Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Transforming Automobile (Car) Gears into a Coffee Table: An Approach to Sustainable Environmental Metal Waste Management

Mohammed Kwaku Baidoo[1] Jonathan Tei Adjeitey[2] Isaac Kwabena Agyei[3] Cyril Etornam Adala[4]

[1]Department of Industrial Art, Kwame Nkrumah University of Science and Technology, Ghana
Email: mkbaidoo@knust.edu.gh

[2]Department of Industrial Art, Kwame Nkrumah University of Science and Technology, Ghana
Email: jonathanadjeitey@gmail.com

[3]Department of Industrial Art, Kwame Nkrumah University of Science and Technology, Ghana
Email: ikegyei@gmail.com

[4]Department of Industrial Art, Kwame Nkrumah University of Science and Technology, Ghana
Email: etorcyl@yahoo.co.uk

* **Corresponding author**: mkbaidoo@knust.edu.gh

Article History
Received 2026-05-11
Revised 2026-06-15
Accepted 2026-07-12
Published 2026-08-04

Keywords
Environmental Sustainability
Innovative Design
Metal Product Design
Upcycling
Waste Transformation;

The research explores the possibility to upcycle used automobile gears into a useful and coffee table as a contribution to the growing metal waste threat in the world. The research was conducted as a guided and driven investigation based on the Stanford Design Model, and with the help of the methodology of practice-based research through the answers to three major research questions: (1) what are the most effective metal fabrication techniques to transform waste into durable and aesthetically pleasing furniture; (2) how the inherent design features and material qualities of gears could be utilized to improve the aesthetics of furniture; and (3) how much upcycling would reduce the environmental impact of using waste gears. The systematic

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

How to cite:
Adjetey Tetteh J. (2026). Transforming Automobile (Car) Gears into a Coffee Table: An Approach to Sustainable Environmental Metal Waste Management. Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability, 4(1): 791-823.

observations at metal workshops, creating designs through iteration, using digital rendering in three dimensions, and the fabrication, including cutting, welding, grinding, and assembly, were

used to gather data. Depending on the outcomes, it has been observed that a combination of arc welding, accuracy in metal cutting, grinding, and surface finishing will produce a sound base of a table which could carry a glass top. The natural forms, symmetry, and texture of the gears play a major role towards the industrial nature of the final product, which highlights the worth of the re-using of these materials in the modern world of furniture. The paper found that recycling waste gears can be economically valuable and has positive environmental outcomes, as it is re-uses materials and gives them a second life, helps to decrease landfill as well as diminish the need to extract new metal, which is the main principle of the circular economy.

Introduction

The high rate of industrialisation and consumerism has caused an unheard-of spurt in the amount of waste generated, steel waste included, with it posing a significant danger to the overall environmental health of all the world (Hoornweg et al., 2015). The globe is facing an unprecedented metal waste epidemic, which is caused by the growth of industrial enterprises, urbanisation, according to the Bureau of International Recycling (BIR), approximately 630 million tons of steel scrap are generated and recycled annually worldwide (Bureau of International Recycling [BIR], 2025). Despite the high recyclability of steel, considerable amounts of steel waste are still improperly managed, particularly in regions with inadequate waste management systems and rapid technological breakthroughs (Moraga et al., 2019). The United Nations Environment Programme (2017) states that the world has increased its material extraction by more than three times in the past 4 decades and the production of metals has become a central factor in this disturbing development. This influx in consumption of metal creates bulk waste, which in turn creates numerous environmental effects. The fact that metal is a unique problem because of its

RESEARCH ARTICLE

resilience, slow rate of decomposition, and possible leaching of harmful chemicals into the environment is disturbing (UNEP, 2017). In addition, refining and recovering of virgin metals are power intensive industry which again consumes more fossil fuel and this contribute to the further degradation of the environment (Norgate et al., 2007).

As a reaction to this acute problem, there is an emerging trend of moving to the model of circular economy (Geissdoerfer et al., 2017). The goal of the circular economy model is to end wasteful spending and resource exploitation. In contrast to the conventional linear economy that operates along the 'take-make-dispose' model, circular economy places emphasis on closing the loop by means of product and material design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. By slowing, closing, and narrowing material and energy loops, this model aims to create a regenerative system that minimizes resource input and waste, emissions, and energy leakage. Its design is essentially restorative and regenerative, with the goal of maximizing the utility and value of all materials, components, and products at all times (Ellen MacArthur Foundation, 2013).

This paradigm shift advocates for minimizing waste generation and maximizing resource utilization through strategies such as reuse, repair, remanufacturing, and recycling (Kirchherr et al., 2017). Upcycling is the process of transforming waste materials, unwanted goods, or by-products into new, higher-quality, or environmentally beneficial goods. The innovative recycling approach used is also the means of reducing the negative effects on the environment by means of decreasing waste and increasing the sustainability as the items that ended up in the trash can be re-utilized instead of thrown away. McDonough and Braungart (2013) argue that upcycling is also different in that it frequently uses fewer energy inputs and resources than the conventional recycling; it represents a specific form of recycling associated with transforming waste into more valuable and high-quality products, and such a modality has received growing momentum in the field (Singhal et al., 2020). By transforming waste products into the desired products through upcycling reduces environmental effects and creates economic opportunities, thus promoting social awareness in the context of responsible consumption (Lee et al., 2021).

Automobile Gears are usually made of steel or alloys of iron, which have admirable material characteristics, such as strength, durability, and resistance to corrosion, which make them applicable in areas beyond their original purpose (Callister and Rethwisch, 2018). Such natural endowments make gears very competitive towards upcycling efforts, especially when used to make furniture and other home appliances (Cooper, 2010). The complex geometries and unique

RESEARCH ARTICLE

style of gears make them well-fitting well in making useful ornamental products such as furniture (McDonough and Braungart, 2013). These mechanical components themselves are very strong and thus guarantee the durability and stability of the final product. Moreover, recycling of waste gears can be attributed to the concept of industrial ecology whereby the waste produced by an industry process is used in another productive manner (Lifset, 2013).

Although a significant environmental cost is caused by metal waste, and an upcycling method of waste management can greatly benefit users, few sustainable waste management activities have been practiced, particularly on converting waste gears into useful commodities. In line with this, this paper attempts to fill in this gap by illustrating the possible viability and aesthetic possibility of converting waste gears into an operational coffee table, and thus, by acting as a catalyst to find new ways of addressing environmental impact of metal waste through the process of metal fabrication. To accomplish this goal, the researcher came up with three major research questions which include:

(1) What are the best metal fabrication processes that can be used to turn waste gears into structurally sound and beauty coffee table?
(2) What are the characteristics of material properties and the inherent design qualities of waste gears that can be utilized to make a piece of furniture?
(3) To what degree can the environmental impact on the metal waste be alleviated through the upcycling of waste gears into a coffee table?

Literature Review

The research paper explored how waste metal gears can be converted into a functional coffee table as one of the sustainable design problems. It is informed based on major concepts which are circular economy, environmental waste management, upcycling, innovative metal product design as well as the concepts that underscore the idea of conservation of resource and environmental responsibility. The research has been conducted using practice-based research approach and Stanford design model. However, the Stanford Design Model provided a systematic structure through which the study progressed from problem identification to solution development. Section below defines the theoretical and methodological underpinnings that were used in shaping the materials and methods used in the study. The practice-based approach enabled the generation of knowledge through hands-on experimentation, material exploration,

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

and the fabrication of the final artefact. However, the Stanford Design Model provided the systematic structure through which the study progressed from problem identification to solution development. The model's five iterative stages Empathise, Define, Ideate, Prototype, and Test guided the researcher in understanding the environmental concerns associated with metal waste, defining the design problem, generating creative concepts, developing prototypes, and evaluating the effectiveness of the final outcomes.

Circular Economy Model

The model of the circular economy is a visionary approach to the realization of both environmental and economic sustainability. Unlike the traditional linear economy that follows the same paradigm, the take, make, dispose model, the circular economy creates a strong, yet closed, loop system aimed at reducing waste and ensuring a high level of resource efficiency. Such a system mitigates the effects on the environment and minimizes the demand of new raw materials as products and materials are continually recycled by using successive stages of their application (Ellen MacArthur Foundation, 2013). The model is based on the principle that waste and pollution should be prevented at the source rather than addressed after they have been created. This requires developing a product robust, repairable, and recyclable in order to reduce waste generation and preserve the environment (Ellen MacArthur Foundation, 2013). In practice, this would mean that items can be designed so that the modular components can be seen as easy to replace and upgrade, and the material used can be recycled efficiently once their usefulness has ended (Bocken et al., 2016). The design of waste gears into coffee tables will be perfect example of effective method to extend their life span. The project prolongs the life of these components, (Flywheel, Pilot bearing, Clutch disc and Ring gear) and recycles their economic performance by using automobile gears in new products and reduces the necessity of virgin raw materials (Leising et al., 2018).

Circular economy model has been embraced in various sectors and initiatives in the world in order to enhance sustainability. An example could be the automotive industry which has been using remanufacturing methods like reassembling used parts of an automobile gears to their original state, hence less waste is produced that reduces the consumption of new resources (Lund, 1984). The implementation of a circular economy approach provides a number of benefits such as lowered environmental cost, increased resource efficiency, and a reduction in financial costs. Position of the consumer and firms can form cooperatively to develop a more resilient and

RESEARCH ARTICLE

sustainable economy by focusing on the extension of product lifecycles and minimisation of waste. Nonetheless, the shift to the circular economy also requires the elimination of challenges like rethinking products, investing in new technologies, and tackling market and regulatory challenges (Korhonen et al., 2018).

Environmental Waste Management

Environmental waste management involves the minimization, re-use, recycling and management of waste with a view of reducing their negative impact on the environment. The conventional methods of waste management include recycling, incineration, and disposal in landfill sites. Recycling can help to recover valuable products; however, it often requires a lot of energy, and it may cause a second wave of pollution (Zaman and Lehmann, 2013). Though recycling is beneficial in terms of recovery of resources, there are high costs of recycling environmental costs in the sense that it is energy-consuming with emissions, besides consuming a lot of energy and water in the processes of melting, shredding, and chemical treatment (Kleijn et al., 2000). In addition, the materials cannot always be recycled, and even those that can be, tend to lose their quality, rendering themselves less useful (Geyer, Jambeck, and Law, 2017).

Upcycling is a possible way of addressing the restrictions associated with the traditional recycling practices. Upcycling will reduce production of waste, waste resources, and use of energy through conversion of waste materials into new products that have higher value. By adopting innovative approaches and rethinking conventional practices, waste can be converted into valuable and functional products. (Goldsmith, 2014). Upcycling can help in generating creativity in people and groups and engaging communities in innovative ways of utilizing waste materials whilst at the same time creating awareness of green practices and environmental concerns (Fisher, 2012). In current project, waste gears were used to create coffee tables thus proving how waste products can be reused into useful and attractive furniture and save on the hetero usage of raw materials and mitigate garbage wastage in landfills (Andrews, 2015).

Sustainable Environmental

With the definition of sustainable development as that which addresses the needs of the present generation without undermining the capacity of future generations to address their needs (Brundtland Report, 1987), one can find a background framework to conceptualize the sustainable environmental practices that will include a continuum of strategies to achieve

RESEARCH ARTICLE

environmental conservation whilst supporting human activity. Upcycling, which refers to transforming waste products into other products that are of better quality or have a better environmental effect, is a salient sustainable activity. This is because upcycling value addition is done through the creative reuse of waste unlike in traditional recycling, which often deteriorates the quality of materials. In such a way, applying this technique will help decrease the amount of waste that is deposited in landfills and the number of new raw materials that are demanded (Bocken et al., 2016). Upcycling grants substantial green benefits; since materials are recycled instead of being produced at the cost of energy, it benefits the environment The transformation of discarded gears into functional coffee tables exemplifies how waste materials can be repurposed to minimise the use of virgin resources and limit the amount of waste sent to landfill sites (Bocken et al., 2016). The strategy is consistent with the principles of the circular economy that aim at maximising the value recovery, reusing resources in order to prolong their effective usage, as well as recycling the materials and products when the usefulness is lost (EMF, 2013).

A decrease in waste and a saving on resources are two major upcycling advantages. Repurposing of existing materials reduces the extraction and processing of the raw materials, which are largely characterized by significant environmental effects through Upcycling. Indicatively, mining, which is a condition of manufacturing new metals, may cause the release of Greenhouse gases, devastation of habitats, and pollution of water (Graedel et al., 2011). Additionally, through investments in discarded items, upcycling will encourage waste cutback. Considering the small size of landfills and the ecological risks of decomposing waste (synthesis of methane gases, etc.), upcycling contributes to the reduction of the amount of waste in landfills and has been used to overcome a significant problem (Geyer et al., 2017). Besides environmental gains, upcycling also brings about social and economic benefits because people and companies get motivated to revisit waste materials hence developing innovation and creativity. This new approach can trigger the establishment of new jobs and business opportunities in the fields where the focus is on a sustainable way of creating goods and services (Singh and Ordonez, 2016).

Functional Metal Product (Coffee Table)

Metal product design is a major subfield of industrial design, which entails the use of various metals in order to make useful and cosmetically fulfilling products. Its use extends to the straightforward consumer goods application to the less straightforward industrial component. When the design is being done, sustainability, manufacturing processes, and properties of the materials are of top priority. Strength, durability, malleability and conductivity are some of the

RESEARCH ARTICLE

properties of the metals, which enable their use in an extensive range of applications. The reasons why the designers often use metals, such as copper, brass, aluminium, and steel, are their performance behaviours and versatility (Ashby, Shercliff, and Cebon, 2013). The choice of a suitable metal is predetermined by the product-related needs, including load-bearing capacity, corrosion resistance, and aesthetics (Callister and Rethwisch, 2018). A unique industrial and eclectic design is created by the addition of waste gears to coffee tables. Such an approach gathers more play in the contemporary interior design, as the contrast between natural textures and hi-tech environments brings about a striking visual effect (Chapman, 2012). Similarly, engineering and architectural design often intentionally expose mechanical and architectural elements (e.g. couplings, gears, shafts, etc.) to create the effect of beauty and invigoration (Elise, 2024; Fractory, 2024).

Fabrication and Welding

Indispensable processes needed to transform waste metals into functional products that can be used include fabrication and welding. These operations, entice various cutting, shaping, joining, and finishing of metal components, are made to ensure that the completed product is structurally sound and physically pleasing to the eye (Kalpakjian and Schmid, 2014). From recycled materials, fabrication and welding are required to make sure that the products are quality and safety-wise. Delicate fabrication and welding activities produce items that are beautiful and robust, and thus, they are competitive alternatives to traditionally produced products (Bocken et al., 2016). More so, the relative value of upcycled goods can be increased through the skills of an artisan, which will stimulate the use of circular economy and sustainability (Stahel, 2016).

Metal fabrication is categorised into different forms. Cutting is the first step in metal fabrication and the methods used include sawing, shearing and laser cutting, which are utilized to create parts with correct shape and dimension. Accuracy during the cutting process is of importance so that the parts could be fitting in parts to the overall design and functioning of the product (Groover, 2010). The metal, after cutting, may also need subsequent shaping, which may include bending, rolling or stamping. These mechanisms increase the structural integrity and beauty, which helps to reach the required dimensions and geometries (Sharma, 2014). The most important method of welding metallic components is welding. The process that is used to attain strong junctions usually involves arc, TIG, and MIG welding. Upcycled products are structurally sound and safe due to properly welded items (Lincoln Electric, 2020). Welding that is used is

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

mainly arc welding wherein a bond is formed by melting base metals and filler metal using an electric arc. The method is quite often applied to re-use the material on upcycling works because of its versatility and because it works well on various metals and depths of the metals (Kou, 2003).

Innovative Design

Innovative design is significant to the success of upcycled products. A combination of creativity and functionality can allow designers to develop products that will stand out in the market and attract consumers. However, it may be quite difficult when it comes to consumer perception since sometimes upcycled products are perceived as more unappealing compared to the new ones. In the quest to overcome this challenge, the consumers need to know about the economic and environmental gains of upcycling (Ellen MacArthur Foundation, 2013). Increased acceptance and recognitions of upcycled products regarding consumers can create demand and set up positive consumption practices as a strategy to be environmentally responsible.

Materials and Method

This study used practice-based research (PBR) in the arts in the form of qualitative research. Qualitative research aims at understanding the human experiences, behaviours and the meanings as understood by individuals or groups. It involves gathering of non-numerical data through focus groups, interviews, content analysis, and observation of words, images or objects. Creswell (2013) states that this type of study is often used to explore the phenomenon with a great complexity and can provide profound and in-depth inquiries into the attitudes of people, their interactions, and thoughts.

De Freitas (2002) argues that practice-based research in art and design aspects focus its studies in which creative practice has the most significant influence on the different components of the research methodologies employed. Incentive comparatively, studio-based projects allow artists to use their artistic vehicle to respond to societal problems which are mainly based on their engagement with the unique working conditions in their studio. The researcher adopted the Stanford Design Model (SDM) to design and fabricate a coffee table using waste gears to address significant environmental risks brought about by metal scraps, leading to depletion of the environment. The SDM assists designers in understanding people's needs, empathizing with their experience, rephrasing the challenge, and then generating out-of-the-box solutions (O'Donoghue, 2022). The Stanford design model has three main parts: understand, create, and

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

deliver. The first two parts fall within the methodological section of the study, whereas the last part is in the results and discussion section.

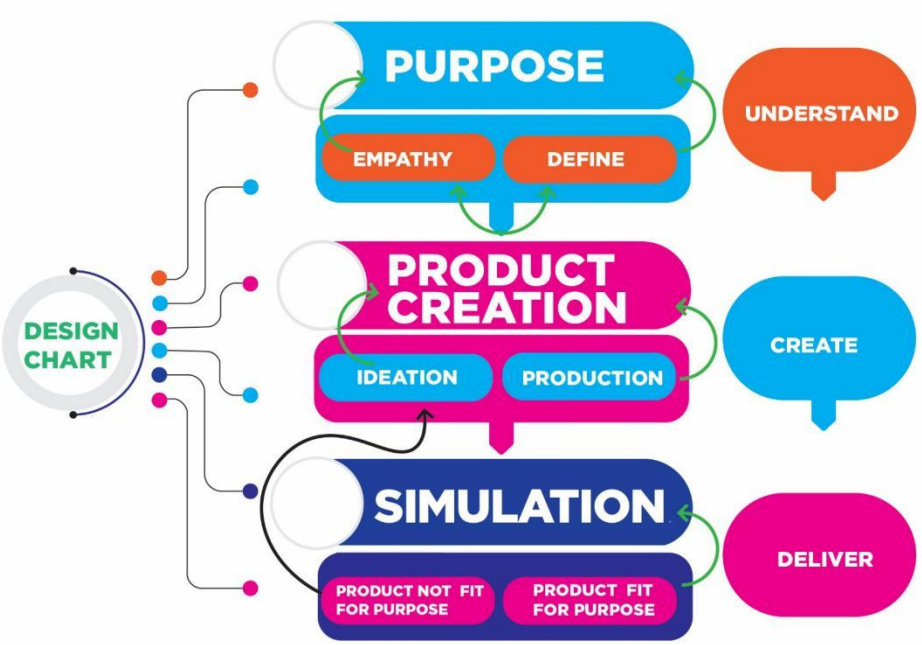

Figure 1: Design chart

Figure 1 illustrates the Stanford Design Model used in this study, showing the stages of understanding user needs, creating design solutions through ideation and production, and evaluating the final production through simulations to ensure that it fits its intended purpose.

Understanding the user's need

Utilizing human-centered design, a coffee table was created by recycling metal scraps to create table artifacts and by researching and comprehending people's perspectives and the reasons behind them regarding the exhaustion of natural resources and the degradation of the environment with waste gears. This is in line with Desai and Nemade's (2016) assertion that success depends on design thinkers having a thorough understanding of the audience they are serving. The ability to observe and pinpoint the motivation behind people's thought processes provided the researchers with crucial insight into the types of people the artist could depend on

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

to produce excellent solutions. Spending time observing the respondents allowed the researchers to gain enough insight into how they generate metal scraps and dispose of them at their workplace, which helped them better understand the people.

Empathy in design process

In the context of design, empathy is the designer's capacity to comprehend and relate to the emotions, ideas, and experiences of the end user. By empathizing, designers are able to create more solutions that are user centred, and this will ensure that the eventual product meets the needs and interests of the individuals who will be interacting with the product. The first stage of the design process design thinking or human-centred design is empathy. It entails getting into the attended environments of the users and observing their behaviours in addition to being informed about their challenges and motivations. Through this in-depth understanding, designers can create goods and services more meaningfully and effectively. According to Brown (2009), empathy helps the designer to assume the position of another person and perceive the world through the perceptions of the folks, and this is very important in coming up with solutions that the users consider compelling. The similar argument is presented by Kolko (2015), who believes that empathy in design also implies accepting the emotions of users along with their needs to come up with more intuitive and emotionally appeal design solutions.

Define

When the designer uses the word define, referring to a coffee table, it would mean the clear definition of the opportunity or problem, which depends on the information acquired during the empathy stage once he or she observes and comprehends how people use their living spaces. To develop a brief statement of the design challenge or problem, this is a phase that will bring together information about needs, preferences, and the environment that the coffee table will be utilized. As an example, a problem statement may state, how can we develop a coffee table that offers adequate storage, fits into modern living room design, and will appeal to the families with young children? upon surveying and understanding the usage of living environment by people. All the further stages of the design process are determined by this problem statement so that all the following decisions are focused on overcoming the certain needs of the user. In order to ensure that the end design is not only up to date but also new, the define phase is necessary because it alludes the path to the ideation and prototyping process. Kelley and Kelley (2013)

RESEARCH ARTICLE

argued that when the problem is defined conversationally based on the insights of users, design solutions involving more innovative and successful solutions will be presented.

Ideation

The step of design that utilises ideation engages the generation of a vast number of ideas and possible solutions to any specified problem that has been identified earlier. With this step, there is creativity and teamwork, and unexplored ideas can be explored freely by sketching, brainstorming, and exploring the idea. The objective is to have a wide-thinking approach and produce many ideas regardless of them seem eccentric or not. The configuration phase of the coffee table design can include the conceptualization in which several materials, shapes, features, and aesthetic inclinations can be utilised. As an illustration, a person can come up with concepts of a modular, height-changeable table, or a table with inbuilt charging stations, or secret storage units. It focuses on considering all the alternatives which may meet the specifications of the needs identified in the define stage, that is, style, usability and family friendliness and safety.

Ideation involves venturing or experimenting with a broad set of alternatives in order to find out possible solutions (Brown, 2009). This step is critical in the area of innovation since it allows designers to think outside the box, which can result in the development of a coffee table that can be distinguished. The researchers were creative and innovative in coming up with ideas that were fitting in the context, besides their technological knowledge of the issue. This was facilitated with the help of the early sketches which were detected as visual artefacts and were examined and critiqued. The design instrument correlates with an activity that Harley (2017a) proposed to design thinking practitioners to accomplish. The ideation phase played a significant role in making sure that the problem was properly defined especially the data obtained. Feedback was received when the design process was taking place to ensure that the final product will serve the purpose it was created (Geiser, 2015). In creating a table constructed of gears which are used as a coffee table, 3D rendering is necessary especially when using gears that have been discarded. The end result can be seen as a complicated and unique design when made out of scrap gears, 3D editing makes it possible to integrate these gears into the coffee table and interrelate the different parts, which in turn provides a perfect fit and makes it more visually appealing (Perez et al., 2021).

The product will be able to produce a set of different gear configurations using 3D rendering to identify the best scenario as far as functional and aesthetic performance is concerned. This

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

becomes particularly important in using scrap gears that do not fit a definite size or shape since it enables the adjustment of the design required prior to actual fabrication (Bertoni & Cascini, 2022). Rendering can also be helpful to determine the technical viability of scrap gears. The possible problems with alignment, spacing, and support can be observed through the interaction of the gears with other mechanisms in the table, which is obligatory to ensure stability and durability after the production (Kim and Maher, 2020). It also allows a better estimation of material and cost: a table with gears rendered will allow estimating the necessary number of materials accurately and reduces the chances of over- and under-ordering in addition to supporting the budgeting process (Kang and Jang, 2019).

Possible and selected designs for the coffee table.

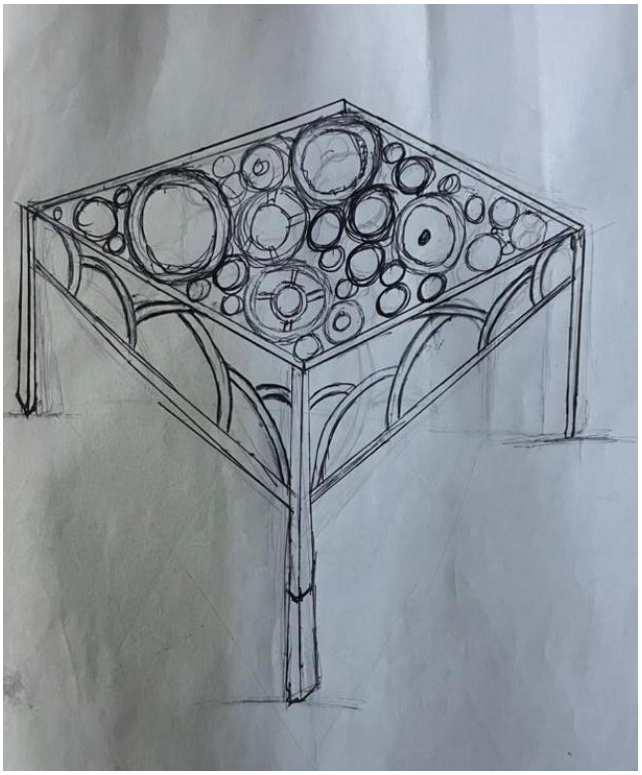

Figure 2: Alternative design of the coffee table

Figure 2 illustrates an alternative coffee table design developed as part of this study.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

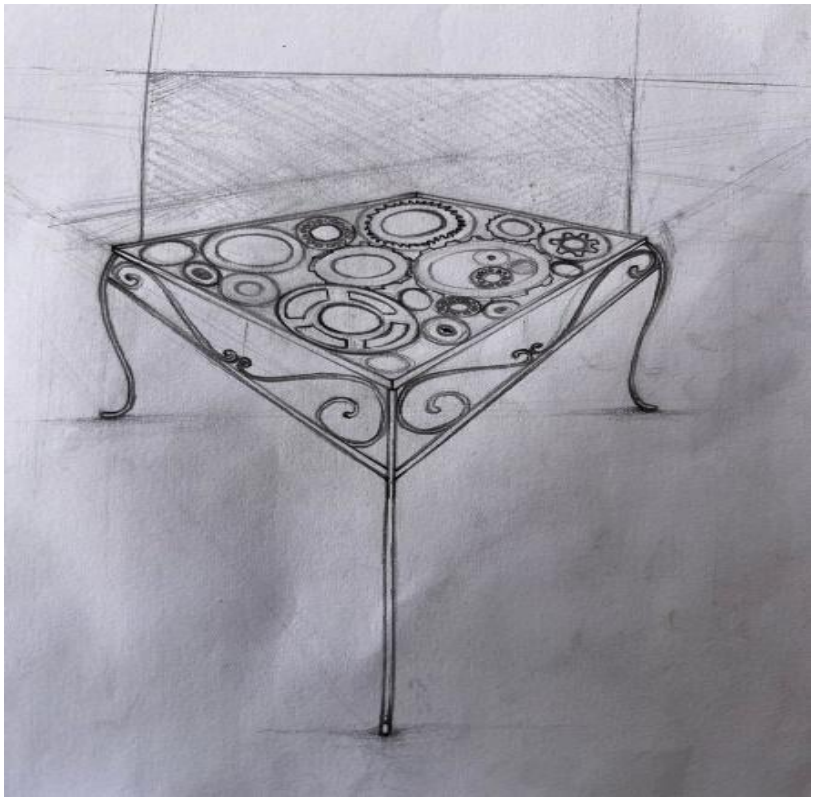

Figure 3: Final design of the coffee table

Figure 3 illustrates the main research design, reflecting the final concept after the design development process.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Figure 4: 3-dimensional rendering on the design

Figure 3 shows the rendered version of the design created using Rhino, KeyShot, and Grasshopper prior to the production of the actual work. Rendering was important for visualizing the final form, proportions, materials, and surface finishes of the coffee table before fabrication. It also aided in testing design accuracy, identifying possible structural and aesthetic issues, and making necessary refinements, thereby reducing material waste, cost, and fabrication errors. Additionally, the rendered model enhanced communication of the design concept and supported informed decision-making before the commencement of physical production.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Table 1: Tools and materials used for the fabrication

TOOLS	USES
Angle Grinder	It is used to shape and size scrap gears to the required degree through cutting, grinding, and polishing.
Welding Machine	Important for creating a solid bond when fastening the gears to the table frame or to each other.
Drill	Drilling holes for screws or bolts in wood or metal components.
Measuring Tape and Ruler	To ensure precise material measurements for correct fit and alignment.
Clamps	to maintain the position of the components during cutting, welding, or assembling.
Sander or Sandpaper	To produce a clean finish by smoothing metal and wood surfaces.
Spray Gun	For painting or applying finishes to metal and wood parts. Materials
Gear	The main materials used for fabrication of the Coffie table.
Iron rods	For the leg and side designs of the table.
Angle iron	To hold gears in place.

The fabrication of the coffee table involved cleaning the gears to remove oil and other materials from the surface of the scrap gears. The process of making a coffee table using gears that are already salvaged makes use of a sequence of systematic procedures, beginning with the purchase of materials used all the way to finalizing the creation of the coffee table. It begins by acquisition of gears usually gotten out of scrapped equipment or car parts or industrial gear. These gears can be manufactured of any good steel or any other strong alloy, which is carefully designed in terms of dimensional compatibility, form factor, and beauty to fit in with the design of the table being manufactured.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

When the gears are collected, they are subject to a high cleaning program, which aims at removing dirt, grease, or corrosion. This step is important in order to guarantee the visual appeal and integrity. Cleaning is generally performed either using industrial solvents or using mechanical processes like sandblasting. A further step is followed by detection of all defects that are not desirable such as fractures or excess wear, which are repaired via welding processes or metal-filling. The interventions are the reason behind the use of these gears having enough bearing capacity to hold the tabletop and all the items laid in it. The second step is conceptualization and writing of the gear layout, which is a very important phase of deciding the ultimate appearance and structural performance of the table. The gears are designed in a way that maximizes the visual interest and proportion. After this design is accepted, the gears are either welded or joined together by bolts in order to create a stable base design. Having assembled the base, the attention is now on the tabletop. The tabletop can be made of different materials such as glass, timber, or metal depending on the preferred mode of style. Glass is often chosen since it allows looking through the complex piece of gear setup, which further emphasized the overall aesthetic nature of the table. The tabletop is accurately shaped and then mounted on the gear base by use of adhesive or mechanical screws. Lastly, the assembly is treated with some finishing system intended to improve the looks and prevent corrosion of the materials used that may be an application of clear coating over the metal surface, a polishing finish finishing system to bring out a lustrous look and a protective coating over the top of the table.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Various Types of Gears used in the fabrication

Figure 5 A (Pilot bearing) , B (Ring gear) and C (Clutch disc)

Figure 4 A (Pilot bearing) , B (Ring gear) and C (Clutch disc): Shows different types of gears used in this study.

Figure 6: Iron rod

Figure 6 represents the iron rods that were used in this study. The main structural element would be a 15- mm smooth iron rod, as it has better strength and really durable but a 9- mm smooth

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

iron rod is used in the frame structure to give way to flexibility in the shaping of the detailed components without losing central stability.

The fabrication process of the coffee table

Figure 7: Base frame work of the coffee table

Figure 6 illustrates the construction sequence of the table, which puts special focus on the arrangement of the structure and the way the gears are arranged in space. The illustration shows the process of the iron rods being cut, contoured and welded to make the supporting skeleton, and the gears located on the tabletop in a strategic manner to serve both aesthetic and structural purposes. This description highlights the tediousness of the incorporation of materials and mechanical elements needed to achieve the desired artistic and structural outcomes.

Figure 8: Welding process of the coffee table

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Figure 8 goes on to elaborate on the developing process which will focus on the assembly and refinement of the structure. This part would show the welding of the framework, accurate fitting of the rest of the gears and the changes required to ensure stability and the correct positioning. It shows how the first design was refined into an improved and graphically resonant table design.

The fabrication process of the coffee table

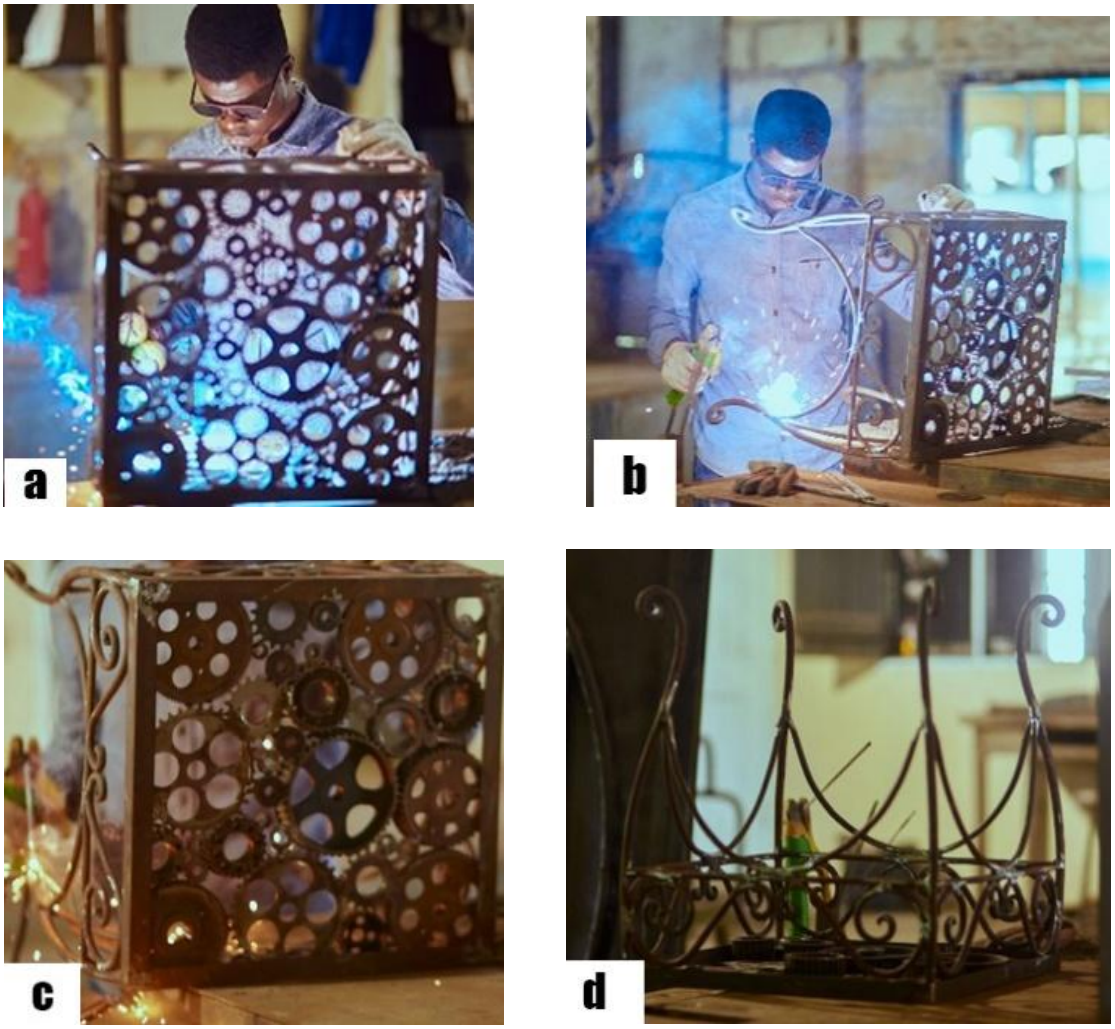

Figure 9 (A, B, C and D): Welding process of the coffee table

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Figure 9 (subfigure A-D) depicts the final phases of the construction in visualizing the coffee table in its assembly to the final output. The photographs show the final finishing, such as the processing of gear and smoothing of metal surfaces.

RESULTS AND DISCUSSION

This exploration proves that it is possible to successfully convert waste metal gears into a useful but aesthetically pleasing coffee table by a human-centred, practice-oriented design strategy. It can be seen at metal workshop that there is a large amount of waste in the form of discarded gears that could potentially be used to create much-valued structural and aesthetic value to the environment. Digital software like Rhinoceros and KeyShot helped the right visualization, fine tuning and simulation of the design before production. At fabrication and welding, independent evidence has shown that scrap metal materials can be taken up to develop a stable and durable furniture piece. According to the results of the simulations, the coffee table can be seamlessly incorporated into a cozy living-room context, both in terms of functionality and aesthetics needs. The results confirm the notion that by implementing the principles of the circular-economy and focusing on the up-cycling of product designs within the metal-product sphere, environmental waste will be minimized, and value-added commodities will be created. Effective implementation of empathy, ideation, digital rendering and fabrication prove that the Stanford Design Model is effective in context of sustainability issues. The exposure of the gears under the glass top improves the industrial aesthetic and transfers the ideas of resource-conservation. On the whole, the project demonstrates how through creative design and manufacture, waste materials can be turned into valuable sustainable products.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Figure 10 (A, B and C): Final Fabrication of the coffee table

Figure 10 (sub figures A-C) shows the finalized coffee table, which was finished with antique coating of spray and brush paint, and a glass lid that was firmly attached. The photographs draw an emphasis on the end aesthetic, that is, the metal structure, ordered gears, and glass surface, all of which are made out of smooth, working parts.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Simulation of the coffee table

Figure 11: First Simulation of the coffee table

Figure 11 is a simulated representation of the finished work in a living-room setting, showing how it is to be used, what scale it should be, and how well it fits the interior design of an apartment in a natural setting.

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

Figure 12: Second Simulation of the coffee table

A close-up simulation of the coffee table with accompanied emphasis on detail and finishing is presented in Figure 12.

Figure 13: Final Simulation

The completed simulation of the research is presented in Figure 12 and it places the coffee table in a full living -room environment and how it interacts with other items in the interior.

Metal Fabrication Techniques for Upcycling Waste Gears

The findings suggest that a complex of fabrication operations is necessary to convert waste gears into a steady piece of furniture. Arc welding was found to be the most suitable means of joining as it is stronger and flexible to different metal thicknesses as well as gears of steel. The use of angle grinder, cutting, and grinding to shape accurately, remove the surface impurities and polish edges before joining. The findings affirm that the old methods of metal fabrications when used in a systematic manner will be able to prolong the use of life of scrap metal components and create the durable furniture structures. The finish, sanding, polishing, and painting were used to achieve both corrosion resistance and pleasing appearance, which is consistent with the literature on fabrication quality criteria that note that proper bonding and finishing of points of

RESEARCH ARTICLE

sale should be undertaken to promote the aesthetic as well as structural performance of recycled metal products.

The existing literature on metal fabrication and sustainable product design provides a solid backing to the finding that several processes of fabrication (cutting, grinding, welding, and finishing) are required to convert waste gears into an operational coffee table. The result of arc welding in this research is consistent with the claim by Kou (2003) that arc welding is one of most dependable techniques in welding steel materials since it forms high tension bonds that resist heavy mechanical forces which are especially significant when the furniture is exposed to both the stationery and moving loads. On the same note, Lincoln Electric (2020) points out that arc welding is viable in a wide range of different metals of varying thickness, and hence this contributes to its appropriateness in repurposed gears which may vary in size, hardness, and wear.

The fact that cutting and grinding are used to form and prepare the gears prior to assembly proves the point that Groover (2010) makes explaining that precision cutting and surface finishing are the initial stages in metal fabrication as they allow to correctly fit the parts to be assembled and enhance the functioning of the finished parts. Grinding is also essential in the removal of contaminants as well as smoothing of surfaces thus increasing the stability of the welded joints as noted by Pavlovic (2018), and it is directly evident in the findings. It is thus not only a technical requirement that the edges are refined before welding but also makes the final piece of furniture structurally sound.

The literature on the study indicates well; the findings that the finishing processes such as sanding, polishing, and painting are effective in enhancing the corrosion resistance as well as aesthetics. According to Schneider and Yli-Pentti (2003) surface finishing is vital to the prevention of oxidation to metal particularly in domestic products under different humidity and temperature environments as the study of surface finishing reveals the presence of increased durability. According to Bocken et al. (2016), to achieve consumer acceptance of upcycled goods, the finishing of the product is necessary to enhance its aesthetic appeal, since the finished goods are not only protected but also increase the perceived value and usability of the products made using waste products.

These results are consistent with the rest of the literature on upcycling and sustainable design. According to the works of McDonough and Braungart (2013) and Cooper (2010), high-quality

RESEARCH ARTICLE

craftsmanship and prudent manipulation of materials are critical to developing discarded materials into high-value products. The fact that the traditional means of fabrication are systematically employed, as demonstrated in the study, can serve as an example of the way in which upcycling may help prolong the lifespan of materials without compromising aesthetic novelty. The findings support the concepts of the circular economy because recycled materials should be used to their utmost value as long as possible by illustrating that used gears can be repurposed into durable and aesthetically pleasing furniture (Geissdoerfer et al., 2017).

The study validates the stance presented by Stahel (2016), who affirms that in the waste reduction and preservation of material values, correct repair, remanufacturing, and refurbishment operations such as welding and finishing of materials are very important steps. In this regard, the conclusion, based on the existing literature, is that the processes of fabrication envisaged in the present project are not only efficient, technically wise, but also comply with the global sustainability scopes of waste reduction and new use.

Leveraging Gear Design Elements and Material Properties

In the research, the intrinsic mechanical properties of gears (tooth patterns, circular, symmetric, and mass) are a significant design advantage that is easily employed as decorative or structural components in furniture. The stability of the load-bearing base is guaranteed by the gears and the creation of an industrial look by their mechanical forms, which appeal to modern trends in interior design.

The most crucial application of this was the use of Rhino, KeyShot, and Grasshopper digital rendering to be able to visualize the layout of the gear before it was real. This reduced material waste and enabled experimentation of various forms to show that digital tools play a very crucial role in current upcycling. The gears being the gears revealed below the glass table top also contributed to the improved level of mechanical craftsmanship of the end product, making the table functional and symbolic in terms of conserving resources. This result helps to confirm the idea that upcycling can produce high-value, desirable objects and retain the authenticity of material characteristics of their original materials.

The discovery that the inherent mechanical and geometrical properties of the gears increase the structural as well as aesthetic values of the recycled coffee table is greatly supported by the extant studies in the field of material science, product design, and sustainable innovation.

RESEARCH ARTICLE

Callister and Rethwisch (2018) believe that gears are very strong due to their high tensile strength; they are resistant to deformation; and they are strong and enduring, which makes them suitable in the load bearing applications. This is in line with observation of the study that the mass and the structural integrity of gears produced a stable base that could safely hold a glass tabletop. They have the inherent strength that guarantees performance over a long period, which is consistent with the recommendation by Ashby, Shercliff and Cebon (2013) when designing functional metal products to ensure that the choice of materials has the best mechanical properties.

Circular symmetry, complex tooth designs, and industrial texture are also aesthetic aspects of gears which played a significant role in the overall design result. According to Chapman (2012) and Elise (2024), industrial-inspired furniture is on the rise due to its glorification of mechanical truthfulness and the unveiling of construction elements that are usually forbidden in consumer items. This pattern is consistent with the observation presented in the study that visible gears under the glass top made the piece more industrial and so the object became both a working object and a piece of art about the reusing. Similar arguments Cooper (2010) and McDonough and Braungart (2013) state that upcycled products acquire aesthetic value when they still hauntingly feature their original items, which supports the notion that authenticity in expression of material is a powerful attribute that leads to consumer attraction.

The digital rendering was also significant in the optimization of the design, and this is highly supported by the works of research in modern design approaches. Perez et al. (2021) clarify that 3D rendering enables designers to see complex assemblies, test assemblies and fitness, and see how materials interact in the virtual world before having to physically make them. This confirms that the tools (Rhino, KeyShot, and Grasshopper) contributed to the study in the reduction of the waste of material, the increased precision in design, and the exploration of numerous options in the most effective manner. Bertoni and Cascini (2022) also emphasize the fact that digital prototyping improves iterative design, which allows the designers to evaluate functional performance and aesthetic results without using physical resources, an important part of the sustainable design practice.

Digital simulation also has the agreement with the larger sustainability literature. Kang and Jang (2019) believe that virtual modeling can help with resource efficiency, cost reduction, and predictability of the design since it can enable the accurate estimation of what is required of materials and fabrication. In the given research, the capability of pre-programming gears virtually

RESEARCH ARTICLE

made sure that the completed design did not only look well but was also mechanically stable and would not have a chance of fabrication errors. Such a combination of digital tools supports the claim by Singh and Ordonez (2016) that technological innovation is the key to the development of the practices of the circular economy, especially in the industry where waste minimization and resource optimization are the priorities.

Lastly, the aesthetic worth of the gears through the glass tabletop is in accordance with the design research on emotional and symbolic worth of sustainable products. According to McDonough and Braungart (2013), the most effective upcycling is when the new item emphasizes the unusual features of the raw materials of which the product was made, which gives rise to emotional appeal and eco-consciousness. Fisher (2012) shares the same opinion by mentioning that the design that renders the material history visible promotes the users to rethink their connection to waste and consumption. This principle is observed in the study: presenting the mechanical beauty of gears, the table conveys the message of conservation of resources, innovation, and environment-sensitivity.

Contribution of Upcycling to Reducing Environmental Impact

These findings affirm the assumption that the reuse of waste gears can contribute to the significant decrease in metal waste levels and can be associated with the ideas of the circular economy. The project shows a low-energy route of increasing material life cycles by reusing discarded gears instead of discarding them or recycling them with energy-intensive methods. The fabrication process consumed less additional resources and manufactured a value-added product, which would otherwise have to be manufactured using new components. The final table was simulated in interior environments to demonstrate that it was integrated into a functional part of the space and helpful, supporting the value of upcycled furniture in society as a whole. The project represents an example of the innovative application of industrial waste to attain better environmental stewardship, relieve the landfill burden, and create awareness of the community about sustainable product design.

The discovery that upcycling waste gears is meaningful in reducing metal waste and in line with the principle of a circular economy is well substantiated in the literature on sustainability. Geissdoerfer et al. (2017) state that the circular economy focuses on decelerating, bridging, and shrinking resource cycles to minimize the waste and environmental deterioration. This paradigm is directly reflected in the study when the authors decide to extend the life cycle of disposed

Journal of Innovations in Art & Culture for Nature Conservation and Environmental Sustainability
Vol 4 No 1 (2026): https://journals.adompublications.com/jinces/index
https://doi.org/10.60129/jinces.v4i1.00826

RESEARCH ARTICLE

gears instead of recycling them through energy intensive processes or disposing them. According to The Ellen MacArthur Foundation (2013), one of the main strategies is the usage of existing material to reduce the mining of virgin raw materials, energy savings, and decreasing the environmental impact of production. The project also illustrates what Bocken et al. (2016) refer to as the processes of value retention by converting gears into a useful piece of furniture, thus, keeping the stored energy, materials, and functionality of the items without returning them to their original state.

The study complies with the argument of Stahel (2016), who states that the reuse and remanufacturing systems have much lower energy and resource implications as opposed to the traditional recycling systems. Unlike recycling which usually involves melting, chemical treatment or intensive sorting (Kleijn et al., 2000), upcycling preserves the structural integrity of the metal, thus leading to remarkably low environmental impact. This confirms the conclusion of the study that the process of fabrication required small extra resources but provided a value-added product that would result in a replacement of the newly produced metal parts. Another area of the wider literature is that Singh and Ordonez (2016) note that creative design helps in material recovery that lowers landfill loads, and it also limits the strain on waste management systems, which agrees with the societal benefits found in the study.

The fact that the realistic simulation of the final coffee table is done in the interior space strengthens its viability in terms of functionality and aesthetics, and, thus, proves that a set of design-based reuse practices have the potential to change the attitude of the population towards waste materials by proving that they may be reused in everyday life. Physical placement of upcycled products in home settings brings greater acceptance of the products and creates, what McDonough and Braungart (2013) would call, material intelligence of the intrinsic value and continued usefulness of the otherwise discarded materials. This is in line with the fact that, as observed during simulations, the table was found to be compatible with the modern interior design, which is to show that the upcycled products need not only match the expectations of consumers regarding product beauty, functionality, and longevity, but they could surpass them.

Moreover, Cooper (2010) and Chanchani (2017) suggest that home decors made of upcycled materials can provoke the interest of the market by integrating sustainability with the craft and the design innovation. This point is reflected in the findings: the gears visible under the glass surface not only do not take away the authenticity of the material but convey the message of environmental awareness and creativity. It is a symbolic visibility consistent with the rise of

consumer desire towards products that convey material narratives which is at the core of the argument by Andrews (2015) that design thinking and sustainability education can more adequately encourage society to reconsider waste in its products. The project supports the idea of resource stewardship and shows how art reuse of industrial materials can be used to promote environmental awareness, by placing the gears in the front of the product.

In general, the findings are highly aligned with the literature that supports the idea of upcycling as a feasible channel of sustainable production and consumption. It minimized metal waste and said goodbye to energy use, as well as increasing awareness of people regarding the reuse of materials, thus, the project is a vivid example of how innovative interaction with used industrial elements can promote the goals of a circular economy and environmental accountability.

Conclusion

Scrap metal recycling is essential for economic growth, environmental preservation, and sustainable development. Reusing metal waste minimizes the negative environmental effects of mining and industrial processing by preserving important natural resources and reducing the demand for raw material extraction. Automobile gears can be successfully converted to a high-quality and aesthetically pleasing furniture, such as a coffee table, by means of the arc welding, fine cutting, grinding, and finishing. Reusing industrial scrap has delivered two-fold advantages: not only does it reduce the amount of material in the landfill in terms of metal waste, but it also reduces the quantity of virgin materials that would be used in manufacturing the metal; not to mention that it results in a lower amount of energy used up, as well as a lower amount of greenhouse-gasses emitted in the course of conventional metal production. The geometry that gears have provides an aesthetic element of its own, thus demonstrating the aspect of compatibility between functionality and artistry that are of high quality. Integration of digital design, simulation and human-based approach also maximises material use, increases design accuracy, and eliminates production flaws, which in turn increases the economic sustainability of up-cycled metal products.

In addition to this case of furniture, these results highlight the overall need of designers, artists, and manufacturers to develop the circular economy. Future studies on durability, exhaustive cost-benefit research work and designing scalable manufacturing processes should be the focus of future research to promote broad implementation. At the same time, the educational facilities will be urged to include sustainability-oriented design projects in their curriculum, and the

RESEARCH ARTICLE

officials and business sector will have to increase efforts to enforce efficient collection, separation, and reuse of metal waste. Using recycled metals as an environmental initiative and design answer can allow the societies to move towards a more resourceful and ecologically sound future.

References

Andrews, D. (2015). *The circular economy, design thinking and education for sustainability*. Journal of Industrial Ecology, 19(5), 725–735.

Ashby, M., Shercliff, H., & Cebon, D. (2013). *Materials: Engineering, science, processing and design*. Butterworth-Heinemann.

Bertoni, A., & Cascini, G. (2022). *Digital prototyping for sustainable product innovation*. Design Studies, 78, 101076.

Bocken, N., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering, 33*(5), 308–320.

Brown, T. (2009). *Change by design*. HarperCollins.

Callister, W., & Rethwisch, D. (2018). *Materials science and engineering: An introduction*. Wiley.

Chanchani, R. (2017). *Upcycling in interior design*. Journal of Sustainable Arts, 14(2), 55–68.

Chapman, J. (2012). *Emotionally durable design: Objects, experiences and empathy*. Earthscan.

Cooper, T. (2010). *Longer lasting products: Alternatives to the throwaway society*. Gower.

Creswell, J. (2013). *Qualitative inquiry and research design* (3rd ed.). Sage.

De Freitas, N. (2002). The role of practice-based research in art and design. *Art, Design & Communication in Higher Education, 1*(1), 5–18.

Desai, P., & Nemade, H. (2016). Human-centered design and design thinking. *International Journal of Design Studies*, 3(2), 45–53.

Ellen MacArthur Foundation. (2013). *Towards the circular economy*. EMF.

Elise. (2024). *Industrial furniture trends*. Interior Design Review.

Fisher, T. (2012). *Designing for sustainability*. Routledge.

Fractory. (2024). *Industrial metal applications in design*. Fractory.com.

Geissdoerfer, M., Savaget, P., Bocken, N., & Hultink, E. (2017). The circular economy: A new sustainability paradigm? *Journal of Cleaner Production, 143*, 757–768.

Geyer, R., Jambeck, J., & Law, K. (2017). Production, use, and fate of all plastics ever made. *Science Advances, 3*(7), e1700782.

Goldsmith, S. (2014). *Upcycling: Creating value from waste*. EcoDesign Press.

RESEARCH ARTICLE

Graedel, T., Harper, E., Nassar, N., & Reck, B. (2011). On the materials basis of modern society. *Proceedings of the National Academy of Sciences, 112*(20), 6295–6300.

Groover, M. (2010). *Fundamentals of modern manufacturing*. Wiley.

Hoornweg, D., Bhada-Tata, P., & Kennedy, C. (2015). Waste production and waste management. *Waste Management Journal*, 34(2), 250–260.

Kalpakjian, S., & Schmid, S. (2014). *Manufacturing engineering and technology*. Pearson.

Kang, S., & Jang, D. (2019). Virtual modeling in sustainable design. *Journal of Industrial Design*, 44(3), 110–125.

Kelley, T., & Kelley, D. (2013). *Creative confidence*. Crown Business.

Kleijn, R., Huele, R., & van der Voet, E. (2000). Recycling and environmental impact. *Resources, Conservation, and Recycling, 29*(3), 223–241.

Kim, M., & Maher, M. (2020). Evaluating structural feasibility with digital simulation. *Design Computing, 17*(1), 61–78.

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy. *Resources, Conservation & Recycling, 127*, 221–232.

Kolko, J. (2015). *Design thinking comes of age*. Harvard Business Review.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics, 143*, 37–46.

Kou, S. (2003). *Welding metallurgy*. Wiley.

Lee, J., Yoon, S., & Lee, K. (2021). Social impacts of upcycling. *Sustainability, 13*(11), 6242.

Leising, E., Quist, J., & Bocken, N. (2018). Circular economy in the built environment. *Environmental Innovation and Societal Transitions, 26*, 221–232.

Lifset, R. (2013). Industrial ecology. *Journal of Industrial Ecology, 17*(5), 639–643.

Lincoln Electric. (2020). *Arc welding guide*. Lincoln Electric Company.

Lund, R. (1984). *Remanufacturing*. Technology & Society.

McDonough, W., & Braungart, M. (2013). *The upcycle: Beyond sustainability*. North Point Press.

Moraga, G., et al. (2019). Circular economy indicators. *Resources, Conservation & Recycling, 146*, 452–462.

Norgate, T., Jahanshahi, S., & Rankin, W. (2007). Assessing metal production impacts. *Journal of Environmental Science and Technology, 41*(10), 3632–3640.

O'Donoghue, J. (2022). *Design thinking in practice*. Stanford Press.

Pavlovic, A. (2018). Metal surface preparation. *Journal of Manufacturing Science*, 27(4), 55–66.

Pérez, A., Martínez, J., & López, M. (2021). 3D visualization in engineering design. *Computer-Aided Design Journal, 139*, 103060.

Schneider, T., & Yli-Pentti, H. (2003). Corrosion protection and finishing. *Surface Engineering Journal, 19*(1), 25–34.

Sharma, P. (2014). *Metal forming processes*. Springer.

Singh, J., & Ordoñez, I. (2016). Resource recovery through design. *Journal of Cleaner Production, 126*, 410–422.

Singhal, D., Tripathi, G., & Jena, S. (2020). Upcycling as a sustainability strategy. *Resources, Conservation & Recycling, 152*, 104–512.

Stahel, W. (2016). Circular economy performance. *Nature, 531*(7595), 435–438.

United Nations Environment Programme. (2017). *Global material flows report*. UNEP.

World Commission on Environment and Development. (1987). *Our common future*. Oxford University Press.

Zaman, A., & Lehmann, S. (2013). Urban waste and recycling. *Sustainable Cities and Society, 8*, 40–48.