled on X/Y axels.		
Product lifespan extension	Flexible design; a decorative mural and a lighting fixture at the same time.		
Design to reduce waste	The dovetailing method without fixed joints facilitates product maintenance without wasted materials.		
Aesthetic & functional determinants	- Multifunctional design. - Additional aesthetic lighting.		
Economic determinants	The product was designed by AutoCAD and was exported for production by a CNC machine to save the design and production time.		
Social determinants	Mural lighting fixture with a creative design with a heritage pattern.		

TABLE 10

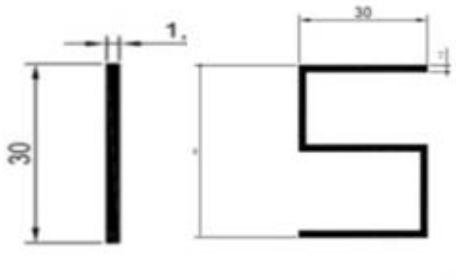
Practical model (6) – Multi level table			
Designed & implemented by:	Shaza Al-Lokmany	**Design & implementation supervised by:**	Dr. Marwa Hussein / Dr. Dalia Khalil
  			
Furniture Design Determinants			
Materials selection	Recycled wood – natural wood paints		
Modular design	The design achieves the standard determinant as it is based on similar iterative parts.		
Product lifespan extension	Flexible design allows controlling using the product in different patterns.		
Design to reduce waste	Product parts can easily be changed when damaged; as the parts are connected in a dovetailing style without any joints.		
Aesthetic & functional determinants	- Multifunctional design. - Iterative geometric design which achieves the golden ratio.		
Economic determinants	The product was designed by AutoCAD and was exported for production by a CNC machine to save the design and production time.		
Social determinants	A multi-level table which can serve different social needs.		

TABLE 11

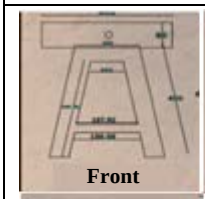
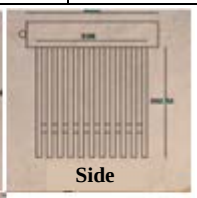
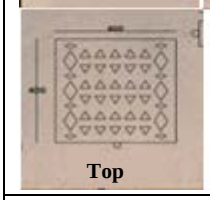
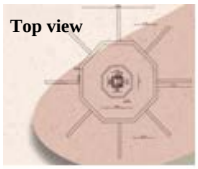
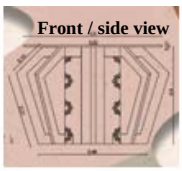
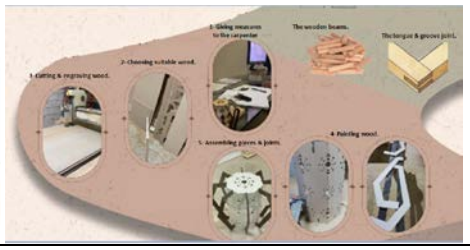
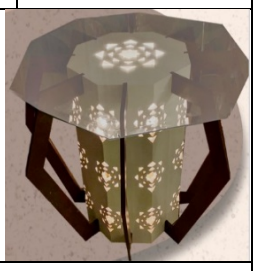
Practical model (7) – Aroma table			
Designed & implemented by:	Shahd Abd El-Rahman / Mada Badr / Raseel Al-Hammad	**Design & implementation supervised by:**	Dr. Marwa Hussein / Dr. Dalia Khalil
 **Front**  **Side**  **Top**	 **Assembling the product at the factory**		
Furniture Design Determinants			
Materials selection	Recycled wood – natural wood paints + resin – velvet padding		
Modular design	The design achieves the standard determinant as it is based on similar iterative parts in its lower part.		
Product lifespan extension	A durable functional product due to its strength and correct use of joints.		
Design to reduce waste	Design details are based on design lines measures, also; the small parts are dovetailed.		
Aesthetic & functional determinants	- Suitable for all spaces. - Innovative unique design.		
Economic determinants	Low-cost product: an old drawer was used for the upper part of the table, while the legs were parametrically formed from small wooden pieces.		
Social determinants	The reused drawer is utilized to store the censer and incense as a social Arab tradition.		

TABLE 12

Practical model (8) – The Jewel table			
Designed & implemented by:	Byan Al-Jizany / Arwa Al-Waqdan / Hadeel Al-Zahrany	**Design & implementation supervised by:**	Dr. Marwa Hussein Dr. Dalia Khalil
Top view  **Front / side view**  			
Furniture Design Determinants			
Materials selection	MDF – glass – dusky natural paints		
Modular design	Axial iterative units assembled on an octagonal tube.		
Product lifespan extension	Parts can be easily changed – flexible joints – easy to demount and assemble.		
Design to reduce waste	The design lines reduce wastes and affirm the aesthetic appearance.		
Aesthetic & functional determinants	- Adherent to human measures. - The added lighting enhances the design beauty and affirms its unique details.		
Economic determinants	High economic profits through its innovative heritage added value.		
Social determinants	Inspired from the national heritage in a contemporary design.		

3. Conclusions

1- Implementing the methodology of circular economy in handling furniture opens broad perspectives for creativity and innovation; and provides sustainable solutions for environmental and economic challenges.
2- Parametric furniture design largely contributes to promoting circular economy principles, through its ability to decrease material waste and enhance production efficiency, thus, supporting sustainability and optimal use of resources.
3- The design step is a distinctive phase in the implementation of circular economy methodology; it is the most important process in the product lifespan, as it affects its sustainability, recourses usage and manufacturing waste.
4- With the recent technological development and increased awareness of the importance of sustainable design; it is expected that parametric furniture will gain more acceptance among customers, as this type of furniture design is characterized by its ability to generate various creative designs according to specific information, making it highly flexible with the potential to be customized based on the user needs; in addition to its competitive prices.

4. Recommendations

1- Designers should take into account all furniture design determinants; starting with choosing materials, achieving modular design and product extended lifespan, designing to reduce losses; as well as the functional, aesthetic, economic and social determinants.
2- Furniture factories should seek optimal utilization of the residuals from cutting materials; and reach a technique to reuse them in innovative designs based on a parametric concept. They should also review the potential that the product complies with the methodology of circular economy during the pre-implementation phase. It is also essential to provide a user's guide which explains the best way to use the product and how to handle it when damaged or disposed.
3- The Ministry of Industry should adopt ideas which are based on the concepts of recycling and reusing; as well as support establishing small enterprises with low costs and high financial return.

5.Refrences

[1]. Abd Al-Gawwad, A. (2022). Furniture renovation from the circular economy perspective (experimenting with decoupage technique). International Design Journal.

[2]. Abu Al-Magd, A., et al. (2022). The implementation of sustainability principles and solid waste management through public art field. International Design Journal.

[3]. Enviroguard, I. (2022, November 25). How to safely work with epoxy coatings. Retrieved from https://int-enviroguard.com/blog/how-to-safely-work-with-epoxy-coatings-ppe-and-safety-measures/

[4]. Focuser Academy. (2023). Lean manufacturing: An effective strategy for improving productivity and reducing waste. Retrieved from https://focuseracademy.com/

[5]. Furuto, A. (2012, September 12). Lightweave Palm Observatory – X Studio. ArchDaily. Retrieved from https://www.archdaily.com/271229/lightweave-palm-observatory-x-studio

[6]. Hasan, D., & Ismail, A. (2020). Circular economy as a mechanism for waste management and achieving sustainable development goals in the Arab Emirates. Ajman Journal for Studies and Research, 20(1).

[7]. Hawwas, A. A., & Magdoub, A. (2019). Circular economy as a system to protect the environment. AFAQ Review of Research and Studies – University Center.

[8]. Lehmann, S. (2010). Designing for zero waste: Consumption, technologies and the built environment. Routledge.

[9]. Newitt, J. (2022). Kaizen: An Ancestral Strategy for Operational Improvement. In J. A. Marmolejo-Saucedo (Ed.), Operations Management and Systems Engineering (pp. 197–212). Springer.

[10]. Sawky, A., & Athers. (2022). Classification of parametric design tools. Journal of Al-Azhar University Engineering Sector, 17(62), 390–405.

[11]. Swift, K. (2022). Best epoxy resin safety tips you will read this year. Retrieved from https://www.resinobsession.com/resin-resin-resin/epoxy-resin-safety/