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Raw Material Stage Assessment of Seating Elements as Urban Furniture and Eco-Model Proposals

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Abstract: As cities strive to become sustainable, it is imperative to consider even the smallest components of the urban environment and prioritize sustainability. Ensuring the sustainability of urban furniture, especially the numerous benches found in cities, is crucial. This study proposes an alternative solution to the sustainability issue in cities regarding urban furniture. This is because a review of the literature indicates that while efforts have been made to evaluate the sustainability of urban amenities and furniture, studies conducting life cycle analysis specifically for urban furniture are lacking. This study will contribute to the identified gap in the literature by analyzing 14 different seating elements in recreational areas located in the city of Rize, Turkey, using the Ccalc program to calculate their carbon footprints. In the subsequent phase of this study, an eco-design process will be conducted based on the findings, aiming to create an eco-seating unit design. Based on the data obtained, materials with high environmental impact were identified, material replacement recommendations were made, and consequently, a model proposal was presented. The potential reduction in carbon footprints with the use of transformed materials was discussed. The findings revealed that carbon footprint values were particularly high in the seating units where concrete and polypropylene materials were used. Additionally, it was determined that solvent paint, especially varnish, affects the carbon footprint, and it was recommended that would be used in its natural form, which is eco-friendly. In conclusion, the recommendations developed for the sustainability of urban furniture in coastal areas will contribute to the future of cities and humanity.

Keywords: eco-design; carbon footprint; sustainability; urban equipment; seating elements; Rize

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Citation: Sipahi, S.; Sipahi, M. Raw Material Stage Assessment of Seating Elements as Urban Furniture and Eco-Model Proposals. *Sustainability* **2024**, *16*, 4163. https://doi.org/10.3390/su16104163

Academic Editor: Marc A. Rosen

Received: 19 February 2024
Revised: 10 May 2024
Accepted: 14 May 2024
Published: 16 May 2024

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1. Introduction

Rapid urbanization, encompassing the economic, ecological, and sociological development process of cities, brings forth urban benefits alongside urban and environmental threats [1]. The rapid depletion of natural and cultural resources, climate change, and urban pressures such as environmental pollution (air, water, noise) highlight the issues of urban resilience and sustainability [2]. In the context of sustainability, which has become a global concern, the aim is to develop policies that enhance the quality of life for all individuals today and in the future by providing equal opportunities in cities and reducing the environmental impacts of all these efforts [3,4]. The lives of urban users directly influence the design of sustainability channels and products in accordance with sustainability principles, making it mandatory [5].

Strategies for achieving sustainable development goals in cities are fundamentally based on the efficient use of raw materials and energy, as well as reducing/preventing their environmental impact [6]. Sustainable cities provide a framework for urban development but also face environmental, local, social, cultural, and economic challenges [7,8]. Within this context, it is not possible identify a single suitable solution for sustainability in cities with different identities, resources, and characteristics [9]. Therefore, each city needs unique urban planning, defining goals and objectives that enhance the quality of life for sustainability at macro- to microscales [10].

Open green spaces, which are prominent among land uses that enhance the quality of life in urban areas, contribute significantly to sustainability due to their quality and usability [11]. Urban open green spaces encompass urban equipment/furniture tailored to user needs, integrated into public spaces [12]. Urban equipment is a crucial element that contributes to the livability of space and shape the identity of a city [13]. This equipment has a systematic structure that ensures the integrity of the city and provides spatial uniqueness [14]. Urban furniture holds significant importance for sustainable cities, being influenced by social, cultural, environmental, and economic factors [15]. Seating units within urban equipment serve various purposes such as creating social spaces, relaxing, and gathering [16]. Outdoor seating units with various designs commonly utilize materials such as concrete, wood, metal alloys, and plastics [17]. Seating units that provide general usability in urban areas should be planned and designed with materials that are compatible with climatic conditions, allowing for adaptation, having long lifespans, and doing no harm to the environment in order to extend their lifespan within the framework of sustainability [18].

Urban equipment has a lifecycle at the product–material scale before and after the design process. Additionally, they significantly impact urban quality of life and sustainability [19]. This furniture is a significant part of urban design approaches and, supported by sustainable design strategies while addressing user needs, will contribute to future generations [15]. Studies emphasizing the contribution of urban furniture to sustainability in sustainable urban designs are available [20,21]. These studies highlight the necessity of considering the environmental impact of materials/products in every aspect, from micro- to macroscales, such as urban furniture. In this context, emerging sustainable approaches adopt an understanding of where natural resources are efficiently used, ecosystems are preserved, and environmental impacts are reduced [22]. In this regard, material choices and the raw material stage are crucial in the life cycle of urban equipment.

Sustainability gives rise to the concept of eco-design, which encompasses processes involving the assessment of and reduction in the environmental impacts of products or systems throughout their life cycle, shaping the design accordingly. Life cycle analysis can be defined as determining the environmental impacts of a design process from the raw material stage to transformation and disposal [23–26].

Rooted in the integrative impact of ecology and design, eco-design aims to create designs that do not harm the environment in any way during their use and return to nature, ensuring the sustainability of the production chain [27,28]. In eco-design, the identification of ecological impacts and consideration of environmental factors are essential from the early stages of product design, such as planning and conceptualization [29–31]. Eco-design is shaped by seven main strategies covering the product's life cycle [32]. These strategies include low-impact material, reduction in material use, optimization of production techniques, optimization of distribution systems, reduction in impact during use, optimization of product lifetime, and optimization of end-of-life systems.

Life cycle assessment (LCA), which forms the basis of eco-design, is a technique that evaluates possible environmental impacts, such as energy usage and waste, in addition to production costs, as well as product usage and recycling [33,34]. In the approach adopted by low-carbon design philosophy, environmental impacts throughout the entire life cycle are considered. The product's carbon footprint is revealed in life cycle design and analysis [26]. In today's discussions, particularly related to climate change, the importance of life cycle analysis is emphasized in connection with low-carbon design [35]. "Life cycle analysis (LCA)" or "life cycle assessment (LCA)" is considered among the methodologies that assess the sustainability of products and is considered a suitable method from the urban scale to the furniture scale [36]. Life cycle analysis encompasses five fundamental cycles: raw material acquisition, product manufacturing, product distribution and application, product use and maintenance, and the recycling or disposal of the product, covering the pre-use, in-use, and end-of-life stages of a product [37–40]. Additionally, life cycle analysis (LCA) occurs in four distinct stages: goal and scope definition, inventory analysis, impact analysis, and interpretation [41–43]. In this context, the first step involves identifying the raw materials, energy, and water used throughout the product's entire process, resulting in an inventory of environmental emissions. Based on the obtained data, the environmental impacts of inputs and outputs are evaluated, and in the final stage, systematic and comparative analyses are conducted with interpretations [41,44] The fundamental principle of life cycle analysis is to determine the environmental impacts of a product or substance, reduce harmful effects, and select environmentally and ecologically friendly products that cause minimal harm to the environment [45–47]. Life cycle analysis has been standardized in the International Organization for Standardization (ISO) standards 14040 and 14044 [48].

Life cycle analysis has various applications such as enhancing the planning and design processes of a product, making strategic decisions, integrating products into the eco-design process, and comparing products [41]. Several tools and techniques are employed to reveal the environmental impacts of a product within the scope of eco-design. In this context, the Material-Energy-Toxicology (MET) matrix and analysis, with environmental indicators, have emerged as significant tools [49–51]. Different software tools with various databases and interfaces, such as Simapro, GaBI, Umberto, and Ccalc, are utilized in the creation and evaluation of life cycle analysis [52]. These software applications make significant contributions to the analysis process [44]. Sustainability within the scope of urban planning, particularly in eco-design, highlights the need for life cycle analysis at both the urban and sub-scales. Selecting and analyzing products or materials in a way that minimizes ecological impact is crucial [47,53]. Therefore, all structural and vegetative areas within the city scope should be included in the sustainability process, and the environmental impacts of furniture that are overlooked at small scales should be identified, and necessary measures should be taken.

According to searches conducted on the Scopus and Web of Science databases, there are no eco-design studies specifically focused on benches in the literature. Although there are studies on sustainable urban equipment, there is a lack of research specifically focused on the life cycle analysis of this equipment. To the best of our knowledge, this article is the first attempt to evaluate the environmental effects on benches of a city using an LCA method.

In reviewing past studies, it has been observed that there are eco-design studies on the wood sector [54] and furniture sector [55,56], sustainability studies on cities and urban spaces [57,58], and sustainability studies on urban equipment [59,60]. In this context, the current study aims to serve as a bridge among other studies and address questions such as "What are the environmental impacts of existing designs for benches as urban equipments? Is it possible to reduce the environmental impacts of these designs through eco-design methods?" The analysis conducted within the scope of this study calculated the current carbon footprints of 14 types of benches in the city, considering the materials. Carbon footprints were reduced by changing materials and reducing material diversity, and a bench model with a low carbon footprint was proposed by implementing ideas for reducing parts. With these studies, the main contribution of this article will be the eco-bench model proposals for cities created through eco-design studies conducted on existing designs. This study underscores the critical need to integrate life cycle analysis for the raw material stage into assessing the sustainability of urban furniture, particularly in the realm of urban furniture. This study only focused on the raw material stage of the life cycle of benches. Given that this study only addressed one stage of the life cycle, focusing on all stages of the life cycle in future studies would be appropriate and serve as a guide for further research. Focusing on seating elements in recreational areas and proposing eco-design solutions, it not only addresses a significant gap in the literature but also offers tangible strategies for reducing carbon footprints and advancing sustainable practices in coastal urban environments. This study, through its analysis of coastal urban furniture with eco-design, will provide a foundation for other similar works.

2. Materials and Methods

2.1. Study Area

The material of this study comprises 14 different seating elements used in the coastal landscape of the city of Rize, which is located in the Eastern Black Sea Region (Turkey) (Figure 1). Rize is a city with a linear structure along the coast of the Black Sea. With a mild climate, Rize receives rainfall throughout the year due to its geographical features, and the humidity in the city is quite high. Due to the topography of the Rize province, land uses are created in areas close to the coast.

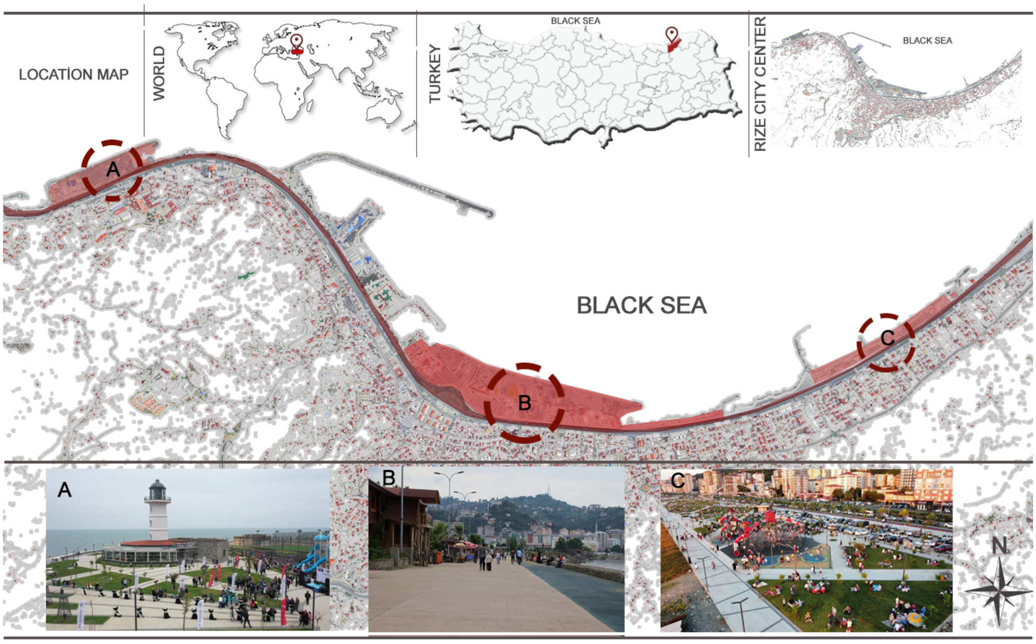


Figure 1. Study areas: (**A**) Fener Recreational Area, (**B**) Mesut Yılmaz Coastal Park, (**C**) Portakallık-Islampasa Recreational Area.

The coastal areas, which are intensively used by users for recreational purposes, have significant importance for the city in terms of social, economic, ecological, and cultural aspects and their structural and plant elements. In this context, 14 different seating units from three different coastal recreational areas heavily used in the city of Rize were included in this study (Figure 2). The sustainability of seating elements with different materials and designs was examined within the scope of this study.

Figure 2. Seating units: A Fener Recreational Area, B Mesut Yılmaz Coastal Park, C Portakallık-Islampasa Recreational Area.

The presence of 14 different seating elements in close proximity to each other in the city center, along with the richness in material diversity, has led to the selection of the city center of Rize as the study area.

2.2. Method

The methodology of this study involves investigating the sustainability of seating units used in coastal areas through a life cycle analysis. In this context, this study consists of 11 stages (Figure 3):

- Collecting data through direct measurements (Figure 4).
- Calculating weights by using the specific densities of the materials and entering the data into the Ccalc program (Version: V3.3, Country: Manchester, UK).
- Identifying the carbon footprint of designs using the Ccalc program, identifying and evaluating materials with environmental impacts above the determined average value, and evaluating carbon footprints of materials for original designs.
- First round of listing alternative materials using brainstorming method, evaluating alternative materials through cost–benefit analysis, and implementation of alternative materials.
- Identifying and evaluating carbon footprints of designs after first round.
- Second round of listing alternative materials using brainstorming method, evaluating alternative materials through cost–benefit analysis, and implementation of alternative materials.
- Identifying and evaluating carbon footprints of designs after second round.
- Final review of designs with alternative materials.
- Listing ideas for reducing parts using brainstorming method, evaluating reduced furniture parts through cost–benefit analysis, identifying ideas for materials with low carbon footprint.
- Generating and evaluating proposals for new designs based on material substitution and material reduction ideas.
- Comparison of the developed model proposals with existing seating elements.

Figure 3. Study method.

In this study, the carbon footprints of seating units were calculated only for the raw material stage, excluding the production stage due to factors such as the ease of regional production and the large number of seating units having on-site assembly. Additionally, the transportation stage was excluded from the study scope because of the on-site assembly implementation. Furthermore, discussions with the municipality revealed the absence of a specific recycling program for old products and the diversity of recycling processes. Hence, the end-of-life stage was also excluded from the study scope. Since seating elements do not consume energy during the usage stage, they were also excluded, because they focused solely on the raw material stage in this study.

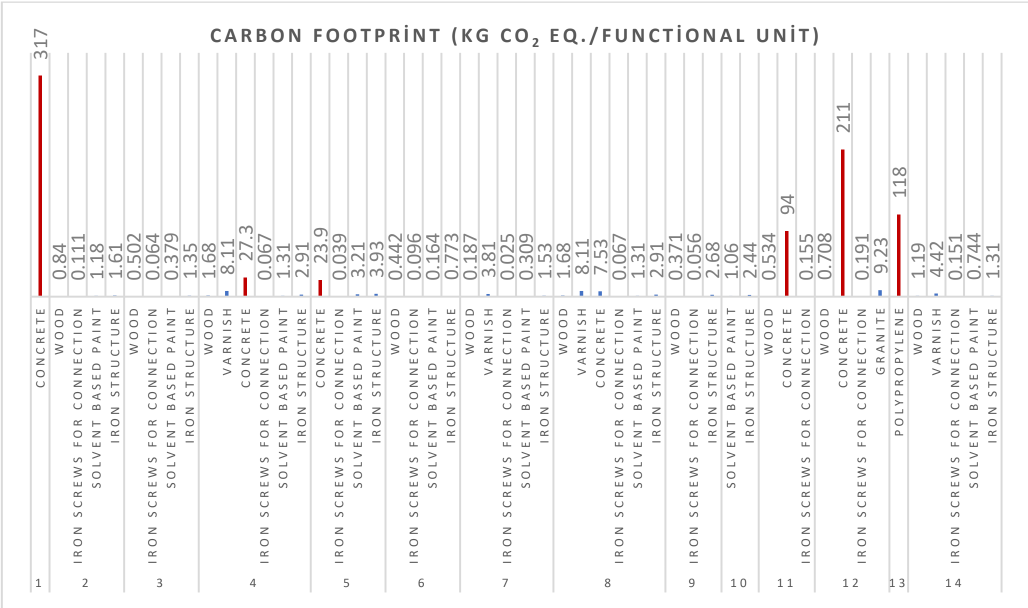


Figure 4. Design, materials, and carbon footprint values (blue: low values, red: high values).

This study began with the collection of data through on-site measurements in the specified areas. During the measurements, a tape measure and a caliper measurement tool were used, while the numbers of parts were calculated through on-site observation.

Initially, the data were collected for 14 seating units located in three different recreational areas. Within this scope, on-site observations, measurements, and analyses of the material details and dimensions of each seating element were conducted and plans and elevations were drawn (Tables 1 and 2). Measurements were taken volumetrically for seating elements without the possibility of dismantling, and their weights were calculated using the density of the materials. The collected data revealed variations in the lengths of the seating units. Accordingly, the seating units had different lengths: designs 2 and 3 were 180 cm long, designs 5, 6, and 13 were 150 cm long, designs 4 and 8 were 270 cm long, design 9 was 196 cm long, design 10 was 350 cm long, and design 14 was 235 cm long. As shown in Table 1, seating units with different seating capacities were included in the study scope. In particular, designs 1, 11, and 12 were observed to serve large groups. To minimize this variation, designs 1, 11, and 12 were considered for three people based on the Neufert handbook and the lengths of other seating units were assumed to be 180 cm for three people [61].

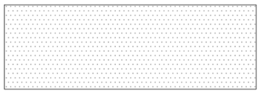
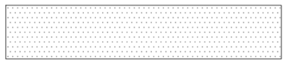
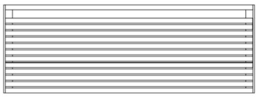
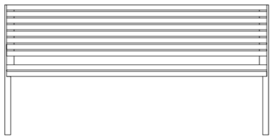
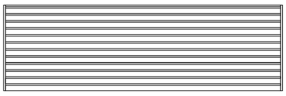
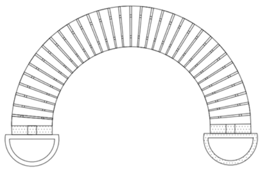
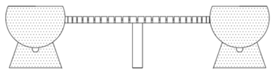
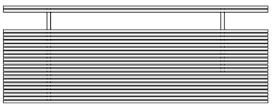
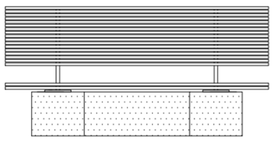
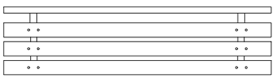
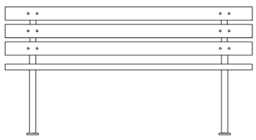
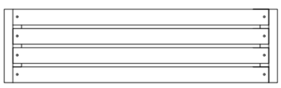
In the second stage of this study, the weights of the materials whose volumes were calculated using the specific densities shown in Table 3 were determined for data entry into the Ccalc program.

In the next stage of this study, the data were input into the Ccalc program used for life cycle analysis. Assuming that 5% of the weights constituted waste and consumable materials [52], the product weights were entered into the program with a 5% increase.

The Ccalc program is a tool that follows the life cycle methodology created according to PAS2050, ISO14040, and ISO14044 standards [52]. This user-friendly program comes with the ecoinvent database. In this study, the ecoinvent database was also utilized. Ccalc allows for cradle-to-grave carbon footprint calculations and helps identify carbon hotspots and carbon reduction opportunities. It is a program with a broad database that calculates the carbon footprint in kg CO_2 eq./functional unit [62]. kg CO_2 eq./functional unit is kilograms of carbon dioxide equivalent [63]. The emission levels of different greenhouse gases can be converted to CO_2 equivalents in order to combine the global warming effects.

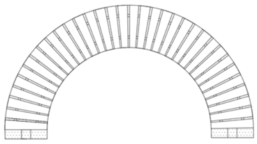
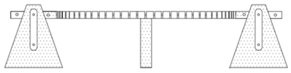
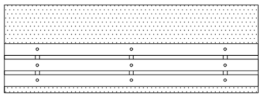
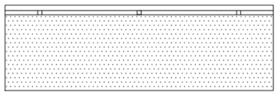
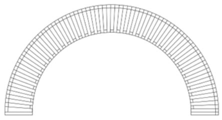
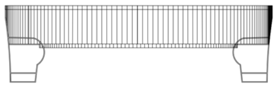
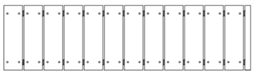
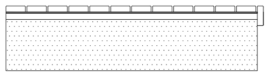
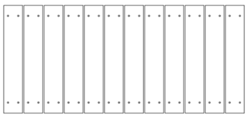
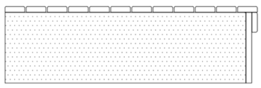
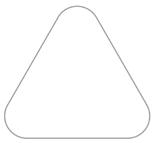
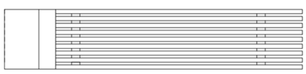
This conversion is based on the global warming potential (GWP), which measures the warming impact of the greenhouse effect of materials [64].

Table 1. Seating units (1–7) examined in the study scope.

No	Top (Plan) View	Front-Side View	Photograph
1			
2			
3			
4			
5			
6			
7			

After calculating the carbon footprint of designs using the Ccalc program, materials with environmental impacts above the determined average value were identified and evaluated in the fourth stage. To determine the average value, the total carbon footprint number of the identified seating units was divided by the number of seating units, resulting in the average total carbon footprint value. Then, the average number of materials used in these 14 seating units was determined. The calculated average total carbon footprint value was divided by the average number of materials, resulting in an average value.

Table 2. Seating units (8–14) examined in the study scope.

No	Top (Plan) View	Front-Side View	Photograph
8			
9			
10			
11			
12			
13			
14			

Materials with values above the calculated average are considered to have a high carbon footprint. For these materials, brainstorming methods were used to list new material alternatives; the listed materials were then evaluated using the cost–benefit technique, and material substitutions were made based on the evaluation results. When the results were evaluated, they were deemed insufficient. Therefore, the calculations and material changes were repeated once more with second round, taking advantage of the iterative nature of eco-design [61]. Finally, the carbon footprints of the new designs obtained from the material changes in the second round were determined, and comparative analyses were conducted with the results from the first round.

Table 3. Seating units examined in the study scope.

Material	Density
Concrete	2.4 g/cm^3
Wood	0.7 g/cm^3
Iron screws for connection	7.87 g/cm^3
Solvent-based paint	0.8 g/cm^3
Iron structure	7.87 g/cm^3
Varnish	1.14 g/cm^3
Granite	2.7 g/cm^3
Polypropylene	0.9 g/cm^3

In the next stage of this study, material reduction ideas were developed based on the new designs obtained by changing the necessary materials while preserving the seating function. In the final stage of this study, a new design model proposal was presented, and a life cycle comparison was made between the initial designs and the new design proposal.

3. Results and Discussion

The findings of this study were evaluated under three main headings. In this context, the results include carbon footprint measurements of existing designs, new measurements by applying eco-design strategies, material reduction ideas, and the development of a new model.

3.1. Identifying and Evaluating the Carbon Footprints of Materials for Original Designs

An analysis was conducted by considering the materials and quantities used in 14 different seating elements, and the materials used along with their carbon footprints are presented in Table 4. The obtained data reveal the frequent use of concrete, wood, and iron materials in seating units, along with the utilization of polypropylene and granite materials. It was identified that varnish and solvent paint are commonly used for seating elements. The average value of the identified carbon footprint for the seating units is 15.58 kg CO_2 eq./functional unit.

Table 4. Seating elements, materials used, and carbon footprints (kg CO_2 eq./functional unit).

Design No	Material	Carbon Footprint (kg CO_2 eq./Functional Unit)	Total Carbon Footprint (kg CO_2 eq./Functional Unit)
1	Concrete	317	317
2	Wood	0.84	3741
	Iron screws for connection	0.111	
	Solvent-based paint	1.18	
	Iron structure	1.61	
3	Wood	0.502	2295
	Iron screws for connection	0.064	
	Solvent-based paint	0.379	
	Iron structure	1.35	

Table 4. *Cont.*

Design No	Material	Carbon Footprint (kg CO_2 eq./Functional Unit)	Total Carbon Footprint (kg CO_2 eq./Functional Unit)
4	Wood	1.68	41.377
	Varnish	8.11	
	Concrete	27.3	
	Iron screws for connection	0.067	
	Solvent-based paint	1.31	
	Iron structure	2.91	
5	Concrete	23.9	31.079
	Iron screws for connection	0.039	
	Solvent-based paint	3.21	
	Iron structure	3.93	
6	Wood	0.442	1.475
	Iron screws for connection	0.096	
	Solvent-based paint	0.164	
	Iron structure	0.773	
7	Wood	0.187	5.861
	Varnish	3.81	
	Iron screws for connection	0.025	
	Solvent-based paint	0.309	
	Iron structure	1.53	
8	Wood	1.68	21.607
	Varnish	8.11	
	Concrete	7.53	
	Iron screws for connection	0.067	
	Solvent-based paint	1.31	
	Iron structure	2.91	
9	Wood	0.371	3.107
	Iron screws for connection	0.056	
	Iron structure	2.68	
10	Solvent-based paint	1.06	3.5
	Iron structure	2.44	
11	Wood	0.534	94.689
	Concrete	94	
	Iron screws for connection	0.155	

Table 4. *Cont.*

Design No	Material	Carbon Footprint (kg CO_2 eq./Functional Unit)	Total Carbon Footprint (kg CO_2 eq./Functional Unit)
12	Wood	0.708	221.129
	Concrete	211	
	Iron screws for connection	0.191	
	Granite	9.23	
13	Polypropylene	118	118
14	Wood	1.19	7.815
	Varnish	4.42	
	Iron screws for connection	0.151	
	Solvent-based paint	0.744	
	Iron structure	1.31	

The examination revealed that the carbon footprint values of the seating units using concrete and polypropylene materials were consistently above the identified average values. Figure 4 shows that seating design No. 1 is entirely made of concrete, while designs No. 4, 5, 8, 11, and 12 use concrete in their legs and structural parts. Additionally, design No. 13 is entirely made of polypropylene. Varnish is used in designs No. 4, 7, 8, and 14, and it is observed that this material has a high carbon footprint. Designs No. 2, 3, 4, 5, 6, 7, 8, 10, and 14 used solvent paint, and it was observed that this material also has a high carbon footprint.

3.2. First Round of Listing, Evaluating, and Implementing Alternative Materials and Evaluating the Carbon Footprints of Designs after the First Round

In the initial assessment of existing designs, it was identified that the carbon footprint of concrete and polypropylene materials is high. In response, alternative material suggestions have been developed. The developed recommendations are provided in Table 5.

Table 5. Alternatives for concrete and polypropylene.

Original	Alternative		
	Material	**Benefits**	**Issues**
Concrete and Polypropylene	Wood	Low cost, renewable, not harmful, no hazard	Low durability
	Natural Rubber	Flexible, easy to care for	Low durability
	Polylactic acid (PLA)	Renewable	Thermoplastic
	Natural stone	High durability	High environmental impact
	Aerated concrete	Recyclable	High initial cost
	Bamboo	Recyclable	High initial cost

Wood, among the alternative materials utilized instead of concrete and polypropylene, can be considered a widespread material used in seating units overall. Additionally, it is known to be highly sustainable and environmentally friendly [65]. Therefore, wood is considered a material that can replace concrete and polypropylene.

In the scope of this study, carbon footprint analyses were repeated by using wood instead of concrete and polypropylene, taking advantage of the repetitive nature of eco-design [52]. The obtained data are provided in Table 6.

Table 6. Carbon footprints after the first round.

Design No	Material	Carbon Footprint (kg CO_2 eq.)	Total Carbon Footprint (kg CO_2 eq.)
1	Wood	1.76	1.76
2	Wood	0.84	3.741
	Iron screws for connection	0.111	
	Solvent-based paint	1.18	
	Iron structure	1.61	
3	Wood	0.502	2.295
	Iron screws for connection	0.064	
	Solvent-based paint	0.379	
	Iron structure	1.35	
4	Wood	1.29	14.687
	Varnish	8.11	
	Iron screws for connection	0.067	
	Solvent-based paint	1.31	
	Iron structure	2.91	
5	Wood	1.14	8.319
	Iron screws for connection	0.039	
	Solvent-based paint	3.21	
	Iron structure	3.93	
6	Wood	0.442	1.475
	Iron screws for connection	0.096	
	Solvent-based paint	0.164	
	Iron structure	0.773	
7	Wood	0.187	5.861
	Varnish	3.81	
	Iron screws for connection	0.025	
	Solvent-based paint	0.309	
	Iron structure	1.53	
8	Wood	1.86	15.257
	Varnish	8.11	
	Iron screws for connection	0.067	
	Solvent-based paint	1.31	
	Iron structure	2.91	
9	Wood	0.371	3.107
	Iron screws for connection	0.056	
	Iron structure	2.68	

Table 6. *Cont.*

Design No	Material	Carbon Footprint (kg CO_2 eq.)	Total Carbon Footprint (kg CO_2 eq.)
10	Solvent-based paint	1.06	3.5
	Iron structure	2.44	
11	Wood	0.534	94.689
	Concrete	1.07	
	Iron screws for connection	0.155	
12	Wood	1.78	11.201
	Iron screws for connection	0.191	
	Granite	9.23	
13	Wood	1.16	1.16
14	Wood	1.19	7.815
	Varnish	4.42	
	Iron screws for connection	0.151	
	Solvent-based paint	0.744	
	Iron structure	1.31	

The average carbon footprint of the new materials was re-calculated and determined to be 1.896. Figure 5 shows that the varnish material exceeds the average value in designs 4, 7, 8, and 14; the solvent paint in design 5; the iron structural elements in designs 5, 8, 9, and 10; and the granite in design 12.

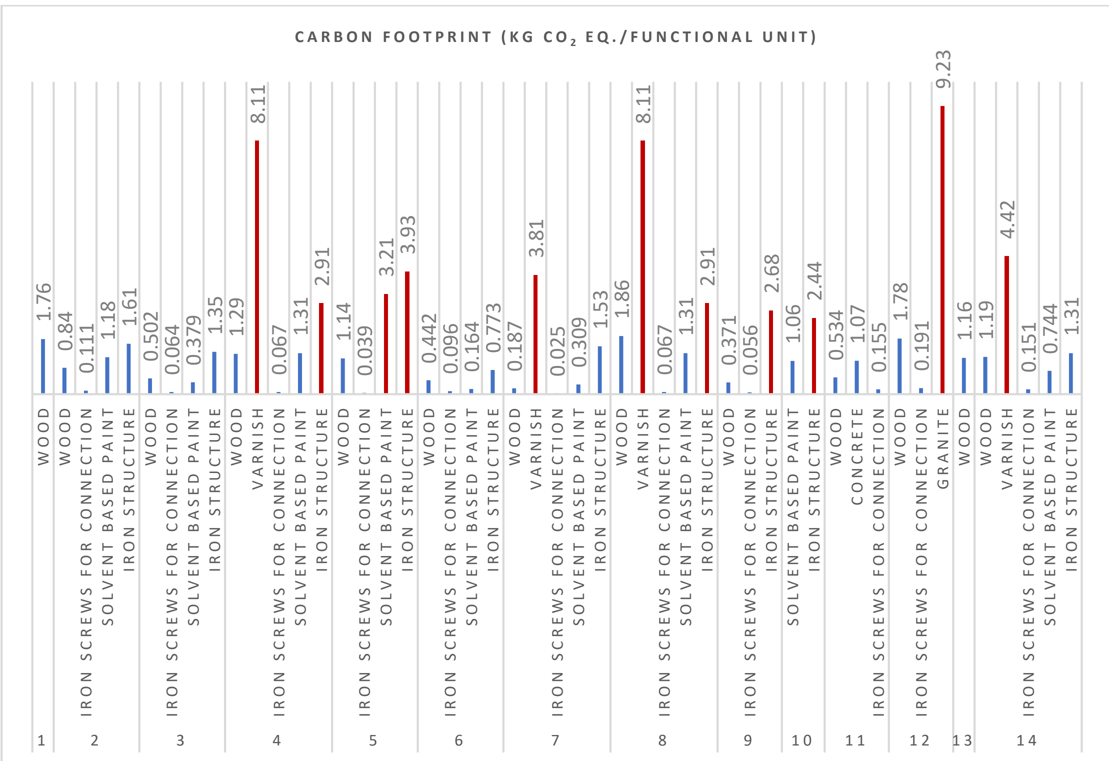


Figure 5. Materials and designs after first review (blue: low values, red: high values).

3.3. Second Round of Listing, Evaluating, and Implementing Alternative Materials and Evaluating the Carbon Footprints of Designs after the Second Round

Believed to serve no purpose other than extending the lifespan of seating elements and adding aesthetic value, solvent paint and varnish from the identified materials may be considered unnecessary. Moreover, products such as paint, varnish, and adhesives often negatively impact human health due to formaldehyde and its derivatives [66]. Therefore, these materials may not be used, as seen in designs No. 1, 9, 11, 12, and 13, where wood is utilized. Although the non-use of these materials may slightly shorten the lifespan, it can be estimated in accordance with ISO standards that opting for a method of replacing deteriorating parts over time would result in a lower carbon footprint. Additionally, it is possible to say that wood retains visual and aesthetic value in its natural color without the use of paint and varnish. Similarly, granite stone cladding has been used for aesthetic purposes in design No. 12. Hence, there is no objection to discontinuing the use of this material. Alternative materials for the use of structural iron in seating elements are presented in Table 7.

Table 7. Alternatives for iron structure.

Original	Alternative		
	Material	**Benefits**	**Issues**
Iron Structure	Wood	Low cost, renewable, no harmful, no hazard	Low durability
	Steel	Low cost, easy to care for	Low durability
	Hemp Concrete	Durable, low weight	High cost
	Bambu		
	Cow Bone	Durable	Difficult to process

After the examinations were conducted, it was concluded that the wood material can be used instead of an iron structure due to its lower cost and environmental characteristics [67]. The carbon footprint values of seating element designs created using wood instead of an iron structure, without the use of granite, varnish, and solvent paint, are provided in Table 8. In design number 10, the need for metal connection elements arises due to the change in the material. The carbon footprint values of the necessary connection elements have been calculated and added to the table.

Table 8. Carbon footprints after final review.

Design No	Material	Carbon Footprint (kg CO_2 eq./Functional Unit)	Total Carbon Footprint (kg CO_2 eq./Functional Unit)
1	Wood	1.76	1.95
	Iron screws for connection	0.19	
2	Wood	1.35	1.461
	Iron screws for connection	0.111	
3	Wood	0.738	0.802
	Iron screws for connection	0.064	
4	Wood	2.03	2.097
	Iron screws for connection	0.067	
5	Wood	1.276	1.315
	Iron screws for connection	0.039	
6	Wood	0.576	0.5672
	Iron screws for connection	0.096	
7	Wood	0.578	0.603
	Iron screws for connection	0.025	

Table 8. *Cont.*

Design No	Material	Carbon Footprint (kg CO_2 eq./Functional Unit)	Total Carbon Footprint (kg CO_2 eq./Functional Unit)
8	Wood	2.18	2.247
	Iron screws for connection	0.067	
9	Wood	0.436	0.492
	Iron screws for connection	0.056	
10	Wood	1.33	1.517
	Iron screws for connection	0.187	
11	Wood	1.601	1.756
	Iron screws for connection	0.155	
12	Wood	1.78	1.971
	Iron screws for connection	0.191	
13	Wood	1.16	1.255
	Iron screws for connection	0.095	
14	Wood	1.235	1.386
	Iron screws for connection	0.151	

3.4. Final Review of Designs with Alternative Materials

The carbon footprints of the existing designs range from 1.475 kg CO_2 eq./functional unit to 317 kg CO_2 eq./functional unit. With the material changes implemented, the carbon footprints of the seating unit designs vary between 0.492 CO_2 eq./functional unit and 2.539 CO_2 eq./functional unit. Despite eliminating practices such as varnish and paint that extend the material lifespan, the changes made are believed to be acceptable considering a carbon footprint change ranging from 60% (design 2) to 99% (design 1), even with a shortened lifespan.

Furthermore, as shown in Figure 6, reducing the carbon footprints of designs from the initial range of 1.76 CO_2 eq./functional unit to 15.257 CO_2 eq./functional unit after the first revision to the final range of 0.392 CO_2 eq./functional unit to 2.539 CO_2 eq./functional unit following the second application of eco-design principles highlights the significance of recycling as applied for the second time.

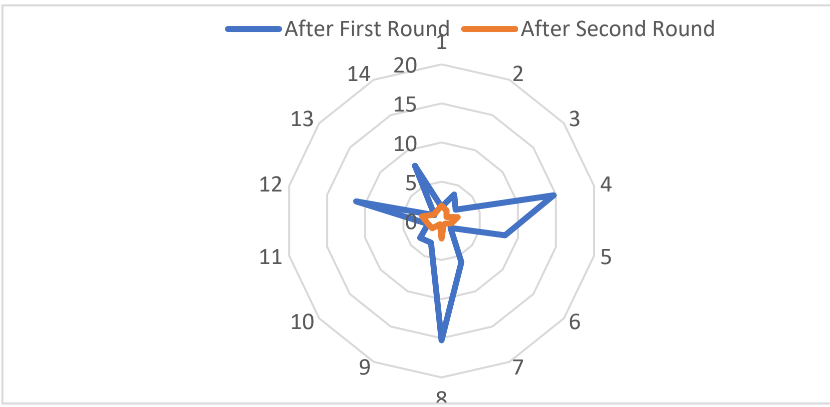


Figure 6. Carbon footprints of objects after first round revision and second round revision (1–20 CO_2 eq./functional unit).

3.5. Material Reduction Ideas and the Development of a New Model

Under the strategies of low-impact material and reductions in material use, wood was used as the main material and iron screws for connections in the model [68,69]. The ideas emerging for reducing the components used in the seating unit, within the scope of the reduction in material use strategy, are presented in Table 9.

Table 9. Component reduction ideas.

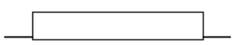
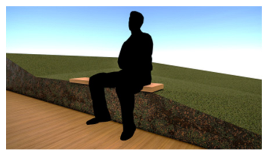
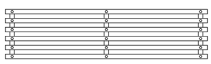
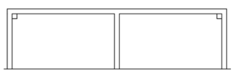
Reduced Component	Reducing Idea	Benefits	Issues
Backrest	Opening gaps on the backrest	Decrease in material usage and carbon emission	Decrease in comfort
	Removing the backrest	Decrease in material usage and carbon emission	Decrease in comfort
Legs	Using the legs with possible reduced dimensions	Decrease in material usage and carbon emission	Decrease in durability
	Placing the seating element on elevated terrain by eliminating the legs	Decrease in material usage and carbon emission	Decreased lifespan of the seating element

Based on the ideas presented in Table 9, it was decided to remove the backrest element due to its potential to affect comfort in all situations and the absence of backrests in some existing designs. Although removing the backrest may have an impact on comfort, it does not pose any inconvenience to the main action, which is the sitting action. Additionally, it has been deemed appropriate to remove the legs, as elevating the existing terrain and designing seating elements to sit directly on the terrain eliminate the need for maintenance and repair of the leg elements. Terrain elevation will be achieved solely by compacting the existing soil on the site and will not involve any additional materials or applications. On the other hand, it is believed that particularly in coastal areas, moist and alkaline soil significantly shortens the service life of the seating unit. Therefore, two versions of the model were designed: one with legs and one without legs, which sit directly on the ground.

3.6. New Design Models

As a result of material reduction ideas, two new design models have been developed. In the first design, no legs were used, but considering that the seating element of sitting directly on the ground could significantly reduce its lifespan, especially in humid areas where the soil contains moisture and alkalinity, a second design was developed (Table 10).

Table 10. New design models.

Design	Top (Plan) View	Front-Side View	Photograph
Model without legs			
Model with legs			

While the materials used in the developed models remain the same, in the second design, legs are added to elevate the seating element from the ground. Gaps are created in the seating part of the model with legs, as there is no direct contact with the ground or wall, whereas no gaps are opened in the seating section of the legless model. Both models were created as shown in Figure 7.

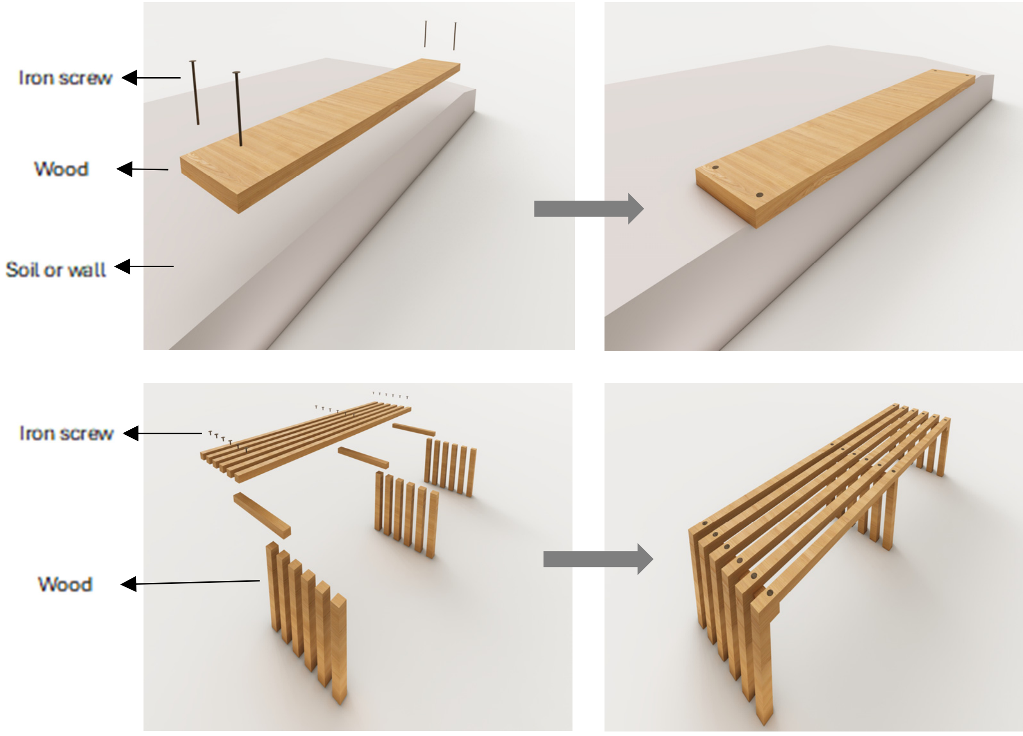


Figure 7. Schematic presentation of new solid model proposal.

In both designs, as a result of the material change ideas implemented in the project, solid wood and a minimum level of iron screws for connection were used. The naturalness of the wood has been preserved in designs without using materials such as solvent-based paint or varnish for protection or aesthetic purposes. Additionally, using entirely recycled materials such as the Wood–Plastic Composite (WPC) [70] produced from waste is also an alternative (Table 11).

Table 11. Carbon footprint of new design models.

Design	Material	Carbon Footprint (kg CO_2 eq./Functional Unit)	Total Carbon Footprint (kg CO_2 eq./Functional Unit)
Model without legs	Wood	0.284	0.474
	Iron screws for connection	0.19	
Model with legs	Wood	0.135	0.244
	Iron screws for connection	0.109	

The carbon footprint of the developed design model without legs was determined to be 0.474 kg CO_2 eq./functional unit. Additionally, the carbon footprint of the model with legs was determined in to be 0.244 kg CO_2 eq./functional unit. The carbon footprints of both models were examined based on the design configurations in Table 10 and the carbon footprint values of the materials in Table 11. The design model without legs could not be designed with a gapped structure due to its direct contact with the ground. Additionally, the material thickness increases to reduce heat transfer from the ground. Moreover, the dimensions and thicknesses of iron connection elements are larger, especially due to the need for stronger connections to the soil. Considering all these reasons, the carbon footprint of the design without legs is greater than that of the design model with legs.

Although there is a difference of 0.230 CO_2 eq./functional unit between the newly created models, it is observed that the carbon footprints of both designs are lower than those of the existing 14 designs and the designs obtained after round 1 and round 2 (Figure 8). However, the effectiveness of the eco-design applied to current designs becomes better understood when considering the smaller difference in carbon footprints between the newly created model and the carbon footprints of the 14 designs.

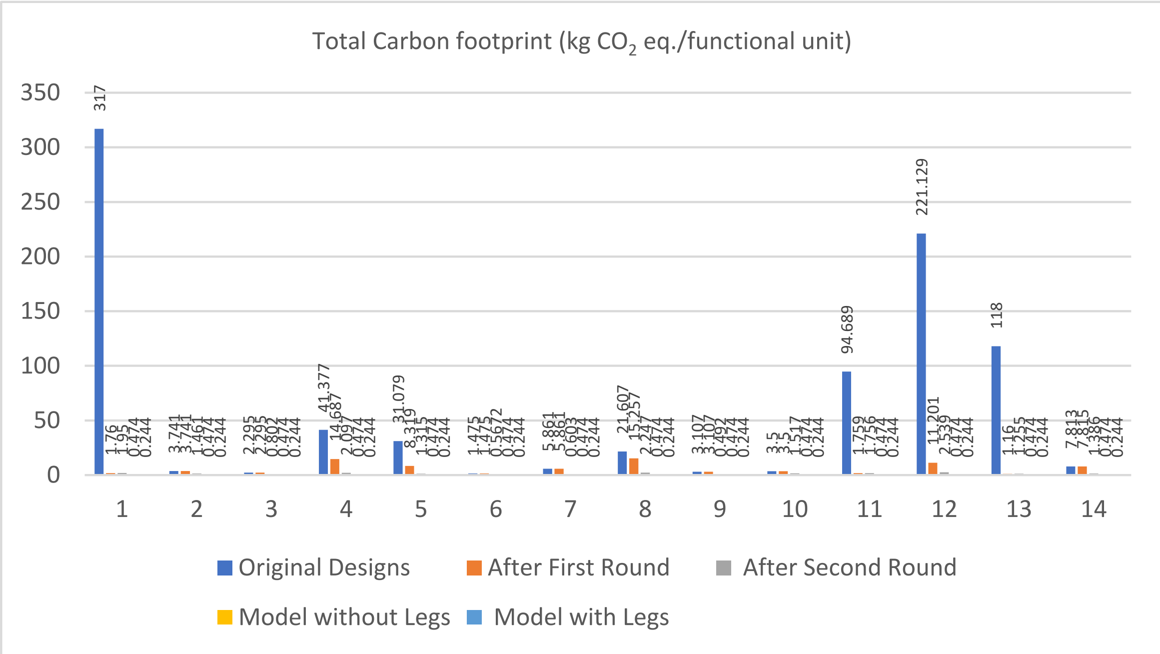


Figure 8. Carbon footprints of original designs after rounds and new design models.

Urban seating groups integrated with landscape areas can contribute to sustainability by reducing material usage. Similarly to the implementation in design 9, seating elements can be designed on existing walls. Additionally, in conjunction with landscaping, designing seating elements by elevating some areas of the seating distance above the ground, along with surfaces applied to the ground, is possible. Surfaces applied above ground may not prefer natural wood without varnish for durability.

Although design models without leg seating element designs provide an alternative for seating elements with low environmental impact, design models with legs seating elements are considered to be a better alternative due to their ability to be more easily applied to any surface and climate, the expectation of longer lifespan, and their lower environmental impact compared to that of the design model with legs.

By implementing such practices and similar ones, sustainability can be achieved for all urban furniture, particularly in the city of Rize and coastal areas, throughout their lifecycle.

4. Conclusions

This research conducted in Rize evaluates seating elements within the city. This paper discusses the possibility of making seating elements sustainable in humid areas, coastal zones, and urban areas by making and implementing certain design decisions. Within the scope of this study, life cycle assessment (LCA) analysis was performed to measure the carbon footprint of existing seating elements in Rize for the raw material phase. Based on the analyses, gradual material changes were proposed and implemented with feedback to reduce the carbon footprint of existing seating units in the city. The focus was on materials that needed transformation to lower the carbon footprint values of the current seating units in the city. The discussion also addressed how much the carbon footprint could be reduced with the transformation of materials.

Once the materials to be used for seating units with a low carbon footprint were identified, ideas for part reduction were developed for creating new design models. The formation of new design models was carried out by implementing these reduction ideas.

As a result, based on the presented solution proposals, emphasis was placed on how sustainable urban seating elements could be achieved.

As a result, it has been determined that the effective use of wood, a natural material, reduces the carbon footprint of sustainable urban seating elements. The findings suggesting the utilization of wood in urban furniture are corroborated by studies such as those conducted by Gabric et al. (2022) and Barcic et al. (2018) [71,72]. According to this study, it is necessary to avoid the use of materials such as concrete, polypropylene, granite, and iron structures as structural materials, as well as varnish and solvent paint as protective materials. In the first round, concrete and polypropylene materials were detected as a high-carbon-footprint material. Varnish, solvent paint, iron structure, and granite were determined to be high-carbon-footprint materials in the second round. Other studies have shown that reinforcements with concrete materials containing recycled aggregates are frequently used [73]. While concrete is commonly used in urban furniture due to its durability and resistance to adverse weather conditions, efforts have been made to enhance its environmental sustainability. These include the addition of coal ash to concrete for urban furniture use [74] and the development of cellular lightweight concrete designs for modular designs [75]. However, based on the findings obtained in this study, concrete can be considered a material to be avoided from an environmental sustainability perspective. Designs with restricted use of metal as connection elements will contribute to environmental sustainability. Restricting and eliminating unnecessary components in the seating elements used for urban furniture is essential. However, the design model without legs presents a suitable design example for implementation everywhere within urban areas, while in landscape design, it serves as a good alternative solution for evaluating elevation differences.

The sustainability of urban seating elements can be optimized based on various environmental conditions through strategies such as the use of eco-friendly materials and the reduction in material usage, as seen in both the design model without legs and the design model with legs. As stated in the study by Yasar (2023) [21], the sustainability of urban seating elements can be optimized for various environmental conditions through strategies such as the use of eco-friendly materials and the reduction in material usage. Additionally, reducing energy consumption for transportation and production, extending product lifespan to decrease the need for replacements, and designing end-of-life usability are all crucial strategies. Therefore, regardless of changes in climatic and geographical conditions, sustainable urban seating elements can be created by implementing these strategies.

However, within the scope of this study, an ecological approach has been taken primarily for the environmental impact dimension at the raw material stage for seating elements. Integration with the environment in the design of seating elements should not only be approached ecologically and for the raw material stage but also encompass all aspects of sustainability in the life cycle of designs, with universality being a forefront consideration. Additionally, the strength of moisture-prone materials, especially wood, in humid regions is a separate subject of investigation. In this sense, conducting studies based on moisture and climatic data, along with determining service life, will contribute to a clearer identification of the environmental impacts of seating elements.

In addition to environmental issues, universal design principles, which are components of sustainable design, are significant in the context of urban areas and urban designs and are used by the entire urban population without discrimination [76]. In this regard, it would be appropriate for future studies to address sustainability in all its dimensions for seating elements, incorporating not only the ecological aspects of environmental impact but also the design element for human usability. In this regard, as highlighted by Spangenberg (2013), this will greatly improve the quality and sustainability of urban spaces [77].

In addition to the scale considered within the scope of this study, other works in different scales addressing infrastructure and social deficiencies, unplanned settlements, parking and traffic issues, and deficiencies in pedestrian and bicycle paths are among the obstacles that could hinder urban sustainability [78]. Because cities have a complex structure as a result of their development [79], all of these components need to be made sustainable for the sustainability of the city.

Furthermore, sharing the findings of studies with urban stakeholders regardless of scale is of utmost importance. To achieve urban sustainability, it is necessary to develop local, national, and international policies that foster stakeholder collaboration to increase public awareness. Environmental standards and regulations hold a significant place in the policies to be developed within this scope. These standards should be prepared to encompass the entire life cycle of materials, from raw material extraction to recycling processes. Assessments should be made considering the environmental impact at the level of seating units, and sustainable products should be promoted when users and stakeholders are educated on this matter. Municipalities should engage in collaborative efforts with public and private institutions to increase awareness about sustainability through practical initiatives.

Environmental issues represent one of the greatest threats facing humanity, and tackling them requires comprehensive efforts at all scales, particularly focusing on urban sustainability. Success in addressing environmental problems can only be achieved through thorough work across all scales in cities. Therefore, starting from the equipment scale and extending to the city scale, a collaborative effort involving not only authorities or designers but also all stakeholders in the city is essential. Through such a collective effort, a sustainable environment can be provided for future generations.

Author Contributions: Conceptualization, S.S. and M.S.; methodology, S.S. and M.S.; software, S.S. and M.S.; validation, S.S. and M.S.; formal analysis, S.S. and M.S.; investigation, S.S. and M.S.; resources, S.S. and M.S.; data curation, S.S. and M.S.; writing—original draft preparation, S.S. and M.S.; writing—review and editing, S.S. and M.S.; visualization, S.S. and M.S.; supervision, S.S. and M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

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