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MODEL PROPOSAL FOR A PORTABLE ROOFTOP GREENHOUSE: IMPROVING MIDDLE SCHOOL STUDENTS' ENVIRONMENTAL CONSCIOUSNESS AND ATTITUDES

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Abstract. Environmental education is crucial for building a sustainable society; however, students in metropolitan areas often lack spaces for active learning and experiencing the environment directly. To solve this problem, this study explores the use of portable rooftop greenhouses (RTGs) in environmental education, utilizing the open-source Wikihouse system. The hypothesis suggests that these RTGs will actively engage students and enhance their environmental awareness. According to findings, students in the experimental group showed significantly higher levels of environmental awareness, attitude and thinking compared to those in the control group. These findings indicate how portable greenhouses can be used as creative tools for delivering engaging and innovative types of environmental education. Future implementations of this project at various schools and across scales will help assess its long-term effects on students' ecological consciousness and attitudes.

Keywords: *Rooftop greenhouse, temporary structure, environmental education, urban agriculture, Wikihouse.*

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1. Introduction

Environmental challenges pose an ever-increasing threat to all humans, living things and the natural order (Alagoz & Akman, 2016). To ensure a safe and healthy environment for future generations, it is necessary to raise environmentally conscious individuals (Şahin *et al*., 2004; Akınoğlu & Sarı, 2009).

Environmental education (EE) plays a crucial role in raising environmental consciousness and awareness (Bozkurt, 2015, Derman & Senemoğlu, 2015). Its primarily aims are to assess environmental concerns, identify solutions to problems and develop sustainable habits (Magnas *et al*., 1997; Kıyıcı, 2009). According to Yalçınkaya and Çetin (2018), EE provides the perfect foundation for developing new lifestyles that are more in accordance with the environment. Through EE, individuals may get to re-assess their place in the world, adapt their way of living towards better co-existence with the nature and acquire relevant competences for a healthier future (Bozkurt, 2015).

UNESCO defined EE as: "A learning process that increases people's knowledge

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and awareness about the environment and associated challenges, develops the necessary skills and expertise to address the challenges and fosters attitudes, motivations and commitments to make informed decisions and take responsible action" (Karama, 2016). As McKeown (2000) states, each country should develop its own sustainability principles and decide on its priorities for managing EE issues based on specific conditions.

Artun and Özsevgeç (2015) argue that theoretical instructions about EE are given in subjects such as the social studies, science and life sciences in Turkish middle schools. However, according to Şimşekli (2001), Uzun et al. (2008) and Tanrıverdi (2009), students struggle to achieve desired outcomes in EE due to lack of a specific curriculum, limited activities and a rote approach rather than experiential methods. For these reasons, it is vital to include more environmental activities in student instruction (Hungerford & Volk, 1990). Additionally, Jensen and Schnack (1997) highlighted that direct action leads to experiential benefits. Thus, EE should use a variety of activities that prioritizes student engagement and participation to help students reach their goals (Ünal & Dımışkı 1999; Artun, 2013).

Despite the importance-of environmentally friendly activities for young individuals, organizing them in metropolitan areas faces serious problems, especially with regards to space availability and access. Due to the high costs of land, there are limited safe and accessible areas for EE, as can be seen in Figure 1 (Tunbiş, 1987). Based on the Spatial Analysis Report (2022), which includes accessibility criteria, the target value of the open and green area per person was determined as 15 m^2 and 9 m^2 was accepted as the minimum value of the World Health Organization. However, according to the same report, 26% of open and green areas provide 1 to 5 m^2 per person and 16% provide only 0.5 to 1 m^2 per person. Additionally, the difficult accessibility of these spaces hinders the provision of EE.

Furthermore, school gardens, which are able to serve as suitable areas for teaching environmental consciousness, fail to meet even basic playground requirements. It has been observed that middle schools on the European side of Istanbul provide 2.46 m^2 of garden space per student. When compared to the standard of 5 m^2 per student set by the Turkish Standards Institute for school gardens, it is evident that the school garden areas in Istanbul are insufficient to support the physical, mental, pedagogical and social development of students (Karaburun *et al*., 2015).

Figure 1. Satellite image of Istanbul and Güngören District (with red border)

Our examination of the school buildings in this study has revealed that many have terraced roofs, which carry the potential to be transformed into covered appropriate areas.

School buildings are typically large structures with reliable service infrastructure and are made of sturdy materials with suitable load-bearing profiles. These rooftops are often left empty and regarded merely as residual areas (Nadal *et al*., 2018; Jans-Singh *et al*., 2019). Rooftop greenhouses (RTGs), therefore, help optimize such unused spaces and offer the chance to apply EE as efficiently as possible in areas with high residential density (Nadal *et al*., 2017a). Safe spaces like RTGs are community-centered and act as showcases for EE and schools can utilize these RTGs as green classrooms (Freisinger *et al*., 2015; Thomaier *et al*., 2015; Jans-Singh *et al*., 2019).

Schools have socio-educational components that affect not only the students but also their families and communities; thus, RTGs can serve as a medium that strengthens understanding of sustainable urban living, agriculture and a nutritious diet (Freisinger *et al*., 2015; Nadal *et al*., 2018). Besides, according to Al-Otaibi et al. (2015), schools in the Mediterranean climate are highly suitable for RTGs with their large flat roofs and central locations: this is because RTGs provide the best possible conditions for plant growth by regulating light, humidity and temperature conditions, so RTGs have the potential to increase local food production even enhance food security. Additionally, RTGs help reduce food transportation, the use of fossil fuels, water consumption along with energy demands and CO_2 emissions (Orsini *et al*., 2014; Freisinger *et al*., 2015; Sanyé-Mengual *et al*., 2015b; Specht *et al*., 2014).

Based on these insights, this study focuses on the implementation of portable greenhouses in EE at middle schools in metropolises, thus addressing a notable gap in existing research. Most previous studies seem to focus predominantly on efforts to improve environmental consciousness through conventional greenhouse constructions (Orsini *et al*., 2014; Freisinger *et al*., 2015; Sanyé-Mengual *et al*., 2015b; Nadal *et al*., 2017a; Sanyé-Mengual *et al*., 2017; Nadal *et al*., 2018; Jans-Singh *et al*., 2019; Zambrano-Prado *et al*., 2021; Drottberger, 2023).

In addition to these scientific pursuits, the RTGs created for educational reasons also conduct a range of educational activities. At Universitat Autonòma de Barcelona, Fertilecity (2024) provides four distinct programs on top of the ICTA-ICP building. Founded by FamilyCentre-FEZ in Berlin, Eco Island provides 14 different programs under the theme “Learning in GreenClass” to students ranging in age from first to tenth grade (FEZ, 2024). Manhattan School for Children (2024) is a private school in New York that educates pupils up to the eighth grade. By the integration of science and the environment through sustainable urban agriculture, the RTG curriculum in this school allows children to develop new questions, examine systems, make predictions and come up with innovative solutions. Amman National School (2024) in Jordan calls RTG a “hidden jewel” and integrates its activities within the curriculum. Bologna's Sustainable Accessible Livable Usable Social Space (SALUS, 2024) aims to be a model space where people of all ages may participate in a variety of environmental activities and test out different technologies. These examples support the idea that practical, modular learning spaces, like the RTG model, can successfully bridge educational gaps in urban settings with little green space.

By using the portable greenhouse as an appropriate model, this study offers a more flexible and widely applicable substitute. Contrary to conventional greenhouses, the portable RTG model allows for flexibility in limited spaces and mobility, making it particularly suitable for crowded metropolitan settings with regulatory constraints. Therefore, this model has unique potential to transform urban middle schools into hubs of ecological learning. The model's portability also makes it possible to expand its impact by moving and relocating the greenhouse to a different school following the original event, which allows numerous schools to participate in EE programs.

According to Kronenburg (2008), portable structures offer the greatest flexibility for adjusting to different layouts and circumstances because their modular components are designed to be easily assembled on a location far from where they were manufactured. In alignment with this, a portable greenhouse model has been developed by using the open-source Wikihouse building system (Figure 2). This approach provides urban middle schools with a more inclusive, flexible, quickly installable and affordable solution through a single production process.

Figure 2. Exploded view of the portable RTG model

The study hypothesizes that the utilization of the portable RTG program will significantly enhance the environmental awareness, attitudes and cognitive capacities of middle school students. There is interdependence among the three levels of cognition. They mutually impact, affect and reinforce each other through active participation (Uzun & Sağlam, 2006). Environmental awareness is the cognitive level required to understand the scope of environmental problems, provide logical solutions and influence individuals' attitudes toward the environment positively (Durgeç & Demirel, 2023). Environmental thinking is the combination of scientific systems thinking in the natural sciences with associated practical actions targeted at the sustainable development of the human living environment (Gilmanshina *et al*., 2018). Environmental behavior refers to the actions exhibited by individuals with the aim of contributing to environmental sustainability (Mesmer-Magnus *et al*., 2013). Students must participate in environmental activities and embrace a methodical active approach centered on education and play in order for these three dimensions to develop as suggested by the model (Gilmanshina *et al*., 2018). In other words, physical spaces such as RTGs promote experiential learning, which is more efficacious for EE compared to conventional classroom instruction. An increasing number of research studies highlights the educational benefits of physical spaces where students can directly participate in the EE process (Jensen & Schnack, 1997). RTGs, in this context, can help students in metropoles solidify abstract knowledge by providing them with the opportunity to interact closely with nature.

This innovative approach offers a new way to increase the effectiveness of EE. The outcomes demonstrate the high efficacy of portable RTGs in enhancing students' environmental awareness, besides revealing important insights for more effective implementation and approaches in cities. These findings carry significant implications for both theoretical and practical implementations in EE.

By filling a critical gap in the literature, this study does not only support the use of portable RTG in EE but will also help achieve several Sustainable Development Goals (SDGs), especially SDG 4 (quality education), SDG 2 (zero hunger), SDG 3 (good health and well-being) and SDG 11 (sustainable cities and communities).

This study focuses on the implementation of a portable RTG model at a middle school in the Güngören district of Istanbul, an area characterized by high population density and limited green space. The sample size consisted of 40 students (22 in the experimental group and 18 in the control group), drawn from two 7th-grade classrooms. While the findings demonstrate significant improvements in students' environmental awareness, attitudes and thinking, the study is limited by its short duration of six months, dictated by local permissions and its focus on a single school. Future research should explore the long-term effects and scalability of portable RTG usage across different schools and environments.

1.1. Review of criterion for RTG integration

Based on the literature, criteria for the successful integration of RTGs in the building and design proposal have been outlined in the following four sections.

Spatial criteria: The stability and accessibility of roofs must be guaranteed. Firstly, the roof's structure and material composition must be resilient enough to accommodate the new installations and to support the greenhouse's weight needs. The total weight per square meter of a standard RTG is between 145 and 165 kg (Sanyé-Mengual *et al.*, 2015b). Because of this, the flat roof must have a minimum load capacity of 200 kg/m^2 in order to give tolerance for miscalculation (Nadal *et al.*, 2017b). In Türkiye, flat roofs of school buildings must be designed with standby weights of 200 kg/m^2 in accordance with the Turkish Standard for Design Loads for Buildings (TS 498) and must have sufficient stability for RTGs. Roof structures of educational buildings in Türkiye are mostly built with reinforced concrete, which allows for easy integration of such RTG models (Al-Otaibi *et al.*, 2015; Jans-Singh *et al.*, 2019).

Another major concern is roof accessibility and roof slope, which needs to be less than ten percent (Nadal *et al.*, 2017b; Zambrano-Prado *et al.*, 2021). According to the Regulation on Fire Protection in Türkiye, one of the main staircases of a schools must lead to the roof and have a width of at least 100 cm (2020).

Agricultural criteria: Planning according to the amount of shadow that will fall on the roof is crucial because RTG must be free of shadows. More specifically, for crops to be grown successfully, the roof needs to receive a minimum of 1900-2000 MJ/m^2 of solar radiation annually (Nadal *et al.*, 2017b). For Solar Radiation Data in Istanbul, the annual average value of daily total radiation is 15,048 MJ/m^2 in Istanbul (Ekmekçi & Şen, 2016).

Plants grow most actively in temperatures between 13°C and 30°C, with the exact temperature depending on the type of plant. Interior heat in the greenhouse must be maintained within this range to support plant growth (Freisinger *et al.*, 2015; Nadal *et al.*, 2017b). We considered Istanbul's particular climate features, such as its warm, temperate temperature with hot, dry summers and mild, rainy winters, when creating the RTG and choosing the crops. To maximize the RTG's local impact and relevance, we focused on crops that thrive in these conditions, such as tomatoes, peppers, cucumbers and leafy greens like lettuce, parsley and arugula. These crops are not only well-suited to the available sunlight and temperature range but are also popular in Turkish agriculture and cuisine, thus the project is in line with local agricultural traditions.

Legitimacy criteria: Main concerns for getting permission from legal authority are building height limits (Cerón-Palma *et al*., 2012; Sanyé-Mengual *et al*., 2015b; Zambrano-Prado *et al*., 2021) and regulations for the maximum usage area of the buildings. The height of building cores determines the maximum height for buildings. Consequently, the design needs to account for the building core's height. According to Planned Areas Zoning Regulation in Türkiye (2017), greenhouses are regarded as temporary buildings if they are portable; hence RTGs can be installed on roofs with a limited certificate from local governments for up to 10 years.

Economic criterion: In context of the socio-educational approach, 50 m^2 of RTG space has been identified as the minimal allowable dimension for the successful development of an educational and nutritional school project, since the sole goal for such models is self-sufficiency (Sanyé-Mengual *et al*., 2015b; Nadal *et al*., 2018). Even though the current study was unable to use these parameters because of financial reasons, the prototype has the inherent ability to grow thanks to its modular structure. For a truly commercial approach, a minimum area of 500 m^2 would be required because surplus produce could then be sold to help offset the construction's initial expenditure (Sanyé-Mengual *et al*., 2015b). However, in this study, since the supporters are funding the development and installation of the prototype, only potential costs for the continuation of agricultural products and of the RTG maintenance need to be guaranteed.

On the other hand, the greenhouse model's economic criterion highlights its contribution to achieving educational goals in addition to self-sufficiency. Students may engage in the complete cycle of plant care, growth and harvest, as over 70% of the crops grown in the RTG are designated for practical teaching purposes. The remaining 30% is allocated for minor economic activities, such as selling products within the school community. This setup provides students with the opportunity to gain hands-on experience in sustainable agriculture and a fundamental understanding of economic concepts like resource management, production and value. As a result, the RTG serves as a model for sustainable economic activities in urban settings as well as an educational tool.

2. Materials and methods

This study aims to explore the potential of a portable RTG model as a tool for enhancing environmental consciousness, attitudes and thinking skills among urban middle school students. This research adopts an inclusive and participatory approach to develop a portable RTG model for EE activities that utilizes the potential of idle surfaces of terrace roofs. By integrating hands-on EE with sustainable agricultural practices, this project addresses the challenge of scarce green spaces in metropolitan schools. In terms of content, the subject covers EE, temporary structures, urban agriculture and RTGs.

In order to establish the theoretical framework of the study, a national and international literature review was conducted, including sub-topics such as successful educational models that forge relationships between nature, agriculture and urban areas and lightweight structural proposals allowing for flexible space design. According to the information, the research seeks to answer the question: "What are the effects of portable rooftop greenhouses on middle school students' environmental consciousness and attitudes?"

The current research follows a quasi-experimental design, including a pretest–posttest control group model. The present study employs a quasi-experimental approach utilizing a pretest-posttest control group model. The quasi-experimental approach was selected to facilitate the comparison of environmental awareness and attitudes between an experimental group interacting with the RTG and a control group utilizing conventional teaching methods. This design was the most practical for a real-school environment where classroom composition cannot be readily modified. The quasi-experimental approach facilitates direct comparison in a controlled setting, effectively isolating the influence of the greenhouse experience on student learning outcomes.

There are two groups in this model, one experimental group and one control group. The groups were formed through unbiased assignment measurements that were conducted before and after the experimental study. In the experimental group, outdoor-based activities compatible with the Turkish science curriculum (Table 3) were implemented. On the other hand, in the control group, related topics were taught by the teacher using traditional methods specified in the Turkish science curriculum.

2.1. Participant School

The pilot school selected for the study is Tozkoparan Middle School (41° 1' 1.1742 N, 28° 53' 40.0302 E) located in Güngören, which has the highest population density (41,348 people/km^2) according to data from the Turkish Statistical Institute (2023).

Table 1. Average weather values of Güngören since 1980 (Weather Spark, 2024)

Average Values	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature	6°C	6°C	8°C	12°C	17°C	22°C	24°C	24°C	21°C	16°C	12°C	8°C
Wind Speed	19.0 kph	19.4 kph	18.1 kph	15.6 kph	14.5 kph	14.8 kph	17.8 kph	19.3 kph	17.8 kph	18.1 kph	18.1 kph	19.0 kph
Daylight Duration	9.6 h	10.6 h	12.0 h	13.3 h	14.5 h	15.1 h	14.8 h	13.8 h	12.4 h	11.1 h	9.9 h	9.3 h
Rainfall	56.9 mm	48.2 mm	44.1 mm	38.8 mm	26.8 mm	23.9 mm	14.4 mm	17.7 mm	33.2 mm	54.7 mm	66.4 mm	72.4 mm
Sun Radition	6480 MJ	9720 MJ	14400 MJ	19800 MJ	24480 MJ	27360 MJ	27720 MJ	24480 MJ	18720 MJ	12240 MJ	7920 MJ	5760 MJ

Tozkoparan Middle School (Figure 3), which is a state school, consists of a four-story rectangular prism building with an 8,636 m^2 construction area. The school includes a total of 33 classrooms, 613 enrolled students and 35 teachers. The school building, finished in 2014, is one of 44 schools rebuilt under the Istanbul Project to Reduce Seismic Risk and Increase Emergency Preparedness (ISMEP), which was launched in 2010.

Figure 3. Güngören Tozkoparan Middle School (photo taken by authors)

As with all schools involved in the project, this school was designed with a flat roof and oversized roof structures, therefore it has reinforced concrete slabs that can easily withstand the minimum loads for the installation of an RTG. The roof is only sloped 4% for water drainage; thus, it fulfills the requirements of RTGs. Although the roof space has different functions, it has a continuous piece of unshaded idle space of 1,095 m^2 right next to the staircase. In addition, the stairs are 130 cm wide with handrails on both sides and do not cause difficulties in transporting materials or students to the roof. Therefore, this school meets the criteria of a greenhouse in terms of its features.

2.2. Tools and Materials

The goal of "portability" in this study led to the development of a structure that is lightweight, durable and simple to assemble and disassemble. The Wikihouse system, an open-source and modular building system, was chosen for these exact characteristics (Romero *et al*., 2023; Esenarro, 2024). The Wikihouse system was selected due to its modularity, durability and ease of installation in order to create a lightweight, portable and reusable greenhouse structure. Moreover, the Wikihouse offers flexibility in scaling and adapting to various environments. Its compatibility with CNC-cut plywood components made it ideal for rapid prototyping on a limited budget, allowing for reassembly and relocation as needed.

This study represents the first use of the Wikihouse system in a greenhouse function, as indicated by the projects listed on the Wikihouse Website (2024). For this purpose, the Design Support Model has been created in Grasshopper, which is a visual programming language provided by Rhinoceros 3D software. The model accelerated processes during the preliminary design stage, especially in terms of considering the limits and advantages of the Wikihouse building system. In addition, this model was able to increase applicability of the prototype to other schools.

A portable RTG with a total area of 24.6 m^2 was installed on the pilot school's roof. This RTG offered pupils an appropriate setting for activities to learn EE within the framework of an eco-gardening project (Sauvé, 1996).

2.3. Participants

A total of 40 students (22 in the experimental group, 18 in the control group) from Istanbul Güngören Tozkoparan Middle School participated in this study (Table 2). The sample group consisted of students attending two different 7th-grade classes. One of these classes was randomly designated as the control group, while the other was assigned as the experimental group. Both groups were taught by the same science teacher, who was in a complete guiding position throughout the activity.

Table 2. Demographic information about participant students

		Control Gr.	Experimental Gr.			Control Gr.	Experimental Gr.
Gender	Female	8	11	Age	12 years old	0	1
	Male	10	11		13 years old	18	21

2.4. EE Procedure

Class-age and activity durations in applied education were decided upon with adherence to the Ministry of National Education of the Republic of Türkiye's Science Course Curriculum, as well as in consideration of 7th-grade course load and the physical, cognitive and social levels of the students. The activities were prepared in a modular manner and in accordance with the 'green classroom concept', which allows students to directly observe nature and explore by using as many different senses as possible (Uzun *et al*., 2008; Artun, 2013; Artun & Özsevgeç, 2015). The class activities occurred between 25 April and 12 June 2023.

As shown in Table 3, the weekly activities designed for the experimental group provide hands-on learning experiences that align with the Turkish science curriculum. In the experimental group, in addition to the theoretical knowledge on topics such as growth and development processes in plants, factors affecting seed germination, dependent, independent and controlled variables, basic factors affecting growth and development in plants and plant care and development processes, students were given the opportunity to engage in practical activities throughout the class prototype, as developed by the research team.

Table 3. Activities applied in the experimental group

	Activity
1st Week / 2 hours	Soil preparation, preparation of vegetable beds, pots and different soil mixtures (peat soil, peat soil with added clay pellets, peat soil with added agricultural perlite, peat soil with added vermiculite), planting seedlings (tomatoes, cucumbers, peppers, strawberries according to planting season) and seeds (parsley, lettuce, arugula, watercress, purslane, spinach, basil according to season)
2nd Week / 2 hours	Compost preparation with household waste household waste such as vegetable and fruit scraps, eggshells and sawdust
3rd Week / 2 hours	Observation, care and fertilization with liquid worm compost of seedlings grown in different pots and different types of soil in the same area under the same temperature, light and humidity conditions
4th Week / 2 hours	Explanation of rainwater systems, water-saving methods and natural balance, harvesting rainwater if it rains
5th Week / 2 hours	Seedling care and art project with waste materials
6th Week / 2 hours	Harvesting, cleaning and examining the smells, flavors and distinctive characteristics of harvested products

In the control group, topics such as growth and development processes in plants, dependent, independent and controlled variables related to seed germination, basic factors affecting growth and development in plants and plant care and development processes were taught using traditional teaching methods. The teacher provided knowledge on these issues through direct instruction. The teacher presented academic knowledge regarding environmental issues during the class.

For the planting activities, crops selected like tomatoes, cucumbers, peppers, parsley, lettuce and arugula, are compatible with Istanbul's climate and the seasonal conditions. These crops were chosen not only for their resilience in the local climate but also for their cultural relevance, making the RTG a practical and meaningful learning environment for students in Istanbul.

2.5. Collecting Data

Every step of the prototype's production, installation, user experience and disassembly processes was documented using photos and videos (Figure 4). The proposal's portability, disassembly capacity, durability and maintenance of system components, thermal and acoustic comfort conditions were evaluated and suitability for agricultural production and student ergonomics were observed. Furthermore, surveys and interviews were conducted.

Figure 4. Video recording of EE events

Data for environmental impact were collected by applying the “Sustainable Environmental Consciousness Survey” developed by Derman and Senemoğlu (2016) and the “Environmental Attitude Scale” consisting of environmental thought and attitude sub-dimensions developed by Uzun and Sağlam (2006) as pre-tests and post-tests. These measures were chosen because of their proven validity and reliability in evaluating students' attitudes and environmental awareness. In literature, several methods can be used for determining content validity (Oluwatayo, 2012). Getting expert opinions and statistical methods are two of the most frequently applied methods. In the current study, the researchers asked the experts (i.e. scale’s developer) to assess each expression in the measuring instrument in terms of the content and appropriateness of the scale for middle school students (Rubio *et al*., 2003). In addition, as statistical methods, the “Sustainable Environmental Consciousness Survey” consists of 10 sample situations, each with 3 options and the Cronbach's Alpha coherence of the scale is 0.87. The “Environmental Attitude Scale” contains environmental thought and attitude sub-dimensions, includes 27 items and is in the Likert scale format with 5 points. The Cronbach's Alpha value of the scale was found to be 0.80.

After participating in the EE program, the students of the experimental group were subjected to “Roof Greenhouse User Experience Survey Questions”, which were presented in two stages. In the first stage, eleven open-ended factual questions were asked about the participants' user experiences. The aim was to identify issues related to the prototype but also to generate different ideas for solutions and to further enhance the model’s potential. In the second stage, the aim was to learn about the participants’ attitudes, thoughts and feelings about the model. For this purpose, evaluations were created from opposing pairs according to the Osgood Semantic Differential Scale (Osgood *et al*., 1975), divided into seven equal parts. 14 sets of adjective pairs were organized based on the set of semantic scales of Hershberger (1972) and were used to measure the meaning of the designed environment and Imamoğlu's

"Spaciousness Crampedness Scale" (1986).

The study was conducted in accordance with strict data protection guidelines to ensure the confidentiality and privacy of every participant. All personal data was anonymized and stored in password-protected, secure systems that only the research team could access. Additionally, all participants and their parents completed an informed consent form outlining the goals of the study and guaranteeing the privacy of their answers. Complete participant privacy protection was ensured since no personal information was disclosed in reports, publications or presentations.

2.6. Analyzing Data

In data analysis, the SPSS program was used for measuring the effect of EE on students' awareness, attitude and thinking levels. Since the data were normally distributed, independent sample t-tests were applied to compare the pre-test and post-test results. A number of assumptions that need to be met before performing an independent sample t-test. These assumptions were tested. For example, by using Levene's test for homogeneity of variances in the statistics package, the assumption of homogeneity of variances was met. This means that comparison groups had the same variance (Table 7). Although the target audience was designed to be the group of 7th-grade student participants, it was expected that the teachers and parents would also somehow be become involved in the testing process, but it was not possible to accurately determine the extent of such a chain effect.

2.7. Ethical Approvals and Other Permissions

The relevant program and data collection tools applied to the participating students were shared with the Yildiz Technical University Social and Human Sciences Research Ethics Committee before application. Approval was obtained as a result of the meeting held on September 16, 2021, where no unethical findings were encountered in the information regarding data collection tools and methods.

With this approval, an application was made to the Ministry of National Education Research, Competition and Social Activities (ayse.meb.gov.tr) portal. The EE stage was initiated with the written permission given by the Istanbul Provincial Directorate of National Education on March 7, 2023 for a period of six months. This permit includes carrying out activities, collecting observations, taking video and audio recordings, conducting interviews and surveys. It was not allowed, however, to publish videos or photos of the students and co-teachers. Besides, before the study, written approval was obtained from all participants and their parents.

In addition, the digital production and application projects of the prototype were shared with the Urban Planning and Construction Directorate of Güngören Municipality and a non-objection certificate was obtained on March 10, 2022.

3. Proposal for a portable RTG

The portable RTG type provides an innovative answer to the problems of urban EE and sustainable agriculture. In densely populated areas with little green space, a portable RTG offers students instant access to experiential EE, improving their ecological awareness and practical skills. Furthermore, by utilizing otherwise underutilized rooftop spaces, it promotes urban gardening, strengthening sustainable food systems. This concept outlines the RTG's design and construction process, emphasizing its adaptability and ability to serve as an easily accessible educational tool in various urban school settings.

The preferred building system that Wikihouse proposes is a production model that consists of three main steps: design and planning, manufacture and installation. The first step is the digital production of the proposal. The second step involves using a Computer Numerical Control (CNC) Router to precisely cut 18 mm thick plywood into the structural components of the model. In the third step, the assembly of the transported parts is finished with simple hand tools. A fourth step has been added to include dismantling and reinstallation in these stages.

3.1. Design and Planning Phase

The Design Support Model was developed and used in the preliminary design stages of the prototype. By simply entering the required side lengths and back height of the RTG, the end user can determine the agricultural and circulation areas and the internal volume. In addition, the model can calculate the number of modules, amount of required materials, their cost and their weight, which were critical in guiding design decisions. The model projected the total weight per module at roughly 112 kg/m^2, leading us to use lightweight plywood to maintain the structure's compliance with the roof's load-bearing capacity. The cost calculations also influenced material choices, as we opted for modular, CNC-cut plywood components to maintain affordability without compromising durability. Figures 5 and 6 show the algorithm structure of the Design Support Model and the parameters calculated for the prototype.

Furthermore, architectural identity and building surveys of the pilot school were prepared. Analysis of the existing infrastructure, electrical systems, plumbing, roof condition and structural system of the building was carried out. Additionally, important factors such as light, seasonal shading projections and rainwater harvesting capacity were calculated.

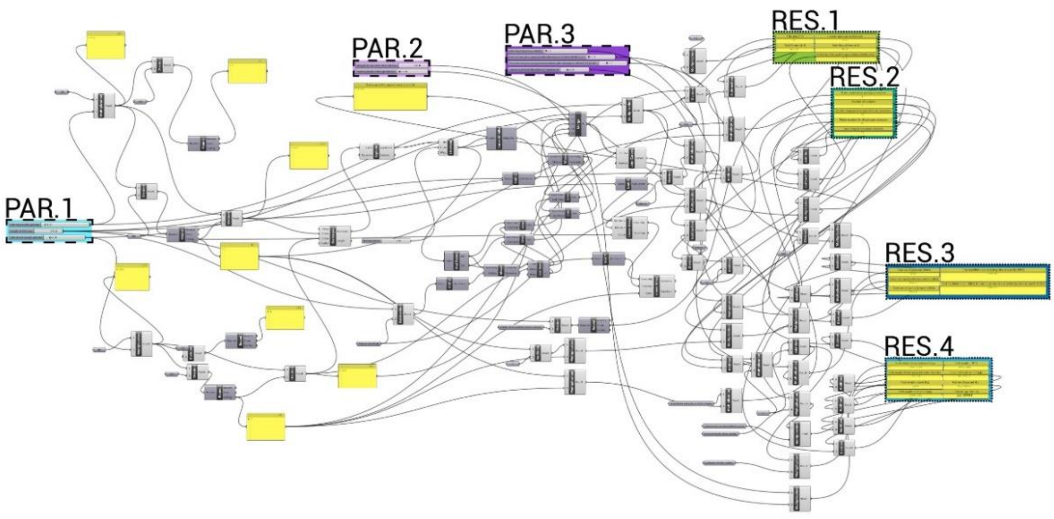

Figure 5. Algorithm diagram of the Design Support Model

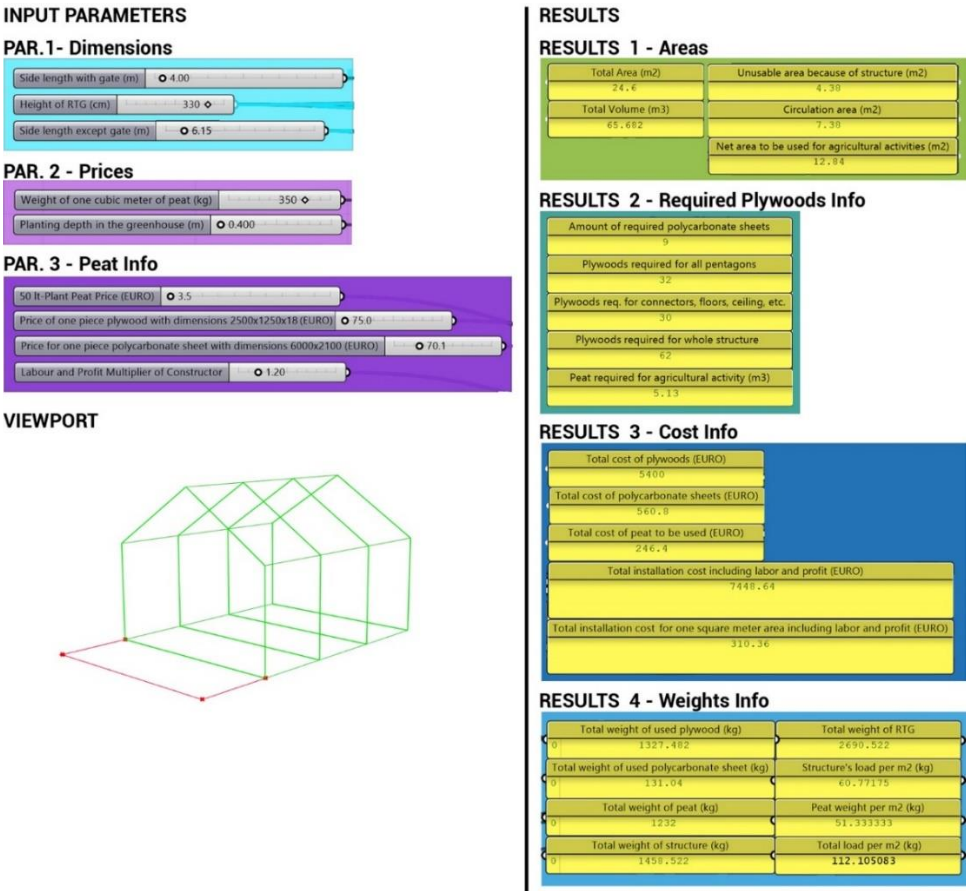

Figure 6. Parameters and calculated results in the Design Support Model for the prototype

To refine the greenhouse's positioning and ensure optimal sunlight exposure, Trimble SketchUp was used to create a precise 3D model of the roof and a solar shading analysis was carried out. By inputting the precise latitude and longitude of the location, seasonal light trajectories and shadows were simulated. This allowed us to position the RTG to minimize any shadowing, thereby maximizing the amount of light available for the crops all year long.

Rainwater harvesting calculations based on local precipitation data from monthly average rainfall records in Güngören. The pilot school has two separate terrace roofs at two different altitudes.We assessed the potential water collection from downspouts on the highest roof surface situated above the RTG. We put two filtered containers at these downspouts to collect and store rainwater for use in irrigation. We collected the water entering the RTG roof using buckets strategically placed throughout the structure. This setup enables efficient water reuse, reducing the need for external water sources and improving the RTG's sustainability.

Before moving on to the physical application of the design, various scale models were created by following the production stages. This allowed for testing of the manufacturing process to identify potential weaknesses, which led to improvement and optimization work on the digital model.

3.1.1. Sustainability Considerations in the Portable RTG

The design and materials used for the portable RTG were chosen with sustainability in mind, aiming to reduce environmental impact while promoting eco-friendly education.

Eco-Friendly Materials: The RTG employs plywood and several recyclable materials as its primary structural elements. The modular design of the Wikihouse building system facilitates reusability, permitting the structure to be disassembled, transported and reassembled at various sites. This method diminishes the reliance on disposable construction materials, hence decreasing waste.

Energy Efficiency: The RTG structure relies on natural light and ventilation to create a suitable environment for plant growth. The transparent polycarbonate panels allow sunlight to enter, reducing the need for artificial lighting and the inclusion of ventilation options helps regulate temperature without energy-intensive cooling systems.

Low Carbon Footprint: The RTG reduces transportation-related emissions by opting for lightweight and locally sourced components. The design is optimized for minimal weight, hence diminishing the greenhouse's effect on the rooftop structure and facilitating sustainable urban agriculture with few structural alterations.

Water Conservation: The RTG supports rainwater harvesting, which can be used for irrigation, further promoting resource efficiency.

Educational and Social Impact: Beyond physical sustainability, the RTG promotes environmental awareness and sustainability education among students. By integrating hands-on activities within a green, urban setting, the RTG encourages students to learn about sustainable agricultural practices, reinforcing their understanding of eco-friendly design principles.

3.2. Manufacturing Phase

The production of the prototype began with the procurement of birch plywood 18mm thick. The CAD files of the digital model were converted to ensure compatibility with the CNC router tool, which is designed to utilize the Autodesk ArtCam software and an 8mm diameter cutting tool for the cutting process.

Birch plywood was specifically chosen to satisfy the structural and functional requirements of a portable RTG due to its lightweight, sturdy, aesthetic and portable characteristics. It was the best option for enabling modular construction and simplifying assembly and transit due to its strength-to-weight ratio. Furthermore, because of its resilience to varying weather conditions, the material could withstand outdoor environmental factors without compromising structural integrity.

Efforts were made to optimize the process by recording the cutting time of all panels, the number of CNC cutting steps and rotation speed, the cleaning of chips after cutting, preparing the machine for the new panel and fixing the new panel to the CNC machine. All components of the RTG were completed with this production cycle.

Each plywood panel was cut using a CNC router and the precision of the cuts was regularly examined to ensure they followed the design specifications. Following each cutting session, components were inspected for consistency and if necessary, sanded to eliminate any imperfections caused by tool wear or speed. During the manufacturing process, little errors occurred during the manufacturing process as a result of the CNC router's speed and the milling cutter's occasional dullness. To address these issues, the router speed was optimized for repeat cuts and sanding was applied to smooth out any rough edges and ensure smooth surface finishes.

3.3. Installation Phase

In the initial stage of installation, two carpenters lay 5x10 cm wooden frames in a simple foundation-like manner to create a flat surface in the areas where the RTG would be placed. These wooden frames were then welded to the bituminous membrane layer using the same bituminous membrane to ensure the existing insulation was fully protected and not damaged by any mechanical fastening elements.

Table 4. Timeline of the installations key steps

Day	Phase	Description
Day 1-2	Foundation Preparation	Construct wooden frames (5x10 cm) and secure them onto the bituminous membrane layer on the roof to create a stable foundation.
Day 3-5	Support Structure Assembly	Assemble pentagonal support elements, first on outer surfaces, followed by intermediate components. Attach floor connection components, forming a 3D support structure.
Day 6	Ceiling Framework Setup	Add ceiling components and secure against deflection of roof material. Lock floor edge components for additional stability.
Day 7	Protective Painting and Weatherproofing	Apply protective paint to areas of polycarbonate sheet contact, ensuring weather resistance.
Day 8	Polycarbonate Panel Installation	Mount bottom cover profiles with EPDM gaskets, then attach pre-cut polycarbonate sheets to the roof and side surfaces, protecting against rain and wind.
Day 9	Final Components and Insulation	Cover pentagonal surfaces with window and door modules, install railing, and finalize roof insulation for thermal protection.

Pentagonal elements that would serve as the main support were first assembled on the outer surfaces. Then narrow parts were added to provide intermediate connections in the other axis, giving the pentagon a 3D shape. Finally, the outer surfaces were hammered to join them. These pentagonal supports that would form the first module were finished and moved to their positions. Subsequently, the intermediate connection components of the floor were attached (Figure 8). The same process was carried out for the other pentagonal supports and floor connection components.

Figure 7. Components of the prototype

The next step was assembling the connection components of the ceiling. Additional ceiling elements were fixed to prevent deflection of the polycarbonate roof material in the adjacent axis. Finally, edge components on the floor were locked with the π component, making the system rigid. After ensuring the system's rigidity, the points where the polycarbonate sheets would be in direct contact were painted with protective paint.

Figure 8. Assembly of the pentagonal supports and the floor connection components

In the next step, the polycarbonate sheets were assembled, which helped prevent the structure from being exposed to rain. Initially, aluminum bottom cover profiles were mounted to the pentagonal posts with trapezoidal screws after attaching EPDM gaskets. After cutting the polycarbonate sheets to the appropriate size and preparing them for assembly, the sheets covering the roof were fixed. Then, the polycarbonates on the side surfaces were finalized and the main component forming the floor surface was assembled. This floor part also serves to make the system resistant to horizontal loads and bring the center of gravity closer to the floor level.

Figure 9. Exterior view of prototype

During installation, components were tested for resistance to wind and precipitation in order to assess the structure's robustness under external conditions. Structural rigidity was changed, particularly in roofing components, to increase stability under various weather conditions.

In the last stage, the pentagonal surfaces with the window and door area were covered, installation of the railing was carried out and layering was done in the same manner to prevent insulation weaknesses on the roof surface (Figure 9).

3.4. Disassembly and Reassembly Phase

The prototype structure that was installed on the roof of Tozkoparan Middle School was uninstalled at the end of the expiration date, on September 18, 2023, as per the permit given by the Istanbul National Education Agency. During this process, no damage was done to the roof or the roof layering. All attachments on the terrace roof were removed, thus returning the roof to its original state, that is to say, to the state before installation of the prototype. Moreover, this process verified the RTG's structural integrity after disassembly and no damage was observed, confirming the reliability of the connections and modular design.

The elements of the prototype were then transported and reinstalled at the YTU Elementary School on the Davutpasa Campus of Yildiz Technical University. This lengthy process allowed for observing reactions on the ground level and the resistance of the building elements to processes like disassembly, transportation and reassembly.

The disassembly and reassembly of the RTG provided valuable insights into the model's functionality and design effectiveness. Firstly, the modular design proved successful in allowing disassembly without damaging structural elements, maintaining the integrity of the prototype for reinstallation. This process highlighted the efficiency of using standardized connectors, which simplified reassembly and ensured consistent alignment across modules. However, some adjustments were required to realign polycarbonate panels, suggesting that future iterations could benefit from reinforced connectors for a precise fit. Secondly, RTG demonstrated strong resilience during transportation to the new site, despite minor wear being observed in some fixing points. Adding stronger edges or flexible joints could help enhance durability, especially for repeated movements.

4. Findings

4.1. Observations for prototype

The prototype was designed to consist of 3 modules with lengths of 4 m by 2.05 m each. The height of the prototype was 3.3 m, thus remaining lower than the regular height of the service stair core structure. Planting depth was approximately 0.4 m. According to the results, calculated with the Design Support Model, the net area allocated to agriculture was 12.84 m^2, the circulation area was 7.38 m^2, area for used structure was 4.38 m^2. Thus, the ratio of net usage area to the total area appeared to be 82.2%. These results and the required material quantities have been proven by the accurate production of the prototype.

However, the calculation of costs was approximately 12.77% lower than the real expenditures, as they depended on the prices and labor/profit multiplier provided by the user. Labor time has also increased as special operations, such as CNC cutting, took longer than expected and accounts for 35% of the total cost (Figure 10). Future projects may aim to increase cost accuracy with more up-to-date price data and detailed labor estimates. For example, cost estimating tools that are more sensitive to supply chain changes, market fluctuations and labor times can be used.

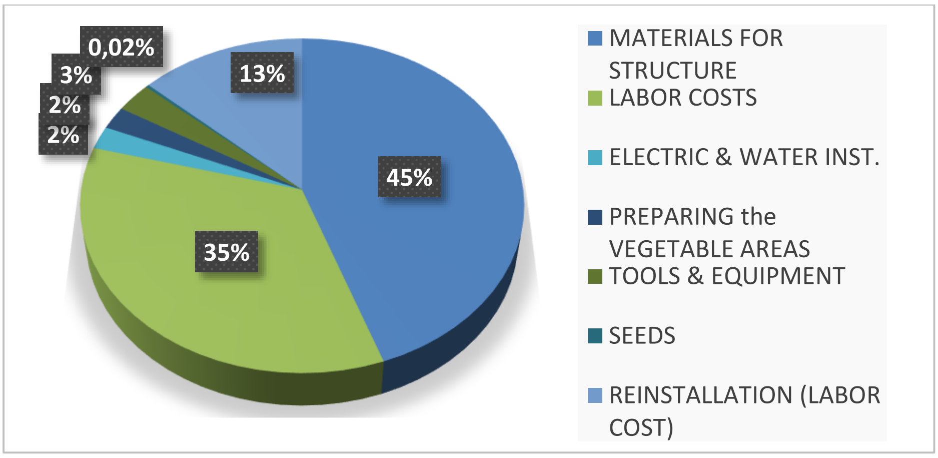

Figure 10. Cost analysis of the model

The weight of the structure was calculated at 60.77 kg/m^2 and the total weight of the RTG was 112.10 kg/m^2. This weight value is well below the safety limit of 200 kg/m^2, thanks to the lightness of the materials used. The balance provided by the reinforced roof structure and modular design has created an area that students can use safely. These rates show that the prototype can be used safely in temporary installations such as educational environments.

With the contribution of the Wikihouse features, the model has low environmental impact, is recyclable and allows for infinite growth through its modular structure. On the other hand, this building system is observed to have some drawbacks, such as requiring technical knowledge in the initial digital production, allowing only for primitive forms and having limitations on dimensions. These findings may seem like disadvantages, but can be considered negligible for the construction of a temporary structure.

Manufacturing Phase: PLUSCAM CNC was used with a RichAuto DSP CNC Control Panel to cut the system components, although they could be manufactured using any CNC router with a cutting area of 130 x 250 cm because the material is an 18-mm-thick standard-type product.

The cutting time of the panels varies depending on the cutting density on the panel, with an average of one panel being cut every 44 minutes. This process, however, has been extended due to the cutting time and post-cutting processes. As a result, a total of 62 plywood panels were cut by repeating 23 different cuts in 11 working days. Leftover panel pieces with relatively even geometries were set aside as spare material. The remaining scraps were stacked for chip-making. Sanding was attempted to correct cutting errors caused by the speed of the CNC router or the bluntness of the milling cutter in some parts.

Installation Phase: During installation on the roof, the impact of wind and precipitation caused interruptions, slowing down the installation process and causing errors. The installation process of the RTG prototype, with an area of 24.6 m^2, was finished in 9 working days. After assembly, the system was usable at full capacity and provided flexibility for electrical installations.

Although the Wikihouse model stands out for being easily assembled and disassembled with simple hand tools, during the assembly, some components on the lower surface came off due to impact and required occasional screwing.

Operating Phase: Upon reviewing the video recordings, it was observed that the accessibility and use of the roof was convenient and safe for the users.

During use, users became somewhat concerned about the noise generated by the polycarbonate panels that make up the top cover during strong winds. In the later stages, however, the users became accustomed to this noise, no longer causing any concern.

It was observed that users did not encounter any issues with the height of the space; in fact, they even made arrangements to hang delicate plants at higher levels. The study area was not large enough, though, to serve 22 students during class at the same time. It was noted that when the number of users inside the space exceeded 12 people, the 1.2 m-wide solid floor was found to be insufficient, leading users to behave cautiously to avoid stepping on the agricultural areas. When the number of users exceeded 12, the available space per user fell below 1.5 m^2, resulting in reduced mobility and potential discomfort. This indicates that the design's optimal capacity should remain at or below this limit for functional use. For future designs, it may be more effective to increase the space allocated per user or provide alternative arrangements for additional users. In addition, subjective evaluation surveys of users' comfort levels can be used to better understand temperature and ventilation conditions.

Indoor temperature was monitored from the completion of installation on April 18, 2023, until the start of dismantling on September 17, 2023. As shown in Table 5, the indoor temperature exceeded the expected range of 13-30°C for the RTG. Indoor humidity was measured between %70 and %90. As seen in Figure 11, it should be noted that data records were taken during spring and summer instead of the more actively used winter and autumn months.

Table 5. Monthly temperature values inside the greenhouse from April 2023 to September 2023 (°C)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
April																		27,2
May	29,8	30,2	31	31,2	30,5	31,3	31,4	31,4	31,7	31,1	31	30,8	31,4	32,2	31,8	33,3	33,6	32,2
June	34,1	34,3	34,8	34,1	34	34,3	34,3	34,8	35	34,9	34,9	35	35,2	35,6	35,7	36,1	36,3	36,4
July	35,1	36,1	36,2	36,7	36,5	36,8	37,6	37,4	37,2	37	37,5	37,7	38	38,1	37,9	37,8	37,6	37
August	37	37,1	37,6	38,2	38	37,9	37,8	37,7	37	37,1	37	37,2	37,4	37,5	37,6	37,5	37,8	38
September	37,4	36,9	36,6	36,5	36,1	36,3	36,4	36,1	35,9	35,5	35,5	35,6	35,6	35,5	35,7	35,8	36	

	19	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**Monthly Avg Temperature**
April	28,3	27,7	29,2	30,2	28,8	28,7	30,5	31,2	27,7	28,9	28,8	29		28,94 °C
May	31	32,1	32,4	32,1	32	31,9	32,1	33,7	33,8	34,2	33,6	33,8	34,1	32,02 °C
June	36	35,9	35,8	36	36,2	36,3	36	36,2	36,6	37,1	35	34,7		35,39 °C
July	36,8	36,5	37,2	37,4	38,8	38	37,7	38,2	37,1	35,7	36	36,7	36,9	37,14 °C
August	38,1	38,1	38,4	38,8	38,6	38,2	37,9	37,7	37	37,2	37,5	37,4	37,5	37,67 °C
September														36,08 °C

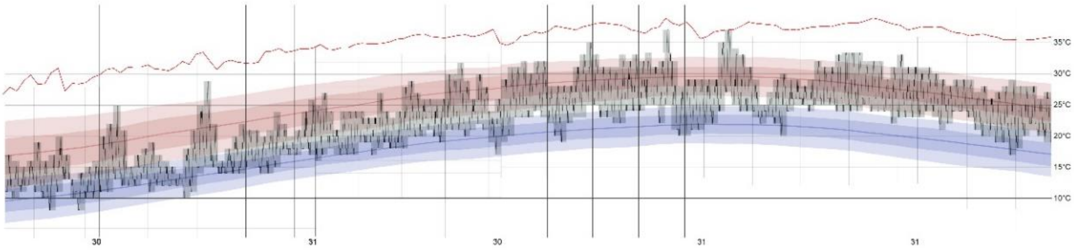

Figure 11. Daily temperature values of Güngören and the greenhouse from April 2023 to September 2023 (°C)

Dismantling and Reinstallation Phase: The proposal's portability capacity was tested during the disassembly and reinstallation phases. The disassembly, transportation and reassembly processes were completed with the work of 3 workers in 4 days total, without any damages occurring. If structural elements are placed precisely and efficiently, an RTG with an area of 24.6 m^2 can be stacked in a volume of 2.88 m^3 (Figure 12). Thanks to this feature, it can be transported by a van or pickup truck.

Figure 12. Transportation of components

4.2. The Effect of EE on Students' Awareness, Attitude and Thinking Levels

The results show that there was no significant difference in the pre-tests between the control and the experimental groups, indicating that both groups had similar levels of awareness, attitude and thinking as shown in Table 6. Analysis of the post-tests revealed that after 6 weeks of program implementation, the levels of awareness, attitude and thinking improved in both groups (control and experimental), but the experimental group's levels of awareness ($t(38) = -2.561$, $p < .05$), attitude ($t(38) = -2.921$, $p < .05$), and thinking ($t(38) = -2.799$, $p < .05$) significantly differed from those of the control group (Table 6, Table 7). Research results show that EE for middle school students, administered in this way through the innovative design of a portable RTG, contributes to the development of students' environmental awareness, attitude and thinking. This innovative RTG design allows students in middle schools to engage directly with the environment and facilitates an active learning process.

Table 6. Descriptive Analysis Results

	Group	N	Mean	Std. Deviation	Std. Error
Awaraness_ pre	Control	18	22,1667	3,46834	,81750
	Experimental	22	22,0909	4,10469	,87512
Awaraness_post	Control	18	22,8333	3,20386	,75516
	Experimental	22	25,5455	3,43272	,73186
Attitude_pre	Control	18	36,6111	10,21037	2,40661
	Experimental	22	37,7273	10,65110	2,27082
Attitude_post	Control	18	37,1667	12,31092	2,90171
	Experimental	22	47,1364	9,27514	1,97747
Thinking_pre	Control	18	58,0556	6,69919	1,57901
	Experimental	22	56,8636	4,44324	,94730
Thinking_post	Control	18	60,7222	4,46958	1,05349
	Experimental	22	64,1818	3,34716	,71362

Table 7. Independent samples T test

		F	Sig.	t	df	Sig. (2-tailed)
Awaraness_ pre	Equal variances assumed	,438	,512	,062	38	,951
	Equal variances not assumed			,063	37,947	,950
Awaraness_post	Equal variances assumed	,300	,587	-2,561	38	,015
	Equal variances not assumed			-2,579	37,296	,014
Attitude_pre	Equal variances assumed	,404	,529	-,336	38	,739
	Equal variances not assumed			-,337	37,003	,738
Attitude_post	Equal variances assumed	2,889	,097	-2,921	38	,006
	Equal variances not assumed			-2,839	31,038	,008
Thinking_pre	Equal variances assumed	3,569	,067	,674	38	,505
	Equal variances not assumed			,647	28,455	,523
Thinking_post	Equal variances assumed	2,704	,108	-2,799	38	,008
	Equal variances not assumed			-2,719	30,912	,011

4.3. Analysis of Roof Greenhouse Space Experience Surveys

Open ended questions: Participants were asked eleven open-ended questions about the impact of the RTG space and duration of use on users, as well as to gather opinions on ergonomics, accessibility and technical performance.

Analysis of the responses to questions measuring usage duration show that students also used the RTG outside of class hours. Additionally, 39% of the students expressed a desire to use the RTG outside of school, in community activity areas such as public parks, fairs and festivals. One student mentioned the potential for setting up greenhouses on university campuses, while another suggested placing them near tram stops that would allow people to both utilize their waiting time and have more interaction with vegetation in urban settings. For example, one student suggests that parks could have greenhouses where people could grow food together, highlighting the potential for RTGs to promote community participation and shared environmental goals.

In their survey responses, 86% of students expressed excitement at the RTG's plant growth and regularly brought up gardening, rural life, plant culture and environmental conservation. Students reported increased enthusiasm for environmental science as they actively participated in plant cultivation, learned about sustainable practices and observed natural cycles firsthand. Indeed, the students have expressed their satisfaction with watching the plants grow over time and being a part of it. This hands-on approach helped reinforce theoretical concepts, making them more relatable and memorable. Additionally, many students expressed interest in future professions in environmental science and even mentioned wanting to implement similar methods at home. As an illustration, one student stated that after the studies, they learned how to grow food in buildings and how we can save space in the city and that they will be able to successfully apply this knowledge anywhere in the future.

Regarding the RTG’s impact on users, it was noted that 36% of students complained about high temperatures inside the RTG, while 18% found the location of the RTG to be quite unusual. Future design iterations should give priority to temperature management techniques, such as better ventilation and the usage of thermal mass materials, in order to improve comfort and usability. First of all, improving air circulation with the addition of movable roof windows or ventilation panels might drastically lower interior temperatures. To increase airflow and enhance comfort, cross-ventilation using carefully positioned vents on opposing sides of the RTG could also be considered. Second, installing types of changeable shading mechanisms such as solar-reflective panels or retractable shades could assist in regulating how much sunlight enters the greenhouse. These components would preserve ideal growing conditions and user comfort while protecting plants from extreme heat. Thirdly, using materials with thermal mass in specific areas of the structure, like clay or concrete, may assist in reducing temperature fluctuations. By absorbing heat during the day and releasing it gradually, these materials help to keep the RTG's temperature more constant, particularly during the hottest parts of the day.

In the assessment of ergonomics and accessibility, all students reported not experiencing any difficulty in accessing the RTG despite its location, while none encountered any risk of accidents inside the prototype. Moreover, 95% of the students mentioned that the RTG met their ergonomic needs and 22% mentioned that they could engage in farming inside the RTG without the presence of an adult.

Regarding the measurement of technical performance, 22% of students believed that the RTG should have a larger area and 31% indicated that while the interior environment's temperature was suitable for plants, it was not comfortable for them.

Likert Scale Questions: A 7-point Likert scale survey was prepared with 14 adjective pairs based on the set used by Hershberger (1972) to measure the meaning of the designed environment and Imamoğlu's Spaciousness-Crampedness Scale (1986). The results were analyzed using SBSS (Table 8).

The main negative aspect of the RTG is that it is perceived by the users to be “suffocating”. This finding is parallel to information obtained from observations and interviews, where the high internal temperature and inadequate space in relation to the number of users were reported as causing discomfort.

Table 8. Descriptive Analysis Results

	N	Mean	Std. Deviation	-3	-2	-1	0	1	2	3
Spacious-Suffocating	22	-1,17	1,978							
Bright-Dark	22	1,94	1,056							
Calm-Crowded	22	1,44	1,822							
Relaxing-Discomforting	22	1,11	2,055							
Accessible-Inaccessible	22	1,61	1,29							
Comfortable-Uncomfortable	22	0,89	1,568							
Functional-Dysfunctional	22	1,89	1,078							
Well-Planned-Poorly Planned	22	2,17	1,249							
Impressive-Ordinary	22	2	1,283							
Organized-Disorganized	22	2,44	0,784							
Safe-Unsafe	22	2,22	0,808							
Original-Not Original	22	1,06	1,434							
Clean-Dirty	22	1,94	1,305							
Inviting-Repellent	22	1,5	1,39							

4.4. The Opinions of Participant Teachers and School Administration

Interviews with teachers and school management highlighted the fact that the application of the RTG model was beneficial for the students who were involved in the project. They also expressed previous difficulties they had encountered when trying to allocate a defined area for similar planting activities in the school garden before this activity. Participants in the project saw that students showed increased attention and active engagement during RTG activities. The participating science teacher highlighted, “Students are much more engaged when they can see and touch what they’re learning about, compared to traditional classroom activities.” This response shows the RTG’s value in creating an immersive learning environment that encourages inquiry-based learning.

As stated by the director and the assistant director, all of the students expressed enthusiasm for the process and wanted to participate in the installation, but they were unable to do so due to authorization issues.

Regarding the design, it was suggested that it would be more ergonomic for the planting areas in the RTG to be raised like vegetable beds, which would reduce the need to bend excessively and make gardening activities more comfortable. Moreover, concrete floors, tables or hanging devices can be used to grow crops. These adjustments are especially beneficial for younger students and individuals with mobility limitations, creating a more inclusive learning environment.

Teachers also recommended adding roof windows to increase natural ventilation against high indoor temperatures. In order to solve the problem of high interior temperatures, in addition to natural ventilation, low-energy mechanical ventilation systems, such as solar-powered fans, can also be considered.

According to the observations of the participating teachers, 9-10 students can move comfortably in the prototype, which includes 3 modules. Difficulties occur, however, when the number reaches 14-15 people; when it reaches 22, the space needs to be used in turns. Based on these opinions, while a module can provide a quality spatial experience for 4-5 people, approximately 5 or 6 modules are required for a class of 22 students, such as is the case in the experimental group.

4.5. Sustainability Metrics of the portable RTG

The design of the portable RTG incorporates various sustainable characteristics. Initially, birch plywood was chosen as the principal building material owing to its lightweight, durability and recyclability. This material guarantees the structure's portability and ecological sustainability while minimizing the carbon impact linked to manufacture and transportation. Moreover, by optimizing material utilization, the modular design minimizes waste in the production process.

Another crucial element is energy efficiency. By optimizing natural light and ventilation, the RTG reduces the need for artificial lighting and climate control systems. The roof structure's ability to collect rainwater for irrigation purposes further promotes water conservation.

The RTG promotes urban agriculture and has a favorable environmental impact by turning unused rooftop surfaces into functional areas. This reduces transportation-related emissions and dependence on traditional agricultural lands. Rainwater collection also encourages sustainable irrigation water use. To ensure a low environmental effect, recyclable materials are used in the RTG's construction, even after the greenhouse's lifecycle is complete.

These metrics show how the RTG supports goals for sustainable development, like cutting greenhouse gas emissions and making the best use of available resources. Future research should investigate these findings further using a more comprehensive lifecycle analysis.

5. Discussions

The findings showed that the portable RTG application led to significant improvements in the environmental awareness ($t(38) = -2.561$, $p < .05$), thinking ($t(38) = -2.799$, $p < .05$) and attitude levels ($t(38) = -2.921$, $p < .05$) of the students in the experimental group, compared to those in the control group over a brief period of time. Long-term effects were not investigated because the permit granted by the Istanbul Provincial Directorate of National Education for the project was limited to six months.

This implementation model of EE together with the RTG prototype has been based on the principle of student participation: the students actively participate in the process, learn by researching and questioning and transfer this learning to life scenarios through case studies. Hence, this study supports the “Action Competence Model” proposed by Jensen & Schnack (1997). The use of portable RTG increases conscious actions envisioned by promoting active student involvement in environmental issues.

In response to the open-ended questions, all the students in the experimental group reported that they did not experience any difficulties or risk of accidents; instead, they responded positively to the spatial arrangements and noted that their interest in the course increased. Indeed, a noticeable increase was observed in the excitements and expectations of the students from the installation phase to the usage phase.

According to findings, the Wikihouse system meets the RTG requirements (Freisinger *et al*., 2015; Nadal *et al*., 2018; Jans-Singh *et al*., 2019) despite its limitations. The system fulfills the required size and openings for an RTG, the right column spacing and peak heights, the desired form diversity and shape, according to the climatic conditions. Moreover, the modular system provides flexibility for future development plans. The system gives opportunities for the installation of a shading element like a screen or blinds, the assembly of various permeable cover types and the integration of irrigation systems or other systems. The main weakness in the design is the absolute need for the installation procedures to be well-organized in accordance with the external weather conditions because the current system is only suitable for dry assembly.

The prototype is produced from three modules and has a floor area of 24.6 m^2. While 7.38 m^2 of this area is offered to students as walkable hard ground, 13.84 m^2 is reserved for agricultural activities. These dimensions were under the minimal allowable dimension for the development of an educational and nutritional school project (Sanyé-Mengual *et al*., 2015b). However, the prototype has infinite growth capacity and the ability to add new modules during the use process. With an RTG investment consisting of six modules and established in a 48.6 m^2 area, all 7^{th}-grade classes can be served simultaneously by using it alternately. The main limiting factor of this study was budget constraints. In order to implement EE more effectively and efficiently in the model, it may be recommended to increase the number of RTG modules, if possible; or if not possible, to carry out activities with smaller student groups.

It was calculated that a total of 1,095 m^2 of walkable terrace roof area on the pilot school building could potentially be used for RTG purposes after the removal of the mechanical equipment area and irregular geometries. By operating this entire area as an RTG, it thus would be possible to create an experiential workshop that could serve approximately 534 students at the same time. In this way, RTGs created for agricultural activities can have the capacity to meet economic production needs according to Sanyé-Mengual et al. (2015b).

The prototype has proven to be successful in terms of portability. All procedures, like disassembly, transfer and reassembly, were finished without incidents or any harm. The necessary permit was obtained from the municipality before operation and there were no legal problems during the installation and use of the prototype on the roof or at ground level.

Furthermore, the prototype solves one of the major concerns: structural limit considerations of the roof. The weight of the structure and the whole RTG were within the limits and well-suited to the endurance limits of the flat roofs of these school buildings (Sanyé-Mengual *et al*., 2015b; Nadal *et al*., 2017b). Besides, the proposed model also meets most of the agricultural and ergonomic requirements.

The relatively high indoor temperature, was the only negative aspect identified both by observation and by the questionnaire. In addition to causing discomfort to humans, the indoor temperature of the prototype exceeds the highest temperature limit that stops root growth of the plants (Freisinger *et al*., 2015; Nadal *et al*., 2017b). The desired temperature values for the RTG could, in fact, be achieved by increasing the number of operable roof windows and using sufficient shading elements against the sun. Only a single-sided window was used in the prototype, even though the prototype has space reserved for two skylights per module. Skylights could also be added after installation in order to release excess humidity (Pons *et al*., 2015). Although infrastructure for the attachment of a shading element was provided, no such element was used in this trial due to budget constraints. In addition to natural ventilation, mechanical cooling systems could also be used. (Gázquez *et al*., 2008.) Besides, data records were taken in spring and summer instead of the more actively used winter and autumn months.

In addition, the structure has a low carbon footprint and consists of 100% recyclable system components, except the material polycarbonate exterior covering. Alternatively, glass could also be preferred as a covering material. In this case, however, polycarbonate has been preferred instead to avoid possible problems during transportation and the installation process. Additionally, glass is a more expensive material and adds extra load to the structure.

Examining alternative sustainable and durable materials, including recycled plastics or biodegradable composites, may reduce the impact on the environment. To determine whether these materials are suitable for long-term use in rooftop applications, future research could look at how well they function in different weather scenarios.

The RTG's modular architecture shows encouraging adaptability, but more research might concentrate on improving the design for faster assembly and longer-lasting durability. The functionality and environmental performance of the RTG could be further improved by experimenting with various structural arrangements or implementing cutting-edge technology like solar-powered ventilation systems.

The Science Course Curriculum Program administered by the Ministry of Education in Türkiye adopts inquiry-based learning through out-of-school learning environments so that students can learn meaningfully and permanently (MOE, 2018). Therefore, the RTG project, as an effective setting, fits into the current science curriculum in terms of both teaching students about environmental issues and developing their awareness, attitudes and thinking.

Among the limitations of this study are the facts that only short-term effects have been assessed and that results are based on practices at a middle school in Istanbul. These factors could influence the applicability of the findings across various educational and cultural contexts. For instance, the outcomes observed might differ in schools with distinct infrastructural or socio-cultural characteristics. These may limit the generalizability of the findings.

To tackle these concerns, future studies could implement similar portable RTG models in different educational settings and investigate their long-term effects on attitudes and environmental awareness. Modifications such as adapting the design for different climates or expanding the activities for broader curricula integration should also be evaluated in order to increase scalability and generalizability. By modifying the model for various contexts, its impact might be better understood and refined.

This study shows, however, that portable RTGs can be used as an innovative tool in EE and are effective in increasing student participation. Furthermore, these findings could make significant contributions to the design of EE programs.

Future studies may focus on the impact of the use of portable RTGs in different schools of different sizes and may evaluate long-term changes in the environmental awareness and attitudes of students and their families. In future research, researchers can examine the same individuals to detect any changes in students’ awareness, attitudes and thinking that might occur over a period of time by using a longitudinal approach. Follow-up assessments could help determine the program's long-term impact on students' environmental awareness, attitudes and thinking.

Future studies could assess the possibility of integrating RTG in educational contexts other than middle schools, like high schools, vocational institutions, or even community centers. This extension would enable the evalution of the wider effects of RTGs on environmental consciousness across a range of age groups and learning settings. Furthermore, greater impact helps in the exploration of possible funding sources, community engagement and collaborations that may help in scaling the RTG model more sustainably. The initial costs of installation and maintenance may be covered by subsidies from the local government, educational funding and environmental organizations. Additionally, involving the local community-such as parent associations or local businesses-in fundraising efforts may also promote a feeling of collective accountability and boost project funding.

Collaborations with academic institutions, nonprofit organizations or environmental organizations may also expansion of the RTG initiative by providing access to more volunteers, funding and additional expertise. These partnerships might encourage continuous enhancements to the greenhouse's architecture, such as the addition of more energy-efficient technology or renewable materials. By diversifying funding sources and promoting community engagement, the RTG model could become a more scalable and sustainable approach to EE in urban schools.

Although the study admits that it did not look at long-term consequences, a framework for further research could be useful in assessing the RTG project's long-term effects on students and the community at large. A longitudinal study, for example, could monitor how students' environmental awareness, attitudes and behaviors change over a number of years, offering insights into how sustainable these learning outcomes are. Researchers would be able to track changes in behavior and knowledge retention by surveys, interviews and observational assessments carried out at regular intervals (e.g., one, three and five years following participation).

Additionally, follow-up studies measuring participation in local environmental activities, volunteer work, or related educational projects could be used to evaluate community interest in the RTG. This framework might help in the creation of evidence-based practices that optimize the RTG's influence on environmental awareness and community involvement by suggesting a structured methodology for long-term studies.

6. Conclusion

This study effectively demonstrates the feasibility and advantages of utilizing portable RTGs for EE in urban middle schools. Rooftop spaces provide a unique opportunity for educational and agricultural activities given the high population density as well as scarce ground level space in Turkish metropolises. The RTG prototype developed in this study met all expectations regarding portability, ease of assembly and adaptability, allowing for easy installation and use on flat roofs with minimal resources.

The findings indicate that RTGs have the potential to significantly increase middle school pupils’ awareness, attitude and thinking about the environment. For example, the experimental group demonstrated a 12% increase in awareness (mean post-test score: 25.55 compared to the control group’s 22.83) and a 27% increase in environmental attitudes (mean post-test score: 47.14 compared to the control group’s 37.17). Likewise, students in the experimental group improved their thinking skills by 6% (mean post-test score: 64.18 versus 60.72 in the control group). These results provide specific evidence that supports the hypothesis and highlight the usefulness of RTGs as educational tools. By providing experiential learning experiences, RTGs enable active student engagement and foster meaningful EE.

Educators can incorporate portable RTGs into scientific and environmental curricula as an innovative tool for experiential learning, improving students’ engagement and knowledge retention. School administrators may consider repurposing underutilized spaces, including rooftops, to develop sustainable educational settings that complement broader institutional goals of environmental responsibility. The study demonstrates to policymakers how RTGs could support national education programs that prioritize urban agriculture, sustainability and experiential STEM education. Supporting similar initiatives that encourage the widespread adoption of RTGs in schools would allow policymakers to advance objectives such as the Sustainable Development Goals (SDGs), particularly those related to high-quality education and sustainable cities. These stakeholders are crucial for scaling the model and adapting it to other urban and educational environments.

The prototype's ability to be assembled and disassembled with simple tools, its lightweight and compact storage, as well as its adaptability in terms of installation and expansion, make it a practicable solution for urban schools. Such studies have a socio-educational and environmental impact that extends beyond the students to their families and communities, fostering an inclusive culture of environmental awareness.

Several areas for improvement, however, were identified in this study. Resolving the issue of high internal temperatures will be critical for improving the usability and effectiveness of the model. These were partially mitigated through adaptive measures, such as shaded planting zones and ventilation adjustments, though further optimization is needed for broader implementation. Additionally, the permission requirements from the Istanbul National Education Agency constrained the research period to six months only, preventing the assessment of long-term effects. Although the study focused on a single middle school in Istanbul, cultural, infrastructure and environmental variations could affect the findings in different settings. Taking into account these limitations, future studies should examine the scalability of portable RTGs in a variety of climates and educational settings in order to provide a more thorough understanding of their potential.

According to the Turkish Statistical Institute’s data (2023), there are 24 metropolitan cities in Türkiye with 3,760,893 students in middle schools. To develop a model that can reach all these pupils, future research should focus on evaluating the long-term sustainability and scalability of RTG projects within various schools and different urban contexts. Local governments and policymakers should promote these efforts by providing funding, infrastructure resources and regulatory frameworks that enable the transformation of underutilized rooftop areas into sustainable learning settings. By initiating such pilot programs, stakeholders can evaluate the broader scalability and adaptability of RTGs, ensuring their integration into future educational strategies. This collaborative approach not only enhances EE but also cultivates a culture of sustainability among students, schools and communities.

To sum up, this research proposes transforming idle rooftops into green classrooms using portable RTGs to achieve positive social-environmental-economic synergies. By balancing urban consumption and production, this approach contributes to the development of sustainable cities and enhances students' environmental consciousness and awareness. Future research will concentrate on these topics to improve and broaden the use of RTGs in urban educational settings.

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References

Akınoğlu, O., Sarı, A. (2009). Environmental education in primary education programs. *Marmara University Atatürk Education Faculty Journal of Educational Sciences*, 30, 5-29. (In Turkish).

Alagoz, B., Akman, O. (2016). A study towards views of teacher candidates about national and global environmental problems. *International Journal of Research in Education and Science (IJRES)*, *2*(2), 483-493.

Al-Otaibi, A., Al-Qattan, A., Fairouz, F. & Al-Mulla, A. (2015). Performance evaluation of photovoltaic systems on Kuwaiti schools' rooftop. *Energy Conversion and Management*, 95, 110-119. https://doi.org/10.1016/j.enconman.2015.02.039

Amman National School (2024, August 8). Explanation of RTG. https://ans.edu.jo/en/facilities/9/rooftop-garden-with-a-greenhouse

Arslan, Y., Albay, F. (2019). The effect of outdoor sports as undergraduate elective course on environmental sensitivity. *Journal of Education and Learning*, *8*(4), 52-57. https://doi.org/10.5539/jel.v8n4p52

Artun, H. (2013). Investigating effectiveness of environmental education modular instruction curriculum designed for grade 7th students. PhD Thesis, Karadeniz Technical University, Institute of Education Sciences, Trabzon.

Artun, H., Özsevgeç, T. (2015). The effect of environmental education modular instruction curriculum on academic achievement. *HAYEF Journal of Education*, *12*(1), 9-22.

Bozkurt, O. (2015). *Environmental Education*, 199. Ankara. (In Turkish).

Cerón-Palma, I., Sanyé-Mengual, E., Oliver-Solà, J., Montero, J.I. & Rieradevall, J. (2012). Barriers and opportunities regarding the implementation of rooftop eco.greenhouses (RTEG) in mediterranean cities of Europe. *Journal of Urban Technology*, *19*(4), 1-17. https://doi.org/10.1080/10630732.2012.717685

Derman, I., Senemoğlu, N. (2015). Sustainable environmental awareness of 9th and 12th. *Ankara University Journal of Faculty of Educational Sciences*, *48*(2), 61-82. https://doi.org/10.1501/Egifak_0000001364 (In Turkish).

Drottberger, A., Zhang, Y., Yong, J.W.H. & Diyiyiubois, M. (2023). Urban farming with rooftop greenhouses: A systematic literature review. *Renewable and Sustainable Energy Reviews*, 188, 1-15. https://doi.org/10.1016/j.rser.2023.113884

Durgeç, P., Demirel, S.D. (2023). A research on the presentation of environmental problems in digital newspapers in the context of raising environmental awareness. *Gumushane University e-Journal of Faculty of Communication*, *11*(1), 500-529. https://doi.org/10.19145/e-gifder.1206345 (In Turkish).

Ekmekçi, I., Şen, Y. (2016). A study on solar radiation calculation for Istanbul with measured data. *Journal of Solar Energy Research*, *1*(2).

Esenarro, D., Porras, E., Ventura, H., Figueroa, J., Raymundo, V. & Castañeda, L. (2024). Use of digital tools (Wikihouse System) in multi-local social housing. *Sustainability*, *16*(8), 1-3231. https://doi.org/10.3390/su16083231

Fertilecity (2024). https://www.fertilecity.com/en/agreements-with-schools/

FEZ (2024). Eco-Island projects. https://oeko-insel.fez-berlin.de/en/auf-der-oeko-insel/projekte-workshops

Freisinger, U.B., Specht, K., Sawicka, M., Busse, M., Siebert, R. Werner, A., ... & Walk, H. (2015). *There's Something Growing on the Roof. Rooftop Greenhouses. Idea, Planning, Implementation.* Müncheberg: Leibniz Centre for Agricultural Landscape Research. https://doi.org/10.13140/2.1.2480.7204

Gázquez, J.C., López, J.C., Pérez-Parra, J.J., Baeza, E.J., Saéz, M. & Parra, A. (2008). Greenhouse cooling strategies for Mediterranean climate areas. *Acta Hortic*, 801, 425-432. https://doi.org/10.17660/ActaHortic.2008.801.45

Gilmanshina, S.I., Sagitova, R.N. & Gilmanshin, I.R. (2018). Science education: Development of environmental thinking. *European Research Studies Journal*, *21*(3), 690-704.

https://doi.org/10.35808/ersj/1093
Hershberger, R.G. (1972). Toward a set of semantic scales to measure the meaning of architectural environments. *In EDRA three, Proceedings of the 3rd Annual Environmental Design Research Conference.* University of California, Los Angeles.
Imamoğlu, V. (1986). Assessing the spaciousness of interiors. *METU Journal of the Faculty of Architecture*, *7*(2), 127-142.
Istanbul Metropolitan Municipality (2022, June). Spatial analysis report of the Istanbul. https://yaysis.istanbul/en/planning-approach/spatial-analysis
Istanbul Metropolitan Municipality (2023, April). Istanbul green space management system strategy document. https://yaysis.istanbul/storage/files/raporlar/yaysis_strateji_belgesi_raporu_final_.pdf
Jans-Singh, M.K., Ward, R. & Choudhary, R. (2019). Co-simulation of a rooftop greenhouse and a school building in London, UK. *Proceedings of Building Simulation 2019: 16th Conference of IBPSA*, 3266–73. Rome. https://doi.org/10.26868/25222708.2019.210355
Jensen, B.B., Schnack, K. (1997). The action competence approach in environmental education. *Environmental Education Research*, *3*(2), 163-178. https://doi.org/10.1080/1350462970030205
Karaburun, A., Demirci, A. & Saka, E. (2015). Spatial assessment of the schoolyards in the European side of Istanbul: A sufficiency analysis based on the number of students. *Marmara Geographical Journal*, 31, 20-47. (In Turkish).
Karama, M.J. (2016). A comparative survey of environmental education goals between the UNESCO framework and 10th grade Palestine curriculum. *International Journal of Curriculum and Instruction*, *8*(2), 1-17.
Kıyıcı, F.B. (2009). General environmental education for education faculties. *Environmental Education.* Ankara, 73-183. (In Turkish).
Kronenburg, R. (2008). *Portable Architecture.* Birkhäuser Basel.
Mangas, V.J., Martinez, P. & Pedauyé, R. (1997). Analysis of environmental concepts and attitudes among biology degree students. *The Journal of Environmental Education, 29*(1), 28-33. https://doi.org/10.1080/00958969709599104
Manhattan School (2024). Curriculum in RTG. https://www.ps333.org/our-curriculum
McKeown, R. (2000). *Education for Sustainable Development Toolkit*. Waste Management Research and Education Institution. https://hrea.org/wp-content/uploads/2021/04/Education-for-Sustainable-Development-Toolkit_English.pdf
Mesmer-Magnus, J.R., Viswesvaran, C. & Wiernik, B.M. (2013). The role of commitment in bridging the gap between organizational and environmental sustainability. *Global Business and Organizational Excellence*, *32*(5), 86-104. https://doi.org/10.1002/joe.21506
Ministry of Education (2018). *Science Course Curriculum Program (Primary and Secondary School 3rd, 4th, 5th, 6th, 7th and 8th Grades*). Ministry of National Education, Board of Education, Ankara. (In Turkish).
Nadal, A., Alamús, R., Pipia, L., Ruiz, A., Corbera, J., Cuerva, E., … & Josa, A., (2017b). Urban planning and agriculture. Methodology for assessing rooftop greenhouse potential of non-residential areas using airborne sensors. *Science of the Total Environment*, 601, 493-507. https://doi.org/10.1016/j.scitotenv.2017.03.214
Nadal, A., Llorach-Massana, P., Cuerva, E., López-Capel, E., Montero, J.I., Josa, A., … & Royapoor, M. (2017a). Building-integrated rooftop greenhouses: An energy and environmental assessment in the Mediterranean context. *Applied Energy*, 187, 338-351. https://doi.org/10.1016/j.apenergy.2016.11.051
Nadal, A., Pons-Valladares, O., Cuerva, E., Rieradevall, J. & Josa, A. (2018). Rooftop greenhouses in educational centers: A sustainability assessment of urban agriculture in compact cities. *Science of the Total Environment*, 626, 1319-1331. https://doi.org/10.1016/j.scitotenv.2018.01.191
Oluwatayo, J.A. (2012). Validity and reliability issues in educational research. *Journal of Educational and Social Research*, *2*(2), 391-400.

https://www.richtmann.org/journal/index.php/jesr/article/view/11851

Orsini, F., Gasperi, D., Marchetti, L., Piovene, C., Draghetti, S., … & Gianquinto, G. (2014). Exploring the production capacity of rooftop gardens (RTGs) in urban agriculture: The potential impact on food and nutrition security, biodiversity and other ecosystem services in the city of Bologna. *Food Security*, 6, 781-792 https://dx.doi.org/10.1007/s12571-014-0389-6

Osgood, C.E., Suci, G.J. & Tannenbaum, P.H. (1957). *The Measurement of Meaning*, 342. University of Illinois press.

Planned Areas Zoning Regulation in Türkiye (2017, December 13). Council of Ministers, Ankara, Türkiye. https://www.mevzuat.gov.tr

Pons, O., Nadal, A., Sanyé-mengual, E., Llorach-Massana, P. & Rosa, M. (2015). Roofs of the future: Rooftop greenhouses to improve buildings metabolism. *Procedia Engineering*, 123, 441-448. https://doi.org/10.1016/j.proeng.2015.10.084

Regulation on Fire Protection (2020, September 22). Council of Ministers, Ankara, Türkiye. https://www.mevzuat.gov.tr

Romero Quidel, G., Soto Acuña, M.J., Rojas Herrera, C.J., Rodríguez Neira, K. & Cárdenas-Ramírez, J.P. (2023). Assessment of modular construction system made with low environmental impact construction materials for achieving sustainable housing projects. *Sustainability*, *15*(10), 8386. https://doi.org/10.3390/su15108386

Rubio, D.M., Berg-Weger, M., Tebb, S.S., Lee, E.S. & Rauch, S. (2003). Objectifying content validity: Conducting a content validity study in social work research. *Social Work Research*, *27*(2), 94-104. https://doi.org/10.1093/swr/27.2.94

Şahin, N.F., Cerrah, L., Saka, A. & Şahin, B. (2004). A practice for student centered ecology course in higher education. *Gazi University Gazi Faculty of Education Journal*, *24*(3), 113-128.

SALUS (2024, September 7). Agricoltura urbana. https://saluspace.eu/agricultura-urbana/

Sanyé-Mengual, E., Cerón-Palma, I., Oliver-Solà, J., Montero, J.I. & Rieradevall, J. (2015b). Integrating horticulture into cities: A guide for assessing the implementation potential of rooftop greenhouses (RTGs) in industrial and logistics parks. *Journal of Urban Technology*, *22*(1), 87-111. https://doi.org/10.1080/10630732.2014.942095

Sanyé-Mengual, E., Martinez-Blanco, J., Finkbeiner, M., Cerdà, M., Camargo, M., Ometto, A.R., … & Rieradevall, J. (2017). Urban horticulture in retail parks: Environmental assessment of the potential implementation of rooftop greenhouses in European and South American cities. *Journal of Cleaner Production*, 172, 3081-3091. https://doi.org/10.1016/j.jclepro.2017.11.103

Sanyé-Mengual, E., Oliver-Solà, J., Montero, J.I. & Rieradevall, J. (2015a). An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. *International Journal of Life Cycle Assessment*, 20, 350-366. https://doi.org/10.1007/s11367-014-0836-9

Sauvé, L. (1996). Environmental education and sustainable development: A further appraisal. *Canadian Journal of Environmental Education*, 1, 7-34.

Şimşekli, Y. (2001). The evolution of the activities done in the schools which have been chosen for the project of applied environmental training in Bursa on the terms of the contribution of the school administrator and the charged teachers. *Journal of Uludag University Faculty of Education*, *14*(1), 73-84. (In Turkish).

Specht, K., Siebert, R., Hartmann, I., Freisinger, U.B., Sawicka, M., Werner, A., … & Dierich, A. (2014). Urban agriculture of the future: An overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*, 31, 33-51. https:/doi.org/10.1007/s10460-013-9448-4

Tanriverdi, B. (2009). Analyzing primary school curriculum in terms of sustainable environmental education. *Education and Science*, *34*(151), 89-103. (In Turkish).

Thomaier, S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, U.B. & Magdalena,

S. (2015). Farming in and on urban buildings: Present practice and specific novelties of Zero-Acreage Farming (ZFarming). *Renewable Agriculture and Food Systems*, *30*(1), 43-54. https://doi.org/10.1017/S1742170514000143

Tunbiş, M. (1987). Roof gardens. *Journal of the Faculty of Forestry Istanbul University*, *37*(4), 2-14. https://dergipark.org.tr/en/download/article-file/175217 (In Turkish).

Turkish Statistical Institute. (2023, February 6). The Results of Address-Based Population Registration System Results. https://data.tuik.gov.tr/Bulten/Index?p=The-Results-of-Address-Based-Population-Registration-System-2022-49685&dil=2

Ünal, S., Dımışkı, E. (1999). Development of environmental education under the auspices of UNESCO-UNEP and secondary school environmental education in Turkey. *Hacettepe University Journal of Education*, 17, 142-154.

Uzun, N., Sağlam, N. & Uzun, F.V. (2008). The effect of the green class model based applied environmental education project on environmental consciousness and its retention. *Ege Journal of Education*, *9*(1), 59-74.

Uzun, N., Sağlam, N. (2006). Development and validation of an environment al attitudes scale for high school students. *Hacettepe University Journal of Education*, 30, 240-250.

Weatherspark (2024, July 10). Climate and Average Weather Year Round in Esenler. https://weatherspark.com/y/95436/Average-Weather-in-Esenler-Turkey-Year-Round

WikiHouse Community (2024). https://wikihouse.cc/ Accessed on 12.06.2024.

Yalçınkaya, E., Çetin, O. (2018). An investigation of secondary school students' environmental attitudes and opinions about environmental education (EE). *Review of International Geographical Education Online (RIGEO)*, *8*(1), 125-148. https://dergipark.org.tr/en/download/article-file/591146

Zambrano-Prado, P., Orsini, F., Rieradevall, J., Josa, A. & Gabarrell, X. (2021). Potential key factors, policies and barriers for rooftop agriculture in EU cities: Barcelona, Berlin, Bologna and Paris. *Frontiers in Sustainable Food Systems*, 5. https://doi.org/10.3389/fsufs.2021.733040