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Safe building design by small architects: A design activity developed for elementary mathematics course

Ahmet Oğuz Akçay, *Eskişehir Osmangazi University,* Turkey, *aoakcay@ogu.edu.tr* ORCID: 0000-0003-2109-976X
Engin Karahan, *Eskişehir Osmangazi University,* Turkey, *ekarahan@ogu.edu.tr* ORCID: 0000-0003-4530-211X
Aytaç Kurtuluş, *Eskişehir Osmangazi University,* Turkey, *aytackurtulus@gmail.com* ORCID: 0000-0003-2397-3510

Abstract. This study aims to develop an acquisition-oriented STEM activity that primary school teachers can implement in the classroom. The design-based teaching activity developed and implemented within this study is intended to be presented as an example of an activity suitable for STEM education focused on mathematics lessons. The activity was developed in line with the design process indicators within the K-12 engineering education framework. The steps of this learning model are (1) problem and background, (2) plan and implementation, and (3) testing and evaluation. The activity particularly targets elementary school students produce an engineering design product using simple and low-cost materials. The four criteria presented to the students in this process were (1) apartments receiving light, (2) being earthquake resistant, (3) being economical and (4) aesthetics and marketing. Throughout the design process, the criterion that students had the most difficulty was observed as the sun exposure of the flats. Also, most of the students focused more on the aesthetic criterion than other criteria, and they emphasized this criterion most in the marketing process of their products.

Keywords: Design-based learning, activity development, primary school, STEM

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INTRODUCTION

STEM education, which is a new approach of the 21st century, has been a subject that educators and researchers have emphasized in our country as in the world in recent years. STEM education is a holistic education approach with an interdisciplinary perspective in all educational levels from pre-school to post-graduate programs covering the fields of Science, Technology, Engineering, and Mathematics. According to Özyurt, Kayıran, and Başaran (2018), "STEM education aims to raise individuals who seek solutions with real-life problems, technology, and engineering approaches, and use science and mathematics as a tool for these solutions" (p 68). STEM education aims to train students with 21st-century skills, to train STEM literate individuals, to include these individuals in the labor force (Honey, Pearson and Schweingruber, 2014) and to develop students' skills such as critical thinking and problem-solving. Individuals' STEM knowledge is needed not only for professional scientists but also for different business areas (Lacey & Wright, 2009). In this direction, many countries that want to increase their qualified workforce focus on STEM education and integrate them into education programs (Van Langen & Dekkers, 2005).

With STEM education, it is aimed that students studying at K-12 level have higher proficiency in science, technology, engineering, and mathematics and they should be directed to these fields (National Academy of Engineering [NAE], 2009). It is important to integrate STEM education into the education process at an early age (American National Research Council, 2011). It is stated that children can develop awareness at an early age (Watson & McMahon, 2005) and this awareness can be transferred to future ages (Freedman, Sears, & Carlsmith, 1989). Giving STEM education in schools, including early childhood and primary school, shows that students tend to STEM disciplines in the next academic year (Marginson, Tytler, Freeman, Brigid and Kelly, 2013). Also, it is emphasized that students' understanding and motivation in science, mathematics, and engineering fields can be increased through STEM-oriented experiences (Bybee, 2009) and permanent learning of science and mathematics concepts can be realized through real-life problems (National Research Council [NRC], 2009). There are studies in the literature that STEM-focused activities have positive effects on students' academic achievement and skills (Ercan & Şahin, 2015; Gencer, 2017; Karahan & Ünal, 2019; Karahan, Canbazoğlu-Bilici, & Ünal, 2015; Yamak, Bulut, & Dündar, 2014).

The quality learning environments offered in early childhood provide children with opportunities to explore, build, and question information, and develop students' creativity, curiosity, collaboration, and critical thinking skills (Chesloff, 2013). STEM skills and knowledge of mathematics provide skilled labor required by a strong economy and it is important to gain this knowledge and competence at a young age (Chesloff, 2013).

Although the importance of laying the foundations of STEM-related learning in early childhood and elementary school is underlined, the lack of competence of teachers in this education level especially in science and mathematics education (Marginson, Tytler, Freeman, Brigid & Kelly, 2013) makes it difficult to carry out STEM-focused activities at these levels. With the secondary school science curriculum published by the Ministry of Education in 2018, engineering and design skills have taken their place among the skills that are specific to the field between the 3rd and 8th grades and the objectives for these skills have been included in the program (Ministry of Education, 2018). On the other hand, the objectives included in the curriculum of different courses, especially science, have potential in the development of STEM-focused activities (Bahar, Yener, Yılmaz, Emen, & Gürer, 2018). Therefore, the successful STEM integration of Turkey depends directly on the STEM knowledge and awareness of teachers who are experts in different branches (Corlu, Capraro, & Capraro, 2014).

Hence, sharing STEM-focused activities developed in line with the achievements at primary school level with teachers is of great importance in the first stage for STEM education-oriented learning processes to take place in these levels. In this way, teachers will have a model for STEM activities that they can develop as well as obtaining an example of STEM activities that they can apply directly in their classrooms.

In this study, it was aimed to develop an acquisition-oriented STEM activity that primary school teachers can implement in the classroom in a safe and new generation building design activity developed in line with the design process indicators within the K-12 engineering education framework (Moore et al., 2014). The K-12 engineering education framework has been proposed by Moore et al. (2014) as a theoretical framework to guide the development and research of effective STEM education practices.

Special Purposes

Although the activity is directly related to the achievements stated in elementary school mathematics science, it will also support the basic objectives of mathematics and science courses curriculum. In this context, the activity can contribute to students' positive attitude towards these lessons by developing their mathematics and science literacy skills and by having experience in learning mathematics and science. Besides, their designing skills are expected to develop by providing basic information about mathematics, science and engineering applications, integrating science with mathematics, technology, and engineering, creating products using the knowledge and skills acquired by discovering students with an interdisciplinary perspective and developing strategies on how to add value to these products. The students' reasoning skills, scientific thinking habits, and decision-making skills can be developed by arousing interest and curiosity about the daily life problems that occur around the activity and by enabling them to use knowledge of mathematics and science to solve these problems. In line with the Primary Education Program published in 2018 for specific purposes, the objectives related to the activity are given below.

Primary School Objectives

M.4.3.3. Measuring Area

- M.4.3.3.1. Specifies that the areas of shapes are the number of unit squares that cover this area.

a) In addition to the known shapes, it is also worked with indented shapes such as leaf and hand-drawn on checkered paper.

b) While samples are given, studies are made on the same circumference and different shapes.

F.4.8.1. Applied Science

- F.4.8.1.1. Defines a problem from daily life.
- F.4.8.1.3. Designs and presents the product.

a) Product design and construction are done in the school environment.

b) Students are expected to experiment during the product development phase, to record the qualitative and quantitative data they obtained as a result of these trials, to record observations, and to evaluate them with graphic reading or creating skills.

Activity Development Process

In the realization of this activity, Moore et al.'s (2014) design process steps of the K-12 engineering education framework are followed. The steps of this learning model are (1) problem and background, (2) plan and implementation, (3) testing and evaluation, respectively. According to this framework, design processes, which are at the center of engineering applications, are an iterative process that includes preparing, planning, and evaluating the solution. Along with this cyclical and renewable process, it is possible to find a solution to a problem or need a situation inherent in STEM activities by design. In addition to this, instead of going through the design that the students developed first by following the steps of the cycle, it is expected that the most appropriate one will be chosen by developing multiple solutions and designs will be realized over the chosen solution.

Activity Supplies

The materials used in the activity process are as follows for each group:

- 80 sugar cubes (although it is mentioned in the name of the sugar cubes, it is said that it is rectangular prism and each sugar is said to be taken as a unit)
- Checked paper (1 piece)
- Glue or liquid adhesive (1 piece)
- Color paint (1 set)
- Cardboard (1 unit)
- Colored cardboards (1 set)

Problem and Background

In design-based teaching processes, students need to solve and discover daily life problems. In this context, the following problem received from a newspaper article was given at the beginning of the activity:

> According to the news of a newspaper, children staying in the hospital completed a study that attracts attention, only a few days to the anniversary of the August 17 earthquake. Sick children who made houses made of sugar with serum on his arm drew attention to building safety and human health. The children, who built beautiful structures by combining sugar cubes with glue, are far superior to architects and pointed out the danger of earthquakes (http://www.haberler.com/hastanede-kalan-cocuklar-sekerden-ev-yapip-depreme-6381246-haberi/).
>
> A very famous Contracting Firm affected by this news organized a design competition on the anniversary of the August 17 earthquake. In the competition,

the prototypes of the buildings must be made of sugar cubes. In this direction, the products expected to be produced by the design groups are (1) the building prototypes created with the materials provided and (2) a poster and slogan that summarizes why the design should be preferred.

It is desired to design a building in the form of a single block, each cube to represent a flat. The main limitation given to the groups in these designs is the use of eighty cubes of sugar. In line with the problem situation, students were expected to create their design products considering the criteria listed below.

Sun exposure flats: It is necessary to consider the lateral surfaces of the cubes as sun exposure sides, considering that each cube sugar represents a flat. In this context, the number of sun exposure sides is scored separately for each flat (such as the flat with three sun exposure sides getting 3 points). To assume that a side of a sugar cube is exposed to sun, the front of the sugar cube must have a width of at least half a sugar cube.

Being economical: Cost is calculated by calculating the land covered by the designed building over the floor area. Since each group is given an equal number of materials, the cost criterion for this activity is evaluated only over the floor area.

Aesthetics and marketing: The modern and aesthetic appearances of the designs of the groups are evaluated by other groups through peer evaluation in line with the presentations they will make and the posters they prepare.

Being earthquake resistant: The earthquake resistance of the designs is tested and scored. In this context, the earthquake resistance of the designed structures placed on a thin plate will be tested in artificial shakes created with the help of a massage tool. All structures will be placed on the plate in order and the shaking intensity will be kept constant. The durability of the structures will be examined by the increasing intensity values by increasing the vibration level of the massager after starting with the same intensity in all structures.

Plan and Practicing

At this stage, design groups are asked to transfer their vertical projections from different directions (top, bottom, right, left, front, back) on squared paper, starting from the base surfaces of their designs that appear in their minds as a result of brainstorming. In these drawings, they are asked to compare the bottom views of the designs and to determine the areas of the underlying drawings on the square per unit of each cubic sugar. It can be ensured that three-dimensional structures with the same bottom views are not always identical. Besides, students realize that all their drawings from different directions are necessary to create the 3D structure.

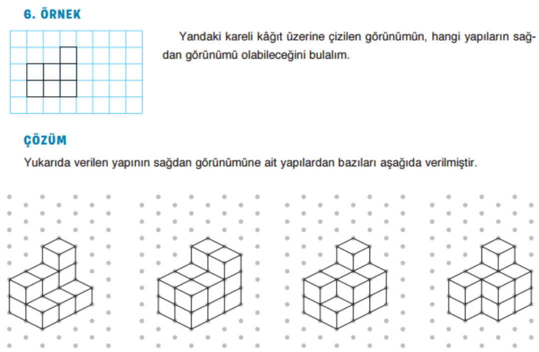

FIGURE 1. Examples of safe and new generation building designs

The groups that transfer their two-dimensional projections on checkered paper will also choose the most suitable designs by considering the criteria. During this selection, the most suitable one is decided by evaluating the solution suggestions made in line with the criteria and limitations. Due to the nature of engineering design processes, it may not be possible to develop a solution proposal that provides all the criteria and limitations. Therefore, at this stage, students are provided with the use of optimization and trade-off skills to create design solutions that best meet the criteria. In this case, it is necessary to design solutions by combining the strengths of possible solutions and to decide what is appropriate by comparing advantages and disadvantages.

Testing and Evaluation

In line with the solution chosen in the previous stage, groups are asked to design three-dimensional structures using unit cubes (sugar cubes). In the design process of the groups, the things that teachers should pay attention to are to give an equal number of sugar cubes to the groups (80 pieces) and to use all the sugar cubes in the form of a single block of 80 flats.

After the groups have completed their designs, they test and develop the scores of each flat based on the number of sides, which are covered by the number of sun exposure sides, the costs over the unit square area covered by the floor surfaces of the buildings, and their designs on the earthquake resistance. The groups design their posters and slogans on cardboard paper based on the final product obtained as a result of the improvements made in line with the testing processes. (See FIGURE 3 for sample designs).

As a result of all these processes, the groups present their final structures with the posters they prepared to the other groups about to what extent they meet the criteria. The basis of the presentation is presenting the arguments about why the target audience should choose the prepared designs. In this context, slogans and posters prepared by the groups are not included in the evaluation but will be used to make the presentations more interesting.

Scoring: In overall evaluation, groups can get 1-6 points for each criterion.

In line with the first criterion, the groups present the total number of sun exposure sides of the eighty flats in the structure designed under the number of sun exposure sides of each flat as a numerical value (Table 1 shows the prototype based on the number of sides that catch the sun.) For example;

10 flats which catch the sun from four sides (10X4 = 40)

10 flats which catch the sun from three sides (10X3 = 30)

40 lats which catch the sun from two sides (40X2 = 80)

A building with 20 flats which have a single sun exposure side (20X1 = 20) gets 170 points on the first criterion.

Table 1. *Sample score table of prototypes depending on the number of sun exposure sides*

	1 Side		2 Side		3 Side		4 Side		Total Number	Overall Score
	Number	Score	Number	Score	Number	Score	Number	Score		
Group 1	20	20	40	80	10	30	10	40	170	1
Group 2	0	0	58	116	21	63	1	4	183	2
Group 3	0	0	40	80	38	114	2	8	202	4
Group 4	0	0	0	0	0	0	80	320	320	6
Group 5	0	0	40	80	10	30	30	120	230	5
Group 6	0	0	60	120	8	24	12	48	192	3

In line with the second criterion, the groups try to estimate the cost with the sugar cubes on the floor area of the building and share it with other groups in their presentations. While calculating the cost of the area occupied by the buildings, the cost of the buildings, which occupy a lot of floor area, will be high as the land cost is high. As a result, the criterion of being economical is ranked and scored inversely proportional to the covered area.

While the earthquake resistance criterion is calculated according to the standing time of the structures, the longest-standing structure gets the highest score, six points. If the structures do not collapse at the end of the process, the groups with these structures get full points.

For "aesthetic and marketing" criteria, peer evaluation is done. Scoring is performed by subtracting one number from the total number of groups. For example, in a practice with six groups, a group can give the highest score of 5 to the group they like in the evaluation process, and 1 point to the group that they like the least (Detailed example evaluation table - Appendix 1).

Practicing the Activity

The design-based teaching activity developed and implemented within this study is intended to be presented as an example of an activity suitable for STEM education focused on mathematics lessons. In this context, the activity was planned as 160 minutes (4x40 minutes) and was carried out with 6 groups of 28 students attending the 3rd and 4th grade. The results of the observations made by the researchers regarding the practice process of the activity will be shared under this title.

Problem and Background

In line with the presented problem situation, the students discussed what was expected of them in groups through brainstorming. In discussions, they talked about what criteria are desired and what they should do in groups for each criterion. At this stage, the teacher walked through the groups and made explanations to the students about the subjects that were not fully understood and answered the questions of the students. Criteria and restrictions are constantly reminded to students. Especially in some groups, students were observed to focus on only one criterion. The practitioner walked through the groups in this process and answered the students' questions.

Plan and Practice

Students were asked to transfer their vertical projections from different directions (top, bottom, right, left, and front, back) on two-dimensional paper, starting from the base surfaces of their designs appearing in their minds in line with the brainstorming. Students working in groups have planned to produce solutions for the problem situation in line with the criteria given at this stage. The students in the group exchanged ideas by presenting their solutions to their friends. The students were asked to transfer their suggestions of solutions from different directions on checkered paper. At this stage, the students had difficulties in transferring their solution suggestions, especially on checkered paper, and they wanted to go through the design process using sugar by passing this step fast as soon as possible. The teacher made explanations to the students to create the best and most useful solution by reminding the importance of this step. The group members discussed their ideas in more detail and reduced them to several alternatives. In this process, the students who presented ideas insisted on making their design by not paying attention to the given criteria, and there were conflicts within the group. The teacher reminded the students what to do at this stage and asked the groups to determine the most appropriate solution in line with the criteria. The students revised the proposed designs by making in-group discussions and chose the most suitable plan for the criteria.

Testing and Evaluation

In line with the solution chosen in the previous stage, all 80 sugar cubes were glued and designed as a single block of 80 flats. In this process, the students first tried to form their structures without sticking the sugars, but when they saw a problem, they redesigned their structures in a way they think would be more suitable to the criteria. At this stage, the students ignored some criteria. For example, two of the groups ignored the criterion of being earthquake resistant and emphasized the criteria of being modern and aesthetic. Another group focused on the criteria of being earthquake resistant and ignored the sun exposure flats criteria.

FIGURE 2: Students working on the problem

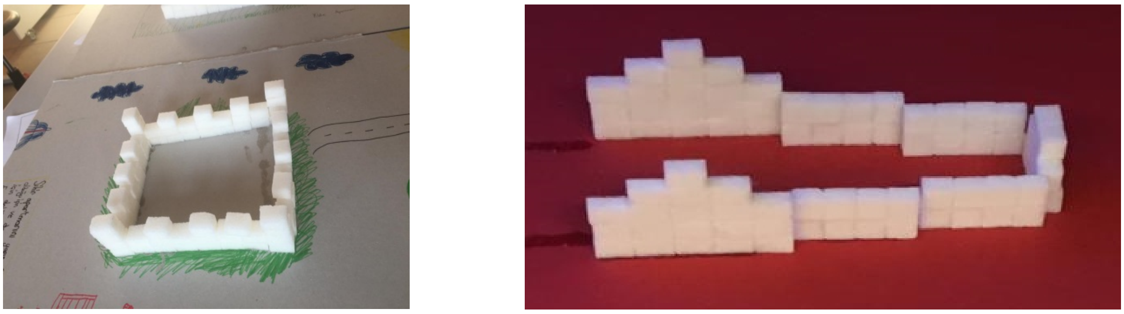

FIGURE 3. Examples of safe and new generation building designs

As a result of all these processes, the groups prepared a presentation on the extent to which they met the criteria, along with the posters they prepared for their final structures. The students created a slogan by naming the project they prepared. The groups presented their designs to other groups with the poster they prepared by explaining why the engineering company should choose their designs at the stage of determining the problem or need. In their presentations, they told their friends about how their designs met the criteria. At the end of the presentations, students in the other group asked questions to the group members who presented. It was observed that 4 of the 6 groups focused more on the aesthetic criteria during the presentation process.

The most difficult criterion for the students in the design process was observed as the sun exposure flats. The students spent a lot of time calculating, as the calculation of the issue of sun exposure required calculations based on numerical data. On the other hand, most of the students focused more on aesthetic criteria than other criteria and highlighted this criterion in the marketing process. Finally, students' arguments about earthquake resistance generally remained abstract. For example, students made presentations in line with the arguments they could not show in their designs such as pile supports that were not in their designs or the type of material used in their designs (steel material, etc.). In this case, the teacher frequently reminded the students that they should score according to the criteria.

RESULTS

In this study, it was aimed that primary school students create an engineering design product using simple and low-cost materials in a safe and new generation building design activity developed in line with the design steps within the framework of quality engineering education. In this process, the four criteria offered to the students were determined as (1) sun exposure flats, (2) being resistant to earthquake, (3) being economical, and (4) aesthetic and marketing. Throughout the design process, the criterion that students had the most difficulty was observed as the sun exposure of the flats. Students spent a lot of time on calculating, as the criteria for the sun exposure of the flats required calculations based on numerical data. On the other hand, most of the students focused more on the aesthetic criterion than other criteria, and they emphasized this criterion most in the marketing process of their products. Finally, the arguments of the students about earthquake resistance generally remained abstract. For example, students made their presentations based on arguments that they could not show in their designs such as rail foundation, pile supports, or the type of materials used.

In the step of developing possible solutions to the design process, the students were asked to transfer the vertical projections of their designs that they developed in the first place on squared paper in two dimensions and to choose the most suitable solution. However, students focused on creating concrete products and materials by passing the process of developing designs on paper as soon as possible. This situation caused differences between the designs they made on checkered paper and the designs they made with concrete materials. Also, they had the opportunity to experience that the unrealistic ideas in the students' drawings could not be transferred to the design.

The role of the teacher in the activity process was to guide the students to remind the criteria and limitations so that they can prepare their designs according to the desired criteria in case of a problem. Students in the design groups focused on different criteria due to their interests and knowledge differences. As a requirement of group work, these students reached consensus by discussing.

While the students were considering the criteria in the design process, they tried to discover and use the basic concepts and judgments of disciplines such as science and mathematics, although they were not included in the outcomes targeted by the activity. For example, they tried to use ideas that are not included in the primary school curriculum, such as pressure, proportion, and the development of three-dimensional objects in their designs. At the end of the process, at the point of preparing a poster and slogan expected from the students, they developed a communication language suitable for their target audience and create messages for their needs. Therefore, an entrepreneurship practice appropriate for the levels of primary school students has emerged.

DISCUSSION

One of the most important limitations that emerge as a result of the meta-synthesis of STEM education studies in Turkey is that the STEM education approach is not suitable for the curriculum and the opportunities in schools. (Kanadlı, 2019). Karahan (2017) also reached similar results in his study on science teachers' views on the STEM education approach. This activity, which was developed in line with the specific objectives and current curriculum outcomes of the mathematics lesson and applied with simple and inexpensive materials from daily life, has the potential to overcome this shortcoming in the field.

In the literature, the need for preparing learning environments and activities for the development of students' creative thinking and solving real-life problems is emphasized (Akbıyık & Kalkan-Ay, 2014). This activity, which aims to help students develop solutions to a current and society-related problem such as an earthquake, aims to provide these skills emphasized in the literature. As a result of the observations made during the application process, it has been determined that the students are willing, and they are qualified to produce creative ideas and offer alternative solutions to the problem. Also, it is criticized that activities related to STEM education are "tinkering", i.e. trial and error, by isolating discipline-specific knowledge and skills. With this activity, which was developed in line with real-life problems and accordance with the specific goals of the disciplines, students’ usage of discipline-specific knowledge and skills while designing instead of trial and error coincide with the objectives of STEM education.

When the literature is analyzed, it shows that three-dimensional structure activities created with unit cubes contribute positively to students' three-dimensional thinking (Olkun, 2003a; Olkun, 2003b; Olkun & Sinoplu, 2008; Yolcu & Kurtuluş, 2010). In their experimental study, Olkun and Sinoplu (2008) revealed that in the context of engineering, the rectangular objects made by students from small cubes help to develop their three-dimensional thinking. In the designed activity, considering that each cube sugar represents a flat, the lateral surfaces of the cubes should be considered as sun exposure sides. In this context, to increase the number of sun exposure sides and to be economical, two-dimensional thinking is required to examine the faces of the building formed in determining the floor area. Examining the properties of the 3D structure they create with unit cubes can contribute to the development of three-dimensional thinking skills, which is an important skill for mathematics, science, and engineering. Also, studies on finding the number of cubes per unit in building studies created with unit cubes may direct students to discover the volume formula themselves (Olkun, 2003a; Olkun & Sinoplu, 2008).

The activity designed in the study can be enriched by adding the criteria of the Impact on the Ground of the created structure. For this purpose, it will be ensured that the pressure created on the ground by the trace left in the flour pool (the amount of dipping into flour) will be observed. By creating graphs showing the relationship between the ground areas of different structures created by different students using the same number of cubes and the amount of dipping into flour, the concept of pressure at primary school level and its associated variables can be intuitively given. If this activity is at the secondary school level, the base surface area is kept constant and they are provided to use the number of cubes per unit. And secondly, they keep the number of cubes per unit constant and form structures whose base surface areas is optional, and in both cases, the sinking amount of the structure in the flour pool and the number of cubes per unit and the base areas of the structures are created. And by planning it in two stages, students can discover the relationships between the variables that make up the concept of pressure and the pressure of change.

It is possible to adapt this activity, which has been developed under the achievements at the primary school level, to the grade levels at different educational levels. For example, it can be aimed to draw the appearance of the building from different directions in line with the achievements at the secondary school level (M.7.3.5.1, M7.3.5.2), to discuss the safest by comparing the pressures of the designed buildings (F.7.2.2.1, F.7.2.3, M. 7.1.4.1, M.7.1.4.2) and to realize the symmetry of the faces and the areas of the formed faces by drawing the views of the buildings from different directions on two-dimensional squared paper (M.7.3.5.1, M7.3.5.2). On the other hand, for students studying at lower education levels, it is possible to reduce the number of cubes per unit (sugar cubes or wooden cubes cut in equal volume) by simplifying the criteria.

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APPENDIX 1: *Evaluation Table*

Groups	Sun exposure flats		Being Earthquake Resistant		Being Economical		Aesthetics and Marketing		Total Points
	Value	Score	Value	Score	Value	Score	Value	Score	
Group 1									
Group 2									
Group 3									
Group 4									
Group 5									
Group 6									