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# Wall Panel Optimization for Refugee Shelters in Germany: An AHP Study

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# WALL PANEL OPTIMIZATION FOR REFUGEE SHELTERS IN GERMANY: AN AHP STUDY

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The German government is experiencing difficulties housing and assimilating Syrian refugees in its borders. Erecting temporary shelters on location is one way to deal with the current crises. This thesis attempts to use Analytic Hierarchy Process (AHP) to determine the optimum combination of materials and construction methods to be used in the shelter's walls in order to improve the living conditions of the refugees and to ensure that the cost is acceptable to the German government. This thesis compares six existing wall panel products from China, which have the lowest cost on the worldwide market. The R-value, strength, price, weight, durability, ease of assembly, assembly time, maintenance costs, comfort, resale value, and appearance were evaluated. Assumptions were made on what the German government would require and on standard building practices in Europe and America. The analysis indicates that the steel frame house from YONGYANG Steel best satisfies the needs in this situation. This thesis produced an AHP template, which is flexible. This model that was developed for the German scenario can be effectively applied to differing emergent situations in other parts of the world.

# Introduction

## Problem Statement

Worldwide, there are many emergency needs for housing because of man-made or natural crises which displace many people. The resulting refugees, forced from their homes, are in urgent need of housing and sanitation facilities. Aid must be provided quickly and effectively to alleviate suffering and help the refugees return to normal and productive lives (Tryssenaar, Jones, & Lee, 1999). Since situations (such as environment, economic, social, etc.) vary throughout the world, the most appropriate building materials and methods to be used also differ. Currently there is a lack of an effective evaluation protocol that can determine the most appropriate solution for these emergency situations.

As an example, in 2011, over 4.8 million Syrian refugees left their own country because of the Syrian Civil War (“Syria's Refugee Crisis,” 2016). To ensure the human rights of refugees, several countries have begun to accept and resettle these refugees within their own borders. In 2015, Germany took in one million asylum-seekers, nearly half of them (484,000) Syrian refugees. Currently, the shelters situated in Germany are fragile and unsanitary, which forces refugees to live in an unacceptable indoor environment; some refugees do not even have a place to sleep (Ben, 2016). Therefore, an immediate need for suitable shelter for the refugees is required in Germany. An effective evaluation tool is necessary to determine the most cost effective method to build housing for this situation.

## Purpose of the Research

This thesis used AHP to determine the optimum combination of materials and construction methods to be used in the shelter’s wall panel.  Germany and its current

Syrian refugee crisis became a case study to illustrate the use of the proposed model which allows users to simulate and evaluate judgments. This research included the available products currently on the market and created a model to help make decisions that would improve the living conditions of the refugees in the most cost effective way.

**Significance of the Research**

Because of a lack of an effective method to determine building methods and materials, there are wastes and inefficiencies in refugee housing. The author developed a decision protocol model to determine a cost effective approach to provide housing solutions in specific situations. With this protocol, the relief agencies would potentially be able to provide improved living conditions for refugees.

**Research Questions**

This research was a case study of the German Syrian refugee crisis and considered variables including environment, labor, cost, life cycle, and the availability of materials. Consideration of each of these must be given in order to determine the proper materials to be used in constructing shelters for the refugees. This research will answer the following questions:

1. What is the most cost effective building method and material for refugee shelters in Germany?
2. Is AHP a suitable method to determine the most cost effective wall panel for emergency housing?

## Assumptions

The German government was expected to respond to the refugee crisis by spending 10 billion euros in 2017. This thesis assume that the German government will keep accept refugees in the future.

Angela Merkel, Chancellor of Germany, said it was important to note that there was a time limit for refugee evacuations in Germany (“Syria's Refugee Crisis,” 2016). Although this inferred that the German government was only looking for a temporary solution for refugees, the time limit was not clear. This researcher assumed the time limit for accepting new refugees was five years, which means that the housing solution would need to be usable for at least that long.

For now, the German government is using hotels to solve the refugees’ accommodation problems, which cost is relatively higher than the shelters. It was reasonable to believe that the German government would be willing to use the shelters to replace renting hotels for living space.

Due to the lack of information on specific German government concerning housing refugees. Therefore, the AHP judgment in this thesis was assumed based on evaluation of publicly available information.

## Limitation and Delimitations

The limitation in this study was the lack of information on specific German government fiscal and social policies concerning housing refugees. Therefore, the judgment input in the AHP was based on evaluation of publicly available information.

There were several delimitations:

1. This thesis built an AHP model based on the case study that focused on the refugees in Germany; only the products considered suitable for this situation were evaluated.
2. This study was based on shelters suitable for the German situation and environment and did not include all locations in the world.
3. This study only evaluated small, simple, easily assembled and disassembled shelters since this was a short-term solution.
4. This thesis was a case study on the German situation by using AHP, therefore the mathematical algorithm was not defended in this thesis and only a brief description of this method was provided.
5. Due to limited resources, the result of this thesis would not be tested. Tests and experiments are strongly suggested for future study.
6. The problem of housing was an immediate need so that the building structures (wall panels) were needed within months. It would take several years for any firm to engineer and manufacture wall panels in sufficient numbers to meet the housing needs. This necessitated the delimitation that only existing products built by those who have the capacity to produce the number of panels needed within a short period would be considered in this study.

## Review of Literature

### Multi-Criteria Decision Making (MCDM) Method

Multi-Criteria Decision Making (MCDM) is a decision-making method used to evaluated multiple criteria which cannot be determined straightforwardly (Triantaphyllou, 2000). Currently, there are a variety of MCDM methods available. Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) allows tackling the problems by working with quantitative or qualitative criteria under uncertainty and imprecision (Ebrahimnejad, Mousavi, Tavakkoli-Moghaddam, Hashemi, & Vahdani, 2012). Multiattribute Utility Theory (MAUT) is a decision-making method based on the decision maker's evaluation of risk exposure and mitigation options (Dyer, 2005). Multicriteria Optimization Problems (MOP) uses the computer to calculate different decisions and the preference based on the data (Ehrgott & Tenfelde-Podehl, 2003). The general characteristics of the different methods are shown in table 1(De, Droste, Omann, Stagl, 2000).

Table 1

*General Characteristics of MCDM methods*

| | AHP | NAIADE | MAUT | MOP |
|---|---|---|---|---|
| Interdependence of criteria | Necessary | Unimportant | Unimportant | Necessary |

| | AHP | NAIADE | MAUT | MOP |
|---|---|---|---|---|
| Transparency of weighting process | Weights given explicitly by mean of pairwise | Weights are not set explicitly | Depend on expert decision | Weights given explicitly |
| Problem solving process | Only decision maker involved | Only experts involved | Only representatives & experts involved to derive the matrix | No stakeholders included. Problems structured regarding to existing data |
| Applicability | Used for local scale problem | Used for local scale problem | Used for local scale problem | Used for local scale problem |
| Types of data | Quantitative & qualitative data used | Crisp, fuzzy & linguistic data used | Qualitative data used | Fuzzy & linguistic data used |

*Note.* The general characteristics of each MCDM method. Adapted from "Criteria for quality assessment of MCDA methods," by De Montis, A., De Toro, P., Droste-Franke, B., Omann, I., Stagl, S, 2000, *3rd Biennial Conference of the European Society for Ecological Economics*.ESEE, Vienna, 3–6 May 2000.

Calculating the best wall panel for the shelter was complicated because it involved a range of factors, from categories ranging from precisely measurable, though difficult to measure, to totally subjective. AHP is a widely-used method that can analyze quantitative and qualitative data together. Therefore, it was a suitable method for this thesis to compare the products.

**Analytic Hierarchy Process (AHP)**

Analytic hierarchy process (AHP) is a structured technique based on mathematics and psychology (Forman & Saul, 2001). It organizes the various factors of a complex problem into an orderly, interrelated pair-wise structure from which they can be evaluated according to certain objective and subjective judgments. AHP directly and effectively combines the judgments to quantitatively describe the relative importance of the elements of the pairwise comparisons. The weights of the relative importance of each element are calculated by mathematical methods and the relative weights of all the elements are sorted by the criteria (Saaty, 1990).

Studies show that AHP is a powerful decision-making tool used worldwide to support decision making (Forman & Saul, 2001). AHP has been applied in information systems, supply chain management, public services, health, strategy, and manufacturing (De, Droste, Omann, Stagl, 2000). However, these studies did not compare product materials with things such as cost, weight, strength, and appearance together. The mathematical calculations of AHP have been proved reliable by a study done by Ishizaka, Balkenborg and Kaplan (2011).

The general procedure for using the AHP can be summarized in five steps (Saaty, 2008).

1. Model a hierarchy which starts with the decision goal, then branch out with alternatives that are evaluated by criteria that affect the decision.
2. Establish a ranking priority system to make pairwise judgments for each element.
3. Synthesize these judgments by using AHP mathematics to set overall priorities for the hierarchy. To calculate the order of importance, a pairwise comparison is reasonable. The intensities of importance in the decision are shown in Table 2 (Bhushan & Kanwal, 2004).
4. Check the consistency rate of the judgments. Since each subject is compared to each other subject one by one, it is possible for these comparisons to be inconsistent. The consistency ratio measures the inconsistencies in AHP. (Saaty 1980). A ratio of 0 means perfect consistency while any ratio over 0.1 is considered inconsistent.
5. Make a final decision based on the numerical result of the analysis.

Pairwise comparison is an important step in AHP. However, AHP is criticized in cases in which too many criteria or alternatives are involved because it has led the person who is making judgments to lose patience which then has led to logistical mistakes. For example, a person makes pairwise comparisons of three items, A, B, and C. If A is more important than B by an intensity of importance of 9, and A is more important than C by an intensity of importance of 7, then C should be slightly more important than B. However, a person rarely considers the relationship between three items since the judgment is independent in each pair of comparisons. The person might consider C to be more important than B by an intensity of importance of 5 or 7, which is logically wrong.

To avoid this mistake, judgments may be altered in iterations until an acceptable consistency ratio is achieved.

If only important criteria are considered and are kept to as few as possible the accuracy of AHP is improved (Saaty 1980). AHP is the most appropriate method for this study because this method is very suitable for complex social issues in which intangible and tangible factors cannot be separated. (Lee & Chan, 2008).

Table 2

*Intensity of Importance in Decisions*

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two elements contribute equally to the objective |
| 3 | Moderate importance | Experience and judgment slightly favor one element over another |
| 5 | Strong importance | Experience and judgment strongly favor one element over another |
| 7 | Very strong importance | One element is favored very strongly over another; its dominance is demonstrated in practice. |
| 9 | Extreme importance | The evidence favoring one element over another is of the highest possible order of affirmation |

*Note*. Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance. Adapted from "Strategic Decision Making: Applying the Analytic Hierarchy Process," by Bhushan Navneet & Kanwal Rai, 2004, London: Springer-Verlag. ISBN 1-8523375-6-7.

## Refugee Situation in Germany

The animosity between the German people and Syrian refugees has increased recently. The Berlin Senate sought hotel rooms for 10,000 refugees throughout the city. Currently, the Berlin government intends to sign a multi-year contract with a total estimated expenditure of at least 455 million euros (Frida, 2015). While homeless Germans have slept on the streets, the government plans on spending more money to support refugees. German citizens have not been happy about the cost of the refugees' problem, which has led to massive conflicts between the German people and refugees ("Syrian Refugee Admits," 2016). On the night of January 1, 2016, Cologne, Germany had a large-scale outbreak of sexual assaults, in which over a hundred Germans were assaulted. Many victims identified the perpetrators as refugees. This pushed the refugee issue controversy to the forefront of public opinion (Melissa, 2016). These problems have led to an urgent need for cheap and reliable shelters in Germany.

Since Germany has limited natural mineral resources (such as steel, aluminum, tungsten, tin, manganese, titanium, etc.), Germany is highly dependent on imports. According to statistics, Germany has a negative import-export balance for resources, which leads to Germany only being able to supply limited resources (Charles et al., 2017). Therefore, this limits the possibility that the German government would be willing to use natural resources from their country. Additionally, German industry cannot process much raw materials and is almost entirely dependent on imports of processed materials. The price of the materials has depended largely on China, which is a major supplier to Germany (Liesner, 1997).

**Germany Requirement Criteria**

In an AHP hierarchy, in which the priorities for the German government's procurement of shelters for refugees are ranked, the goal is not only to choose the best shelter for the refugees but also to build shelters for which the German government is willing to pay.

Germany's fourth-largest city spent almost $7 million to rent the four-star hotel Bonotel in the summer of 2014 (Carlo, 2014). According to Carlo's report, the German government has been looking for cheaper hotels. Cost has been a huge factor in this situation, however, because they have been looking for a temporary housing solution for refugees, the German government has not wanted to build standard housing for them.

The refugees' safety was also an important criterion to be considered. Germany has ratified most international human rights treaties and is endeavoring to be a leader in aiding refugees. Reports from independent organizations such as Amnesty International certify Germany to have a high level of compliance in terms of human rights ("Germany," 2009).

**The Benefits of Using Temporary Housing**

By 2015, the total number of refugees arriving in Germany had reached 1.1 million. How to help refugees integrate into the German society has become a major financial problem for Germany. Meanwhile, a report released by the Central Florida Commission shows that homelessness is not cheap either. In 2014, the true expense for the US government for one homeless individual was roughly $31,000 a year. This cost included emergency services, law enforcement, and hospital visits ("The Cost of Long-Term Homelessness," 2014). In contrast, a research conducted by homeless expert Kate

Santich (2014) showed that providing permanent housing to homeless individuals cost about $10,000 per person per year. This study also showed that if homeless people were given their own permanent housing, their health improved significantly and cost to treat them was reduced significantly. Germany has homeless issues similar to America, and the deadly winters in Germany have resulted in almost one thousand homeless frozen to death each year (Langnäse & Müller, 2001). The refugees from Syria have endured long, grueling journeys, often with appalling living conditions, to reach Germany. Studies on refugees signified that the mental state of refugees is comparable the homeless (Anderson, 2001).

By promoting these shelters, it would not only save the government money but also improve the stability of society by offering shelters to both homeless people and refugees. This research could not only improve living conditions but also promote job opportunities among the refugees by giving them the opportunity to help construct their own shelters, and thereby gain valuable employment skills.

**U-Value**

The highest annual temperatures tend to be in the southwest, the area which this author assumes that the German government is planning to settle refugees. Eurima has done a study to show the requirements and recommended U-values in Germany in Table 3 (Morris & Chapman, 2007).

Table 3

*Requirements and/or Recommendations on Component Level*

| Existing requirements U-value [$W/m^2K$] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| City | Country | ISO 3166-1 | Wall | | Roof | | Floor | |
| | | Country code | Low | High | Low | High | Low | High |
| Berlin | Germany | DEU | 0,30 | 0,30 | 0,20 | 0,20 | 0,40 | 0,40 |

*Note*. This recommendation was formed in 2007. Adapted from "U-values in Europe. European Insulation Manufacture Association," by Morris & Chapman, 2007, April, Retrieved from: http://www.eurima.org/resource-centre/facts-figures/u-values-in-europe.html

**Type of Construction**

The following presents possible shelters that could satisfy the basic needs of the shelters for Germany, and a comparison to each other. In order to be able to determine all the reflective and possible materials that could be used for the shelter, including the framing materials and internal wall materials, it was necessary to compare different framing styles for the shelter.

There are numerous platform methods worth investigating, but by far, the timber-based platform method has been the most popular way to frame houses. However, wood has been proven vulnerable to rot and termites, and frames have often shrunk and caused cracks in the plasterboard and coating (Glover, White & Langrish, 2002). Steel framing and structural insulated panel (SIP) would be the more reliable choice for Germany.

**Steel Framing Structure (Engineered Building)**

Metals like steel have been used for constructing conventional free-standing homes, which are suitable for shelters in this situation. Portable dwellings are a good option and have been very popular around the world (Saab, 1991). This building style has normally employed light steel as the skeleton, covered by a single steel sheet with insulation material, and used bolt for components. It could be quickly and easily assembled and taken down to achieve a common standard for temporary buildings and to establish a green energy efficiency.

The main advantages of the steel frame building have been space separation, flexibility, lightweight materials, material savings and speed of construction. Because of the flexibility with the architectural layout, a larger living space could be arranged. However, there have been several shortcomings of the frame structure system. First, the stress is significantly concentrated on the frame. Under the force of a strong earthquake, the horizontal displacement of the structure is large, which can cause serious non-structural damage. Second, the amount of large frame members requires lifting equipment. Overall, this would use more manpower than other methods of construction. Third, it is not suitable for the construction of high-rise buildings. The framework is composed of beam and column structure. Therefore, its bearing capacity is low, especially in the horizontal direction (even with the consideration that the cast-in-place floor and the beam work together to increase the horizontal stiffness of the floor). Its force characteristics are similar to the vertical cantilever shear beam. The overall horizontal displacement is large, but relative to the floor, the deformation between the layers is small. Lateral stiffness is an important factor for the reinforced concrete frame.

Therefore, cross-sectional size and reinforcement increase causing complications to the design layout and rational use of building space. Fourth, in the case of material consumption and cost, the frame structure also tends to be unreasonable when building a high-level building (Baddoo, 2008). It is generally applicable to the construction of not more than 15 floors of housing. The author found that this is insignificant in this case because the shelters will not be high rise construction.

**Advantage of Portable dwellings**

Portable dwellings use a steel framing structure. Its features are favorable: easy to disassemble, easy to transport, easy to move, and suitable for activities located in the hills, grasslands, deserts, and riverside. It does not take up much space, and so it can be built for a range of 15-160 square meters. It is not only easy to clean and use, but it also can be built with complete indoor facilities, which include a toilet and kitchen. The stability and durability of portable dwellings are relatively higher than normal shelters. According to the customer requirements for design, both elegant and good insulation properties are necessary. However, most of the activities of building the structure are completed in a factory (Baddoo, 2008).

**Sample of Steel Framing**

A typical steel frame consists of 80x80x15mm solid square steel, which is standard steel framing in China. If the size is changed, it will add an unnecessary customization fee. From Alibaba.com, three company products have satisfied these needs with a low price.

First, Andy Steel Structure's product, presented with a lower price of US $30-60 / Square Meter with assured quality, was a good choice ("Andy Steel," 2016). These are made of carbon structural steel Q235 and high-strength structural steel Q345. These qualify for  all the standard certificates to build these walls for the shelter which include ISO9001:2000, code for design of steel structure; GB 50017-2003, technical code of cold-formed thin-wall steel structure; GB50018-2002, load code for the design of building structures; GB 50009-2006, construction quality acceptance of steel; GB50205-2001, code for design, construction and acceptance of high strength for steel structure; JGJ82-2011, technical specification for welding of steel structure building; JGJ 81-2002, technical specification for steel Structures of tall buildings (JGJ99-98).

The structure assembly of this project used factory welded steel that was bolted together on site construction and bolts. The surface treatment was either galvanization or paint. This product has displayed these advantages: (a) Environmentally friendly; (b) Higher reliability of steel work; (c) Highly quakeproof; (d) Higher degree of industrialization; (e) Quickly and accurately assembled; (f) Larger interior space.

The second product choice was light steel villa from Hunan ADTO industrial group co. (“Light Steel Villa,” 2016). They offered a light steel frame with a cost of US $30-65 / Square Meter. They also used carbon structural steel Q235 and high-strength structural steel Q345 grade B. They were qualified to hold the standard certificates, which include GB50661, JGJ81, BS4592, ASM, and JIS ISO.

The last steel product was the structural steel frame house from YONGYANG Steel (“Structural Steel Frame House,” 2016). This company offered a product made of welded W shaped steel (wide flange beam). The columns were connected to the foundation by pre-embedding anchor bolts. The unit price range was from USD45/m2 to USD120/m2. It could last for 50 years. The walls and roof were made of colored steel sheets or color steel sandwich panels, which were connected to purlins by self-tapping nails. This product was also environmentally friendly, structurally stable, earthquake resistant, waterproof, and energy conserving.

**Structural Insulated Panel (SIP) Walls**

Structural insulation panels (SIP), also known as structural insulation boards, are constructed like a sandwich. Inside of SIP is a rigid foam material or other insulation materials. The external thin layers could be made of plate, wood, cement pressure plate and other thin material. The common types of core materials are EPS, XPS, PU and inorganic insulation materials. The common types of materials for external panels are pressure plates, Ou Song boards, Campanulas and other wood panels, cement pressure plates, gypsum boards, and other inorganic plates. This structural type of composite sheet has had good thermal insulation properties, seismic performance and light high strength characteristics (Steven, Harvey, John & Dennis, 1997). In North America, Europe and other western countries, the SIP residential system was widely used in civilian and commercial residential work. SIP constructions were as simple as building blocks, which greatly save construction time and cost. As an important part of the building, the wall not only needed to achieve enclosure, fire resistance, noise resistance, insulation and other needs, but also needed to bear wind and earthquake pressure. The wall needed to have sufficient carrying capacity to ensure safety (Michael, Mullens & Mohammed, 2006).

**Studies on SIP**

The test data and research information on SIP have mainly been gathered in the past 20 years. In the mechanical properties, Steven B. Taylor, Harvey B. Manbeck, John J. Janowiak & Dennis R. Hiltunen (1997) have researched the SIPs components in an experimental study which established the directional particleboard panels, polyurethane foam board and polystyrene foam board core SIP bending creep model. They derived a formula for SIPs bending or deflection over with time. Borjen Yeh, Thomas Williamson & Edward Keith in 2008 designed SIP tests to do bending, axial pressure, and shear and pressure testing. They published the SIP standardized test on EWA (The Engineered Wood Association). The report of this test specifies the requirements for SIP panels, core materials and adhesives. Abdy Kermani and Robert Hairstans tested SIP's ability to bend, axial compression, and use of directional particleboard as a panel. These tests showed the SIP's strength and stiffness meet the requirement of design loads (2006). Kermain also summarized the influence of the height on the axial bearing capacity and the effect of the opening ratio on the lateral force of the structural insulation board. Cao Hai and Yan Shuai studied SIP insulation characteristics and derived the best thickness for the energy-saving insulation requirements (2006). However, in this study they did not consider the cost of insulation materials.  Cao Hai and Yan Shuai also did a SIP bending test on four points of the SIP wall, and the results show that the lateral bearing capacity of the popcorn plywood is higher than that of the camouflage plywood when it is used as the sip panel (2006).

At present, there is little independent research on the seismic performance of the SIP plate structure (Panjehpour, & Voo, 2013).  JB Jamison's study found that during the test of the full-scale SIP shear wall for low-cycle repeated loads, SIP could withstand greater deformation than balsa wood plywood 50% (2007) when compared with the light wood structure of the wall. Overall, although the SIP plate structure system as a building structure sheet has a significant advantage, the study of SIP as a wall is insufficient.

**Disadvantage of SIP**

First, SIP has a high level of air-tightness. Because of the air-tightness of the building, a suitable ventilation system will be required in the house. This requirement applies to any air tight construction. To maintain energy efficiency, a mechanical ventilation system using methods such as air to air heat exchangers is necessary. If a window is used for fresh air, then the heat loss negates the value of the air-tightness. SIPS are, by nature, air tight so this ventilation problem is noteworthy, but any air-tight construction would require the mechanical ventilation requirement to be energy efficient.

Secondly, SIPs quality varies greatly. The manufacturers might deliver very different qualities due to the lack of high standard controls. It is necessary to study and keep a close relationship with the manufacturer.

Thirdly, modification on a SIP is very pricey. After they are shipped from the factory, any amount of required change would be very expensive due to the standardization (Michael, Mullens & Mohammed, 2006).

**Sample of SIP**

To compare with steel framing, a standard size of SIP walls would be 4X2.5M. From Alibaba.com, there were three company products that could satisfy the product's needs with a low price.

First, SIP panels from ZHONGJIE was available with a price of US $12.56 / Square Meter ("China SIP Panels," 2016). They use steel for SIP skin and offer three types of skin: pre-painted steel, stainless steel, and aluminum. The thickness of steel is 0.4mm-0.8mm and provide customized coloring, which includes white, blue, red, and any other RAL colors based on quantity. The insulation material is 100mm polyurethane foam. The SIP panels are connected by using tongue and groove of 75mm corrugated polyurethane insulated sandwich panels. Because of the design of SIP panels, its insulating property can be sustainable for more than 30 years for its special closed-cell structure and resistance to gas diffusion. The average life expectancy of rigid polyurethane foam can be more than 30 years under normal use and maintenance. It won't be destroyed by fungi and algae growth or rodents. It is also fireproof with a high temperature resistance. It can resist 250 degrees Celsius and decomposes at a higher temperature. A layer of carbon will be formed if it is lit, which will effectively prevent the spread of the flame.

The second one was a lightweight fiber cement MgO board SIP panel by Leader ("Fiber Cement MgO Board SIP," 2016). This SIP panel uses Magnesium Oxide Board and Galvanized Steel sheets as skin on both sides and EPS as isolation materials. It only costed $50 per square meter. With deadweight light, giraffe fitting, and random incise characteristic, the fitting is much simpler, and it can save a lot of time to build the shelters. This panel is guaranteed to last for 10-15 years, and the panel's life expectancy is raised to 35 years by painting the antisepsis material.

The third product was an EPS cement sandwich wall made by Longhe ("Longhe Lightweight Interlocking EPS," 2016). It uses cement fiber reinforcement board or calcium silicate board on both sides of the surface panels and poly-phenyl granule, cement, coal ash (sand) and other additives as filling materials inside. The cost of this material was $40 per square meter. The weight of this panel is 1/8 of a solid brick wall, which means it can be carried by human beings without the aid of heavy equipment. The intensity is C30, which helps adjust the indoor humidity automatically. Because it is similar to brick, it is easier for operation and installation. It also uses cement for installation, which is easier for the worker.

Table 4

*Characteristic of Each Product*

| Characteristic | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber Cement MgO Board | EPS Cement Sandwich Wall |
|---|---|---|---|---|---|---|
| Insulation | Good | Good | Good | Good | Good | Good |
| Price $ | 30-60 | 30-65 | 45-120 | 80 | 50 | 40 |
| Withstand pressure Kg/m2 | 85 | 95 | 110 | Good | Average | Very good |
| Withstand earthquake | 7 | Resistant | Resistant | NA | NA | NA |
| Withstand typhoon | 10 | 10 | 10 | 6 | 5 | 6 |
| Lifetime/years | 10 | 15 | 50 | 30 | 35 | 50 |
| Weight/Carry | 80 | 90 | 100 | 60 | 40 | Human carry |
| Resale value % | 75-100 | 75-100 | 50-75 | 75-100 | 75-100 | 0 |

**Type of Insulation Material and Cost**

All these companies offered different choices of insulation material, which included extruded Polystyrene (XPS), expanded Polystyrene (EPS), and PU/PF (polyurethane). These are the most common insulation materials around the world. According to the study done by Jon Haehnel and Mike laCrosse (2017), the $/R-value column is the most accurate way to compare insulation types. It can compare insulation systems' effectiveness at the same level of cost. The $/R-value is shown in Table 5. This data was used in chapter four to decide which insulation material is best suited for this case.

Table 5

*General Insulation Costs*

| Insulation Type | R-value/inch | Thickness for R19 | $/sq.ft.(R19) | $/bd.ft |
|---|---|---|---|---|
| Expanded Polystyrene(EPS) | 4.0 | 4.8 | 4.04 | 0.85 |
| Extruded Polystyrene(XPS) | 5.0 | 3.8 | 4.37 | 1.15 |
| Polyurethane Board | 7.2 | 2.6 | 3.17 | 1.2 |
| Fiberglass Batt | 3.2 | 5.9 | 0.88 | 0.15 |

# Methodology

## Create AHP Template

The author used analytic hierarchy process to create a template that organized and analyzed the feasibility of the differing panels for the shelter. To satisfy the needs of refugees, it was necessary to understand what the German government is willing to offer and what they expect.

## Object Selection

To find a better combination of the materials to be used in the shelters' walls, it was first necessary to select the objects to be compared. Two methods of building walls were presented in chapter two. The three best samples of each method were compared to each other for further study. Based on the assumption that the shelters need to be built now to meet the needs of the refugee crisis, the time to engineer a new type of panel is prohibitive. Thus, existing SIPs on the market was evaluated.

## Methodology of Comparison

To compare the six samples shown in this research, knowing that there are many pairwise comparisons to depict, this researcher made worksheets to align the comparative information. Table 6 is an example of a worksheet which gives the mathematical content of each set of comparisons. This example shows four subjects compared to one factor.

Table 6

*Example of Comparisons Worksheet*

| Comparisons | | | Factor | | Better subject | Difference amount | Better by ratio | Under/(Over) Basic amount 15 | |
|---|---|---|---|---|---|---|---|---|---|
| # | A | B | A | B | | | | A | B |
| 1 | Subject A | Subject B | 10 | 30 | A | 20 | 3 | 5 | (15) |
| 2 | Subject A | Subject C | 10 | 15 | A | 5 | 1.5 | 5 | 0 |
| 3 | Subject A | Subject D | 10 | 5 | B | 5 | 2 | 5 | 10 |
| 4 | Subject B | Subject C | 30 | 15 | B | 15 | 2 | (15) | 0 |
| 5 | Subject B | Subject D | 30 | 5 | B | 25 | 6 | (15) | 10 |
| 6 | Subject C | Subject D | 15 | 5 | B | 10 | 5 | 0 | 10 |

Table 6 worksheet did not consider things like budget, or the relative value to the German government of saving between $100 and $500 per shelter. However, these considerations can be very important in making decisions. This importance can vary greatly because of different situations for the government and the people involved. In some situations, the German government would never be allowed to exceed their budget.

The AHP put value judgments of the decision maker into the data, rather than just the data itself. Therefore, after imputing the data, another worksheet was built to help judge the data by AHP standards. The comparative values were derived from perceptions of the strength of component properties, which were imported into the AHP software.

For instance, in this example situation, the decision maker was willing to exceed their basic amount by up to 5, but anything more was unacceptable. However, subject B would score as low as possible on this factor, but it wouldn't t be removed from the list. For subjects under the basic amount, a 5-point difference to the basic amount does not matter much to the decision maker, but a 10-point difference is very important, and a 15-point difference is extreme. Based on this situation, the example of a judgment worksheet is shown in Table 7.

Table 7

*Example of Judgment worksheet*

| # | Better subject | Intensity | Note |
|---|---|---|---|
| 1 | A | 7 | B is over basic amount |
| 2 | A | 3 | Almost same to decision maker |
| 3 | B | 3 | Almost same to decision maker |
| 4 | B | 7 | A is over basic amount |
| 5 | B | 9 | A is over basic amount |
| 6 | B | 5 | A is 10 more |

After the judgments shown above are entered, this research built a decision matrix and assigned priorities to all the alternatives. The decision matrix of this example is represented by Table 8. In this example situation, this factor is 0.22 of global priority. The example of priority in respect to the decision is shown in Table 9. The calculation of this AHP would be done by Excel because of calculating it by hand is not practical. Additionally, Excel helped researcher to draft the table easier than by hand.

Table 8

*Example of Decision Matrix*

| Subject | Subject A | Subject B | Subject C | Subject D |
|---|---|---|---|---|
| Subject A | 1 | 7 | 3 | 0.33 |
| Subject B | 0.14 | 1 | 0.14 | 0.11 |
| Subject C | 0.33 | 7 | 1 | 0.20 |
| Subject D | 3 | 9 | 5 | 1 |

Table 9

*Example of Priority*

| Subject | Local priority | Global priority |
|---|---|---|
| Subject A | 0.264 | 0.05808 |
| Subject B | 0.037 | 0.000814 |
| Subject C | 0.140 | 0.0308 |
| Subject D | 0.559 | 0.12298 |
| Total | 1.000 | 0.22 |

**Comparing the Alternatives with Respect to the Criteria**

The next step was to evaluate each of the samples with respect to importance. In the technical language of AHP, this paper compared the alternatives with respect to the criteria and arranged the global priorities for each of the alternatives. The total of the components must equal 1.000, the best choice is the highest value. Each alternative had a priority for Germany's judgments concerning. After this comparison, there was a clear decision for this case, which can also clearly be seen, traced, and evaluated by all concerned. Finally, all the components were incorporated into a matrix which indicated the optimum panel for the shelters in Germany.

## Findings or Results

### Calculating Wind Load

High-speed winds can be very detrimental because the pressure against the surface of walls can be destructive. This pressure is the wind load. The effect of the wind is dependent upon the size and shape of the structure (Dyrbye & Hansen, 1996). To decide the strength of the shelters and safety, it was necessary to calculate the wind load.

To assure the shelter's safety against strong winds, suppose the wind speed is 70mph, which is a scale ten typhoon. The ceiling height in Germany is 2.5M for this application (Lentz, 1982). To ensure comfort for the refugees, the shelter walls needed to be 4M$(length)\times$ 2.5M (height) for the living area and 3M$(length)\times$2.5M (height) for the kitchen and toilet.

To define the wind load in this situation, the Uniform Building Code (UBC) formula which was developed in 1997 was used. The formula for wind load is F = A x P. The A stands for projected area and P stands for the pressure. P = Ce x Cq x Qs x Iw is the formula to define the pressure. Ce stands for combined factors like height, exposure and gust response. Cq stands for the pressure coefficient. Qs stands for the wind stagnation pressure. Iw stands for other importance factors (John, 2015).

The formula to calculate A (area) is A=length×width. The area is 4M×2.5M for the panels for the shelters. Because units area are calculated in $ft^2$ in the UBC formula, A=13.1234$ft$×8.2021 $ft$=107.6$ft^2$.

Ce value is chosen based on Table 16-G of UBC and takes three exposures into account, exposure B, C, and D. Exposure B represents terrain buildings or trees 20ft or higher covering 20% of the surface within a mile of the building. Exposure C represents generally open terrain within a mile of the building. Exposure D represents very open terrain (as near bodies of water) with the highest wind speeds. In this situation, it was reasonable to choose exposure B based on Table 16-G. Using the height of 7.62 ft, Ce is 0.72 (Zahid, 2010).

Cq is the same as the drag coefficient. According to Mark D. Powell, Peter J. Vickery & Timothy A. Reinhold's researches on drag coefficient (2003), the Cq for the short flat plate is 1.4.

Qs = $0.00256 \times V^2$, where V represents the wind speed (mph). A wind speed value of 70 mph, corresponding to a scale ten typhoon, was used to maintain a reasonable factor of properties. So, Qs=12.544psf.

Iw stands for the importance factor. It was determined by using Table 16-K of the UBC. These shelters were standard buildings; therefore, the Iw was 1.

Thus, the wind load of this situation was F= $A \times P = A \times Ce \times Cq \times Qs \times Iw = 107.6 \times 0.72 \times 1.4 \times 12.5 \times 1 = 1356.25 Lbs$= 615 kg. So the pressure on the wall P would be P=$\frac{F}{S}$=$\frac{615}{4 \times 2.5} = 61.5 kg/m^2$. Therefore, further experiments would prove that the panels on the shelters should resist a pressure of $61.5 kg/m^2$.

To summarize, the basic need for the shelter was that it can hold a wind load of at least $61.5 kg/m^2$, 3.33 R-value, and 2 million of these must be supplied to accommodate the current and coming needs. These basic needs defined the minimum requirements of what this shelter must be able to accomplish. Therefore, any shelter that couldn't satisfy these basic needs should not be considered. All six selected products satisfied this basic requirement.

**Create a AHP Hierarchy**

According to the criteria considered in Chapter two, the German government might decide to consider cost, properties, and the ability to easily assemble and style as the criteria for making their decision. The cost criterion could be subdivided into price per shelter, weight (the heavier the shelter, the greater the cost for transportation), maintenance costs, and resale value. Properties can be divided into durability, R-value and strength.

The decision in this situation required a reasonable but complex hierarchy to describe. It involved factors from the tangible and precisely measurable (price per shelter, R-value, weight), through the tangible but difficult to measure (maintenance costs, marketing price, resale value, durability) to the intangible and very subjective (style, feeling, ease of assembly). The hierarchy could be diagrammed as figure 1.

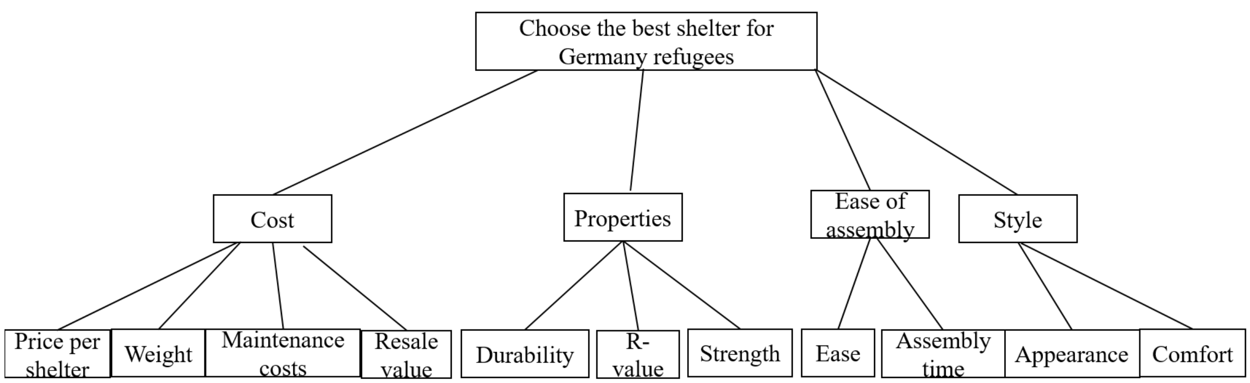


*Figure 1.* AHP hierarchy for the shelter decision. The decision tree was divided into four criteria: cost, properties, assembly ease, and style. Criteria cost was divided into four sub-criteria: price per shelter, weight, maintenance costs, and resale value. Properties were divided into three sub-criteria: durability, R-value, and strength. Assembly ease was

divided into two sub-criteria: ease of assembly and assembly time. Style was divided into two sub-criteria: appearance and comfort.

The measurements for some criteria, such as price per shelter and R-value, can be stated with absolute certainty numbers. Others, such as resale value, ease of assembly, is estimated with less confidence. Additionally, criteria such as appearance and comfort, are subjective and are hard to state quantitatively at all. The AHP accommodated all these types of criteria, even when they were all present in a single problem.

To incorporate the judgments about the various elements in the hierarchy, it was necessary to compare the elements two by two. The criteria was judged by how important they were to the German government. To calculate the order of importance, a pairwise comparison was reasonable. The comparisons were shown in Table 2 (Bhushan & Kanwal, 2004). Each pair of items in this row were compared; there were a total of six pairs (cost/properties, cost/style, cost/ease of assembly, properties/style, properties/ease of assembly, and style/ease of assembly). This thesis used an AHP software, BPMSG AHP Online System, which helped to determine the inconsistencies of each of the pairwise comparisons. The judgment of each subject would be reconsidered if the consistency ratio was higher than 0.1.

The first pairwise comparison was cost vs. properties. This could be a difficult decision. On the one hand, nothing was more important than a life. But on the other hand, the German government had a limited amount of money to spend, and due to the increasing conflict between refugees and citizens, it was necessary to keep the budget as low as possible. So it was necessary to help the German government decide which criterion was most important to them in reaching their goal, and how much more important each criterion was in comparison to the other criteria. However, since the AHP was a flexible process, it could always change the judgment later if circumstances change.

For now, it was reasonable to assume that the German government considers properties most important. The Berlin government intended to sign a multi-year contract with a total estimated expenditure of at least £ 455m (Frida, 2015). This was quite generous to refugees. Since these two criteria were almost of equal importance to the Germans, this would be a 3 in favor of properties.

The second pairwise comparison was cost versus ease of assembly. For the German government, the cost of the shelter was more important since the major issue was that the cost of refugees was too high for people to accept. However, the assembly ease determined the speed at which the shelter can be set up. Therefore, this would be a 7 in favor of cost.

The third pairwise comparison was cost versus style. The German government's priority for this shelter was the basic life needs of people living there, which led to style being less important compared to cost. So this would be a 7 in favor of cost.

The Fourth pairwise comparison was properties versus ease of assembly. Since properties was slightly more important than cost, this would be a 9 in favor of properties.

The fifth pairwise comparison was properties versus style. Even for refugees themselves, properties were before style because they would want a safe place to live rather than just look better. So this would be a 9 in favor of properties.

The last pairwise comparison was assembly ease to style. For the German government, ease was more important since it affected the time to set up. This would be 3 in favor of ease of assembly. There was a logical loop between assemble ease, style and cost. In this case, if the consideration was 1 between ease of assembly and style, the CR would be reduced to 3 %. However, this author considered the assemble ease was more important than style. According to AHP rules, as long as CR is lower than 10%, it was reasonable and logical.

The final judgment is shown in Table 10. The calculations to convert these judgments to priorities for each of the four criteria was shown in Table 11.

Table 10

*Judgment in Major Criteria*

| Criteria | Cost | Properties | Assembly ease | Style |
|---|---|---|---|---|
| Cost | 1.00 | 0.33 | 7.00 | 7.00 |
| Properties | 3.00 | 1.00 | 9.00 | 9.00 |
| Assembly ease | 0.14 | 0.11 | 1.00 | 3.00 |
| Style | 0.14 | 0.11 | 0.33 | 1.00 |
| Total | 4.29 | 1.56 | 17.33 | 20.00 |

*Note*. CR=9%<10%.

Table 11

*Normalized Score Table*

| Criteria | Normalized score cost | Normalized score properties | Normalized score ease of assembly | Normalized score style | Row sum | Percent ratio scale of priority |
|---|---|---|---|---|---|---|
| Cost | 0.23 | 0.21 | 0.40 | 0.35 | 1.20 | 30.03 |
| Properties | 0.70 | 0.64 | 0.52 | 0.45 | 2.31 | 57.80 |
| Ease of assembly | 0.03 | 0.07 | 0.06 | 0.15 | 0.31 | 7.80 |

| Criteria | Normalized score cost | Normalized score properties | Normalized score ease of assembly | Normalized score style | Row sum | Percent ratio scale of priority |
|---|---|---|---|---|---|---|
| Style | 0.03 | 0.07 | 0.02 | 0.05 | 0.17 | 4.30 |
| Total | 1.00 | 1.00 | 1.00 | 1.00 | 4.00 | 100.0 |

*Note*. The normalized score is the comparison of each pair of criteria.

In the next row, there was a group of four sub-criteria under the cost criterion, a group of three sub-criteria under the properties criterion, a group of two sub-criteria under ease of assembly, and a group of two under style.

In the cost subgroup, each pair of sub-criteria would be compared regarding their importance with respect to the cost criterion. Once again, there were six pairs to compare (Price per shelter/Weight, Price per shelter/Maintenance Costs, Price per shelter/Resale Value, Weight/Maintenance Costs, Weight/Resale Value, and Maintenance Costs/Resale Value).

The first pairwise comparison was price per shelter versus weight. Although the weight affected not only the transportation but also the assemble time, the price per shelter directly affected the cost. Therefore, the comparison would a 3 in favor of price per shelter.

The second pairwise comparison was price per shelter versus maintenance costs. The maintenance costs were less important than the price per shelter because the maintenance of the shelter could also provide job opportunities for local areas. Therefore, this would be a 7 in favor of price per shelter.

The third pairwise comparison was price per shelter versus resale value. The resale value was less important than the price per shelter because the priority for the

Germany government right now was that the cost be as low as possible, yet the resale value hardly affected the shelter. So this would be a 9 in favor of price per shelter.

The fourth pairwise comparison was weight versus maintenance costs. Since the weight affected the transportation and assembly time, this would be a 3 in favor of weight.

The fifth pairwise comparison was weight versus resale value. Weight affected cost more than resale value. So this would be a 7 in favor of weight.

The last pairwise comparison was maintenance costs to resale value. For the German government, the lower maintenance costs were more important than resale value because it was reasonable for them reuse it. Therefore, this would be 5 in favor of maintenance costs.

The judgment is shown in Table 12. The calculations to convert these judgments to priorities for each of the four criteria is shown in Table 13. The priority of each sub-criterion is shown in Table 14. There was a logical loop between weight, maintenance and resale value. In this case, changing the consideration would reduce the CR. However, according to AHP rules, as long as CR is lower than 10%, it was reasonable and logical.

Table 12

*Judgment in Sub Criteria of Cost*

| Criteria | Price per shelter | Weight | Maintenance | Resale value |
|---|---|---|---|---|
| Price per shelter | 1.00 | 3.00 | 7.00 | 9.00 |
| Weight | 0.33 | 1.00 | 3.00 | 7.00 |
| Maintenance | 0.14 | 0.33 | 1.00 | 5.00 |

| Criteria | Price per shelter | Weight | Maintenance | Resale value |
|---|---|---|---|---|
| Resale value | 0.11 | 0.14 | 0.2 | 1.00 |
| Total | 1.58 | 4.47 | 11.2 | 22.00 |

Note. CR=7.5%<10%

Table 13

*Normalized Score Table for Cost*

| Criteria | Normalized Score Price per shelter | Normalized Score Weight | Normalized Score Maintenance | Normalized Score Resale value |
|---|---|---|---|---|
| Price per shelter | 0.63 | 0.67 | 0.63 | 0.40 |
| Weight | 0.21 | 0.22 | 0.27 | 0.32 |
| Maintenance | 0.09 | 0.07 | 0.09 | 0.23 |
| Resale value | 0.07 | 0.03 | 0.02 | 0.05 |
| Total | 1.00 | 1.00 | 1.00 | 1.00 |

Table 14

*Normalized Score Table of Priority for Cost*

| | Row sum | Percent ratio scale of priority | Percentage of total |
|---|---|---|---|
| Price per shelter | 2.33 | 58.36 | 17.50 |
| Weight | 1.01 | 25.49 | 7.65 |
| Maintenance | 0.48 | 12.02 | 3.61 |
| Resale value | 0.17 | 4.13 | 1.24 |
| Total | 4.00 | 100.00 | 30.00 |

In the properties subgroup, each pair of sub-criteria were compared regarding their importance with respect to the properties criterion. There were three pairs to compare (Durability/R-value, Durability/Strength, R-value/Strength).

The first pairwise comparison was durability versus R-value. Durability affected how long the shelter was going to last, and the R-value affected the ability to withstand cold temperatures. The shelter was built for short-term, although if it can last longer, the resale value would increase. However, the R-value directly affected the indoor environment, and Germany is cold during the winter. Therefore, the comparison would be a 3 in favor of R-value.

The second pairwise comparison was durability versus strength. The strength affected how much the shelter can hold, which was highly important for refugees, and so this would be a 3 in favor of strength.

The third pairwise comparison was R-value versus strength. The R-value affects the resistance against cold and directly affected the indoor environment. However, strength was also important, so this would be a 1 in both columns.

The judgment is shown in Table 15. The calculations to convert these judgments to priorities for each of the four criteria is shown in Table 16.

Table 15

*Judgment in Sub Criteria of Properties*

| Sub-criteria | Durability | R-value | Strength |
|---|---|---|---|
| Durability | 1.00 | 0.33 | 0.33 |
| R-value | 3.00 | 1.00 | 1.00 |

| Sub-criteria | Durability | R-value | Strength |
|---|---|---|---|
| Strength | 3.00 | 1.00 | 1.00 |
| Total | 7.00 | 2.33 | 2.33 |

Note. CR=0%

Table 16

*Normalized Score Table for Properties*

| Sub-criteria | Normalized score durability | Normalized score R-value | Normalized score strength | Row sum | Percent ratio scale of priority | Percentage of total |
|---|---|---|---|---|---|---|
| Durability | 0.14 | 0.14 | 0.14 | 0.43 | 14.29 | 8.25 |
| R-value | 0.43 | 0.43 | 0.43 | 1.29 | 42.86 | 24.77 |
| Strength | 0.43 | 0.43 | 0.43 | 1.29 | 42.86 | 24.77 |
| Total | 1.00 | 1.0 | 1.00 | 3.0 | 100.0 | 57.80 |

In the assembly ease subgroup, each pair of sub-criteria was compared regarding their importance with respect to the assembly ease criterion. There was one pair to compare (Ease of assembly/Assembly time).

Ease of assembly was equally important as assembly time. Therefore, the comparison would be a 1 in each column.

The judgment is shown in Table 17. The calculations to convert these judgments to priorities for each of the four criteria is shown in Table 18.

Table 17

*Judgment in Sub-Criteria of Ease of Assemble*

| Sub-criteria | Easy | Assemble time |
|---|---|---|
| Easy | 1.00 | 1.00 |
| Assemble time | 1.00 | 1.00 |
| Total | 2.00 | 2.00 |

Note. CR=0%

Table 18

*Normalized Score Table for Ease of Assembly*

| Sub-criteria | Normalized score ease of assembly | Normalized score assemble time | Row sum | Percent ratio scale of priority | Percentage of total |
|---|---|---|---|---|---|
| Ease of assembly | 0.50 | 0.50 | 1.00 | 50.00 | 3.90 |
| Assembly time | 0.50 | 0.50 | 1.00 | 50.00 | 3.90 |
| Total | 1.00 | 1.00 | 2.00 | 100.00 | 7.80 |

In the style subgroup, each pair of sub-criteria was compared regarding their importance with respect to the style criterion. There was one pair to compare (Appearance/ Comfort).

The idea of this shelter was to have it built to make refugees feel at home so the comparison will be a 3 in favor of Comfort.

The judgment is shown in Table 19. The calculations to convert these judgments to priorities for each of the four criteria is shown in Table 20.

Table 19

*Judgment in Sub Criteria of Style*

| Sub-criteria | Appearance | Comfort |
|---|---|---|
| Appearance | 1.00 | 0.33 |
| Comfort | 3.00 | 1.00 |
| Total | 4.00 | 1.33 |

Table 20

*Normalized Score Table for Style*

| Sub-criteria | Normalized score appearance | Normalized score comfort | Row sum | Percent ratio scale of priority | Percentage of total |
|---|---|---|---|---|---|
| Appearance | 0.25 | 0.25 | 0.50 | 25.00 | 1.08 |
| Comfort | 0.75 | 0.75 | 1.50 | 75.00 | 3.26 |
| Total | 1.00 | 1.00 | 2.00 | 100.00 | 4.35 |

After the process of judging the importance, the priority of the criteria was placed in order. The detail is shown in figure 2, and the priority of each criteria in order was: R-value, strength, price per shelter, weight, durability, ease of assembly, assembly time, maintenance costs, comfort, resale value and appearance. The percentage of importance is shown in Table 21.

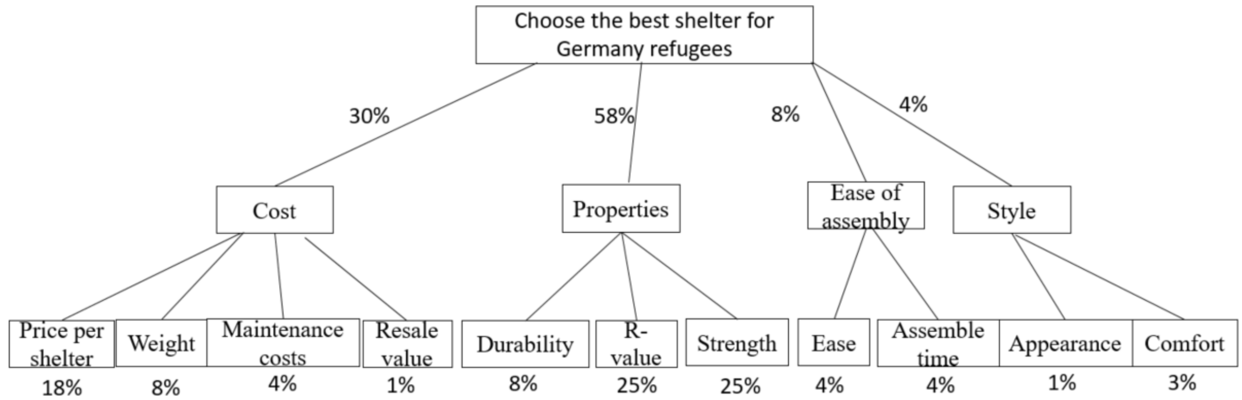


*Figure 2.* AHP hierarchy of the importance of each criterion in the shelter decision.

Table 21

*Priority of Importance*

| Priority order | Percent of importance |
|---|---|
| R-value | 0.25 |
| Strength | 0.25 |
| Price per shelter | 0.18 |
| Weight | 0.08 |
| Durability | 0.08 |
| Ease of assembly | 0.04 |
| Assembly time | 0.04 |
| Maintenance costs | 0.04 |
| Comfort | 0.03 |
| Resale value | 0.01 |
| Appearance | 0.01 |

*Note.* The results of priority are rounded for simplicity of comparison.

**Comparing the Alternatives with Respect to the Criteria**

All six samples went through the procedure of AHP which compared the Alternatives with Respect to the Criteria, which are R-value, strength, price per shelter, weight per shelter, durability, easy to assemble, assemble time, maintenance costs, comfort, resale value, and appearance. Four factors were precisely measurable: price per shelter, assembly time, R-value, and weight. However, R-value was not only linked to the cost, but was also linked to the thickness of the insulation system. Simply importing the data of R-value would lead to miscalculation of the results. Therefore, before samples went through the procedure of figuring the R-value, it was necessary to define the thickness of insulation systems. To calculate the thickness, the equation of the cost of using each insulation system is shown as follows: [area] x [thickness] x [cost] = [total cost]. This data was imported from chapter two. Cost and R-value's priority were also needed to make the calculation. Some of the companies did not offer the exact R-value of the products, and in this case, the same data of similar materials was imported.

Another four factors which are difficult to measure are strength, maintenance costs, resale value and durability. The factor of strength considers characteristics like earthquake resistance, wind load, and physical properties of the samples. Durability considers life span and things such as moisture resistance, resistance to deterioration, and integrity of components such as doors and walls. AHP allowed factors that are not directly measurable to be compared in each sample, because each criterion was weighed for its value relation to other factors in a particular situation and for a particular person.

The last three factors were completely subjective, which are ease of assembly, comfort, and appearance. To compare each sample, this research compared the customer's review of each factor.

The following comparisons depended on the comparison method presented in Chapter 3. The methods were different for each factor because some of the information is quantifiable while some is subjective. Following is the comparison of each of the factors.

**R-value**

Ambient temperature affects the R-value needs of the shelter. However, in Europe it is typical to use U-values. U-values are defined by the equation: $U_{\text{value}} = \frac{watts}{kelvin \times meters^2}$. The lower the U-value, the greater the ability to resist thermal conduction. U-value is the mathematical reciprocal of R-value (Ken, 2010). To translate an R-value into a U-value, divide 1 by the R-value, then multiply the result by 5.682. To convert a U-value to an R-value, multiply the U-value by 0.176, then divide 1 by the result. According to Eurima (Morris & Chapman, 2007), houses in Berlin need an Ht value (the average U-value of the entire building is called Ht in Germany) of 0.3 $W/m^2k$, which is 3.33 in R-value per inch. The worst heating degree day in Berlin is 3800 (Knoema, 2014). According to the IRC (International Residential Code), the R-value in this time zone is R13 ("International Residential Code," 2003).

This author assumed that no matter which product the German government selected, the thickness of the wall panels would be the same. This is because customizing wall panel for specific needs is cost prohibitive. Each product satisfied the basic IRC code. The R-value inputted into each product at Table 22 was provided by Table 5. Table 22 is the judgments number of R-value entered for each comparison, then input the judgment into Table 23. When the judgments in Table 23 were entered, the AHP calculated the data by Excel (see Table 24), then presented the priorities for the seven products with respect to the R-value in Table 25 and Table 26.

Table 22

*Comparisons Worksheet-R-value*

| Comparisons | | | R-Value | | Better R-Value |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 4.0 | 4.0 | A=B |
| 2 | Andy Steel | YONGYANG Steel | 4.0 | 5.0 | B |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 4.0 | 7.2 | B |
| 4 | Andy Steel | Fiber cement MgO board | 4.0 | 4.0 | A=B |
| 5 | Andy Steel | EPS cement sandwich wall | 4.0 | 4.0 | A=B |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 4.0 | 5.0 | B |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 4.0 | 7.2 | B |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 4.0 | 4.0 | A=B |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 4.0 | 4.0 | A=B |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 5.0 | 7.2 | B |
| 11 | YONGYANG Steel | Fiber cement MgO board | 5.0 | 4.0 | A |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 5.0 | 4.0 | A |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 7.2 | 4.0 | A |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 7.2 | 4.0 | A |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 4.0 | 4.0 | A=B |

Table 23

*Judgment R-value Worksheet*

| # | Better subject | Intensity |
|---|---|---|
| 1 | A=B | 1.0 |
| 2 | B | 0.8 |
| 3 | B | 0.6 |

| # | Better subject | Intensity |
|---|---|---|
| 4 | A=B | 1.0 |
| 5 | A=B | 1.0 |
| 7 | B | 0.8 |
| 8 | B | 0.6 |
| 9 | A=B | 1.0 |
| 10 | A=B | 1.0 |
| 12 | B | 0.7 |
| 13 | A | 1.3 |
| 14 | A | 1.3 |
| 16 | A | 1.8 |
| 17 | A | 1.8 |
| 19 | A=B | 1.0 |

Table 24

*Calculation of Decision Matrix AHP-R-value*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 1.00 | 0.80 | 0.56 | 1.00 | 1.00 |
| Light Steel Villa/ ADTO | 1.00 | 1.00 | 0.80 | 0.56 | 1.00 | 1.00 |
| YONGYANG Steel | 1.25 | 1.25 | 1.00 | 0.69 | 1.25 | 1.25 |
| SIP panels from ZHONGJIE | 1.80 | 1.80 | 1.44 | 1.00 | 1.80 | 1.80 |
| Fiber cement MgO board | 1.00 | 1.00 | 0.80 | 0.56 | 1.00 | 1.00 |
| EPS cement sandwich wall | 1.00 | 1.00 | 0.80 | 0.56 | 1.00 | 1.00 |
| Total | 7.1 | 7.1 | 5.6 | 3.9 | 7.1 | 7.1 |

Table 25

*Normalized Score of Each Product-R-value*

| Subject | Normalized score Andy Steel | Normalized score Light Steel Villa/ ADTO | Normalized score YONGYANG Steel | Normalized score SIP panels from ZHONGJIE | Normalized score Fiber cement MgO board | Normalized score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| Light Steel Villa/ ADTO | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| YONGYANG Steel | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 |
| SIP panels from ZHONGJIE | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 | 0.26 |
| Fiber cement MgO board | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| EPS cement sandwich wall | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 26

*The Global Priority of Each Product-R-value*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.85 | 14.2 | 0.03552 |
| Light Steel Villa/ ADTO | 0.85 | 14.2 | 0.03552 |
| YONGYANG Steel | 1.06 | 17.7 | 0.04425 |
| SIP panels from ZHONGJIE | 1.53 | 25.5 | 0.06372 |
| Fiber cement MgO board | 0.85 | 14.2 | 0.03550 |
| EPS cement sandwich wall | 0.85 | 14.2 | 0.03550 |
| Total | 6.00 | 100.0 | 0.25000 |

**Strength**

Strength was evaluated based on its ability to withstand pressure. However, some of the products did not provide this information, so this thesis compared the product's strengths based on the scale of typhoon it was rated for. The data inputs into Table 27 of each product is provided in Table 4. Table 27 is the judgments number of strength entered for each comparison, then input the judgment into Table 28. The intensity of difference in Table 28 was divided into three levels for ease of comparison. If the difference was 10~25, which is slightly different, it was indicated as level 3. If the difference was 30~45, it was indicated as level 5. If the difference was 50~60, it was indicated as level 9. When the judgments in Table 28 were entered, the AHP calculated the data by Excel (see Table 29) then presented the priorities for the seven products with respect to strength in Table 30 and Table 31.

Table 27

*Comparisons Worksheet-Strength*

| Comparisons | | | Strength | | Better Strength |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 85.0 | 95.0 | B |
| 2 | Andy Steel | YONGYANG Steel | 85.0 | 110.0 | B |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 85.0 | 60.0 | A |
| 4 | Andy Steel | Fiber cement MgO board | 85.0 | 50.0 | A |
| 5 | Andy Steel | EPS cement sandwich wall | 85.0 | 60.0 | A |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 95.0 | 110.0 | B |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 95.0 | 60.0 | A |

| Comparisons | | | Strength | | Better Strength |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 95.0 | 50.0 | A |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 95.0 | 60.0 | A |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 110.0 | 60.0 | A |
| 11 | YONGYANG Steel | Fiber cement MgO board | 110.0 | 50.0 | A |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 110.0 | 60.0 | A |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 60.0 | 50.0 | A |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 60.0 | 60.0 | A=B |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 50.0 | 60.0 | B |

Table 28

*Judgment Strength Worksheet*

| # | Better Subject | Intensity | Disparity |
|---|---|---|---|
| 1 | B | 3 | 10 |
| 2 | B | 3 | 25 |
| 3 | A | 3 | 25 |
| 4 | A | 5 | 35 |
| 5 | A | 3 | 25 |
| 6 | B | 3 | 15 |
| 7 | A | 5 | 35 |
| 8 | A | 5 | 45 |
| 9 | A | 5 | 35 |
| 10 | A | 9 | 50 |
| 11 | A | 9 | 60 |
| 12 | A | 9 | 50 |
| 13 | A | 3 | 10 |
| 14 | A=B | 1 | equal |
| 15 | B | 3 | 10 |

Table 29

*Calculation of Decision Matrix AHP-Strength*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 0.33 | 0.33 | 3.00 | 5.00 | 3.00 |
| Light Steel Villa/ ADTO | 3.00 | 1.00 | 0.33 | 5.00 | 5.00 | 5.00 |
| YONGYANG Steel | 3.00 | 3.00 | 1.00 | 9.00 | 9.00 | 9.00 |
| SIP panels from ZHONGJIE | 0.33 | 0.20 | 0.11 | 1.00 | 3.00 | 1.00 |
| Fiber cement MgO board | 0.20 | 0.20 | 0.11 | 0.33 | 1.00 | 0.33 |
| EPS cement sandwich wall | 0.33 | 0.20 | 0.11 | 1.00 | 3.00 | 1.00 |
| Total | 7.9 | 4.9 | 2.0 | 19.3 | 26.0 | 19.3 |

Table 30

*Normalized Score of Each Product-Strength*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 0.33 | 0.33 | 3.00 | 5.00 | 3.00 |
| Light Steel Villa/ ADTO | 3.00 | 1.00 | 0.33 | 5.00 | 5.00 | 5.00 |
| YONGYANG Steel | 3.00 | 3.00 | 1.00 | 9.00 | 9.00 | 9.00 |
| SIP panels from ZHONGJIE | 0.33 | 0.20 | 0.11 | 1.00 | 3.00 | 1.00 |
| Fiber cement MgO board | 0.20 | 0.20 | 0.11 | 0.33 | 1.00 | 0.33 |
| EPS cement sandwich wall | 0.33 | 0.20 | 0.11 | 1.00 | 3.00 | 1.00 |
| Total | 7.9 | 4.9 | 2.0 | 19.3 | 26.0 | 19.3 |

Table 31

*The Global Priority of Each Product-Strength*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.86 | 14.4 | 0.03612 |
| Light Steel Villa/ ADTO | 1.46 | 24.3 | 0.06078 |
| YONGYANG Steel | 2.77 | 46.1 | 0.11526 |
| SIP panels from ZHONGJIE | 0.36 | 6.0 | 0.01470 |
| Fiber cement MgO board | 0.19 | 3.2 | 0.00755 |
| EPS cement sandwich wall | 0.36 | 6.0 | 0.01470 |
| Total | 6.00 | 100.0 | 0.25000 |

**Price per Shelter**

This thesis did not include the mark-up of any companies involved in the process. Shipping was not considered because all the products come from China. The cost of assembling the shelters was not considered, because the assembly of the shelter is to be largely done by those who are living there. The *cost* of assembly was evaluated in the ease of assembly and assembly time. However, because of the flexibility of AHP, the data could always change in the future due to different concerns. The data inputs into Table 32 of each product is provided in Table 4. Table 32 is the judgments number of price per shelter entered for each comparison, then input the judgment into Table 33. The intensity of difference in Table 33 was divided into five levels for ease of comparison. If the difference was 0~10, which is slightly different, it was indicated as level 1. If the difference was 10~25, it was indicated as level 3. If the difference was 30~55, it was indicated as level 5. If the difference was 60~70, it was indicated as level 7. If the difference was 70~100, it was indicated as level 9. When the judgments in Table 33 were entered, the AHP calculated the data by Excel (see Table 34) then reported the priorities for the seven products with respect to price per shelter in Table 35 and Table 36.

Table 32

*Comparisons Worksheet-Price per Shelter*

| Comparisons | | | Price Per Shelter | | Better Price |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 60.0 | 65.0 | A |
| 2 | Andy Steel | YONGYANG Steel | 60.0 | 120.0 | A |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 60.0 | 80.0 | A |
| 4 | Andy Steel | Fiber cement MgO board | 60.0 | 50.0 | B |
| 5 | Andy Steel | EPS cement sandwich wall | 60.0 | 40.0 | B |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 65.0 | 120.0 | A |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 65.0 | 80.0 | A |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 65.0 | 50.0 | B |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 65.0 | 40.0 | B |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 120.0 | 80.0 | B |
| 11 | YONGYANG Steel | Fiber cement MgO board | 120.0 | 50.0 | B |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 120.0 | 40.0 | B |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 80.0 | 50.0 | B |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 80.0 | 40.0 | B |

| | Comparisons | | Price Per Shelter | | Better Price |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 50.0 | 40.0 | B |

Table 33

*Judgment price per shelter Worksheet*

| # | Better Subject | Intensity | Disparity |
|---|---|---|---|
| 1 | A | 1 | 5 |
| 2 | A | 7 | 60 |
| 3 | A | 3 | 20 |
| 4 | B | 1 | 10 |
| 5 | B | 3 | 20 |
| 6 | A | 5 | 55 |
| 7 | A | 3 | 15 |
| 8 | B | 3 | 15 |
| 9 | B | 3 | 25 |
| 10 | B | 5 | 40 |
| 11 | B | 7 | 70 |
| 12 | B | 9 | 80 |
| 13 | B | 5 | 30 |
| 14 | B | 5 | 40 |
| 15 | B | 1 | 10 |

Table 34

*Calculation of Decision Matrix AHP-Price Per Shelter*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 1.00 | 7.00 | 3.00 | 1.00 | 0.33 |
| Light Steel Villa/ ADTO | 1.00 | 1.00 | 5.00 | 3.00 | 0.33 | 0.33 |
| YONGYANG Steel | 0.14 | 0.20 | 1.00 | 0.20 | 0.14 | 0.11 |
| SIP panels from ZHONGJIE | 0.33 | 0.33 | 5.00 | 1.00 | 0.20 | 0.20 |

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Fiber cement MgO board | 1.00 | 3.00 | 7.00 | 5.00 | 1.00 | 1.00 |
| EPS cement sandwich wall | 3.00 | 3.00 | 9.00 | 5.00 | 1.00 | 1.00 |
| Total | 6.5 | 8.5 | 34.0 | 17.2 | 3.7 | 3.0 |

Table 35

*Normalized Score of Each Product-Price Per Shelter*

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.15 | 0.12 | 0.21 | 0.17 | 0.27 | 0.11 |
| Light Steel Villa/ ADTO | 0.15 | 0.12 | 0.15 | 0.17 | 0.09 | 0.11 |
| YONGYANG Steel | 0.02 | 0.02 | 0.03 | 0.01 | 0.04 | 0.04 |
| SIP panels from ZHONGJIE | 0.05 | 0.04 | 0.15 | 0.06 | 0.05 | 0.07 |
| Fiber cement MgO board | 0.15 | 0.35 | 0.21 | 0.29 | 0.27 | 0.34 |
| EPS cement sandwich wall | 0.46 | 0.35 | 0.26 | 0.29 | 0.27 | 0.34 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 36

*The Global Priority of Each Product-Price Per Shelter*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 1.04 | 17.3 | 0.03110 |
| Light Steel Villa/ ADTO | 0.80 | 13.3 | 0.02404 |

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| YONGYANG Steel | 0.16 | 2.7 | 0.00487 |
| SIP panels from ZHONGJIE | 0.42 | 7.0 | 0.01243 |
| Fiber cement MgO board | 1.61 | 26.8 | 0.04826 |
| EPS cement sandwich wall | 1.98 | 33.3 | 0.05945 |
| Total | 6.00 | 100.0 | 0.18000 |

**Weight**

The data of weight inputs into Table 37 of each product is provided in Table 4. Table 37 is the judgments number of weight entered for each comparison, then input the judgment into Table 38. The intensity of difference in Table 38 was divided into five levels for ease of comparison. If the difference was 0~10, which is slightly different, it was indicated as level 1. If the difference was 20~30, it was indicated as level 3. If the difference was 40~45, it was indicated as level 5. If the difference was 50~80, it was indicated as level 7. If the difference was 80~100, it was indicated as level 9. When the judgments in Table 38 were entered, the AHP calculated the data by Excel (see Table 39) then presented the priorities for the seven products with respect to weight in Table 40 and Table 41.

Table 37

*Comparisons Worksheet-Weight*

| Comparisons | | | Kg per side of wall | | Less weight |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 80.0 | 90.0 | A |
| 2 | Andy Steel | YONGYANG Steel | 80.0 | 100.0 | A |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 80.0 | 60.0 | B |
| 4 | Andy Steel | Fiber cement MgO board | 80.0 | 40.0 | B |
| 5 | Andy Steel | EPS cement sandwich wall | 80.0 | 50.0 | B |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 90.0 | 100.0 | A |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 90.0 | 60.0 | B |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 90.0 | 40.0 | B |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 90.0 | 50.0 | B |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 100.0 | 60.0 | B |
| 11 | YONGYANG Steel | Fiber cement MgO board | 100.0 | 40.0 | B |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 100.0 | 50.0 | B |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 60.0 | 40.0 | B |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 60.0 | 50.0 | B |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 40.0 | 50.0 | A |

Table 38

*Judgment Weight Worksheet*

| # | Better Subject | Intensity | Disparity |
|---|---|---|---|
| 1 | A | 1 | 10 |
| 2 | A | 3 | 20 |
| 3 | B | 3 | 20 |
| 4 | B | 5 | 40 |
| 5 | B | 3 | 30 |
| 6 | A | 1 | 10 |
| 7 | B | 3 | 30 |
| 8 | B | 7 | 50 |
| 9 | B | 5 | 40 |
| 10 | B | 5 | 40 |
| 11 | B | 7 | 60 |
| 12 | B | 7 | 50 |
| 13 | B | 3 | 20 |
| 14 | B | 1 | 10 |
| 15 | A | 1 | 10 |

Table 39

*Calculation of Decision Matrix AHP-Weight*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 1.00 | 3.00 | 0.33 | 0.20 | 0.33 |
| Light Steel Villa/ ADTO | 1.00 | 1.00 | 1.00 | 0.33 | 0.14 | 0.20 |
| YONGYANG Steel | 0.33 | 1.00 | 1.00 | 0.20 | 0.14 | 0.14 |
| SIP panels from ZHONGJIE | 3.00 | 3.00 | 5.00 | 1.00 | 0.33 | 1.00 |
| Fiber cement MgO board | 5.00 | 7.00 | 7.00 | 3.00 | 1.00 | 1.00 |
| EPS cement sandwich wall | 3.00 | 5.00 | 7.00 | 1.00 | 1.00 | 1.00 |
| Total | 13.3 | 18.0 | 24.0 | 5.9 | 2.8 | 3.7 |

Table 40

*Normalized Score of Each Product-Weight*

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.08 | 0.06 | 0.13 | 0.06 | 0.07 | 0.09 |
| Light Steel Villa/ ADTO | 0.08 | 0.06 | 0.04 | 0.06 | 0.05 | 0.05 |
| YONGYANG Steel | 0.03 | 0.06 | 0.04 | 0.03 | 0.05 | 0.04 |
| SIP panels from ZHONGJIE | 0.23 | 0.17 | 0.21 | 0.17 | 0.12 | 0.27 |
| Fiber cement MgO board | 0.38 | 0.39 | 0.29 | 0.51 | 0.35 | 0.27 |
| EPS cement sandwich wall | 0.23 | 0.28 | 0.29 | 0.17 | 0.35 | 0.27 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 41

*The Global Priority of Each Product-Weight*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.47 | 7.9 | 0.00611 |
| Light Steel Villa/ ADTO | 0.33 | 5.6 | 0.00481 |
| YONGYANG Steel | 0.25 | 4.1 | 0.00329 |
| SIP panels from ZHONGJIE | 1.16 | 19.3 | 0.01541 |
| Fiber cement MgO board | 2.19 | 36.6 | 0.02929 |
| EPS cement sandwich wall | 1.59 | 26.5 | 0.02187 |
| Total | 6.00 | 100.0 | 0.08000 |

**Durability**

To compare the durability, the expected lifetime was used in this situation. The data of durability inputs into Table 42 of each product is provided in Table 4. Table 42 is the judgments number of weight entered for each comparison, then input the judgment into Table 43. The intensity of difference in Table 43 was divided into two levels. If the difference was 0~5, which is slightly different, it was indicated as level 3. If the difference was more than 10, it was indicated as level 5. Some of the products had a very long life; however, the German government was only looking for a short-term solution for refugees, which indicated that anything more than 10 years is of the same importance to the decision maker. When the judgments in Table 43 were entered, the AHP calculated the data by Excel (See Table 44) then showed the priorities for the seven products with respect to durability in Table 45 and Table 46.

Table 42

*Comparisons Worksheet-Durability*

| Comparisons | | | Lifetime/years | | Longer Lifetime |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 10.0 | 15.0 | B |
| 2 | Andy Steel | YONGYANG Steel | 10.0 | 50.0 | B |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 10.0 | 30.0 | B |
| 4 | Andy Steel | Fiber cement MgO board | 10.0 | 35.0 | B |
| 5 | Andy Steel | EPS cement sandwich wall | 10.0 | 50.0 | B |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 15.0 | 50.0 | B |

| Comparisons | | | Lifetime/years | | Longer Lifetime |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 15.0 | 30.0 | B |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 15.0 | 35.0 | B |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 15.0 | 50.0 | B |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 50.0 | 30.0 | A |
| 11 | YONGYANG Steel | Fiber cement MgO board | 50.0 | 35.0 | A |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 50.0 | 50.0 | A=B |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 30.0 | 35.0 | B |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 30.0 | 50.0 | B |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 35.0 | 50.0 | B |

Table 43

*Judgment Durability Worksheet*

| # | Better Subject | Intensity | Note |
|---|---|---|---|
| 1 | B | 3 | Less than 5 years |
| 2 | B | 5 | more than 10 years |
| 3 | B | 5 | more than 10 years |
| 4 | B | 5 | more than 10 years |
| 5 | B | 5 | more than 10 years |
| 6 | B | 5 | more than 10 years |
| 7 | B | 5 | more than 10 years |
| 8 | B | 5 | more than 10 years |
| 9 | B | 5 | more than 10 years |
| 10 | A | 5 | more than 10 years |
| 11 | A | 5 | more than 10 years |
| 12 | A=B | 1 | Equal |

| # | Better Subject | Intensity | Note |
|---|---|---|---|
| 13 | B | 3 | Less than 5 years |
| 14 | B | 5 | more than 10 years |
| 15 | B | 5 | more than 10 years |

Table 44

*Calculation of Decision Matrix AHP- Durability*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 0.33 | 0.20 | 0.20 | 0.20 | 0.20 |
| Light Steel Villa/ ADTO | 3.00 | 1.00 | 0.20 | 0.20 | 0.20 | 0.20 |
| YONGYANG Steel | 5.00 | 5.00 | 1.00 | 5.00 | 5.00 | 1.00 |
| SIP panels from ZHONGJIE | 5.00 | 5.00 | 0.20 | 1.00 | 0.33 | 0.20 |
| Fiber cement MgO board | 5.00 | 5.00 | 0.20 | 3.00 | 1.00 | 0.20 |
| EPS cement sandwich wall | 5.00 | 5.00 | 1.00 | 5.00 | 5.00 | 1.00 |
| Total | 24.0 | 21.3 | 2.8 | 14.4 | 11.7 | 2.8 |

Table 45

*Normalized Score of Each Product-Durability*

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.04 | 0.02 | 0.07 | 0.01 | 0.02 | 0.07 |
| Light Steel Villa/ ADTO | 0.13 | 0.05 | 0.07 | 0.01 | 0.02 | 0.07 |
| YONGYANG Steel | 0.21 | 0.23 | 0.36 | 0.35 | 0.43 | 0.36 |

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| SIP panels from ZHONGJIE | 0.21 | 0.23 | 0.07 | 0.07 | 0.03 | 0.07 |
| Fiber cement MgO board | 0.21 | 0.23 | 0.07 | 0.21 | 0.09 | 0.07 |
| EPS cement sandwich wall | 0.21 | 0.23 | 0.36 | 0.35 | 0.43 | 0.36 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 46

*The Global Priority of Each Product-Durability*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.23 | 3.9 | 0.00308 |
| Light Steel Villa/ ADTO | 0.35 | 5.8 | 0.00461 |
| YONGYANG Steel | 1.93 | 32.2 | 0.02574 |
| SIP panels from ZHONGJIE | 0.68 | 11.4 | 0.00911 |
| Fiber cement MgO board | 0.88 | 14.7 | 0.01172 |
| EPS cement sandwich wall | 1.93 | 32.2 | 0.02574 |
| Total | 6.00 | 100.0 | 0.08000 |

**Ease of Assembly/Assembly Time**

All the products could be divided into two methods of building. Therefore, the author assumed that the ease of assembly and assembly time is the same for each product with the same methods. The Table 47 is the judgments for each comparison. Table 48 is the judgment sheet. The intensity of difference was divided into two levels. SIP is almost twice more fast to construct and erect than steel framing methods. When the judgments in Table 48 were entered, the AHP calculated the data by Excel (see Table 49) then showed the priorities for the seven products with respect to durability in Table 50 and Table 51. The same methods were utilized to compare assembly time. The priorities for assembly time are presented in Table 52.

Table 47

*Comparisons Worksheet- Ease of Assembly/Assembly Time*

| | Comparisons | | Ease of assembly | | Easier |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 1.0 | 1.0 | A=B |
| 2 | Andy Steel | YONGYAN G Steel | 1.0 | 1.0 | A=B |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 1.0 | 2.0 | B |
| 4 | Andy Steel | Fiber cement MgO board | 1.0 | 2.0 | B |
| 5 | Andy Steel | EPS cement sandwich wall | 1.0 | 2.0 | B |
| 6 | Light Steel Villa/ ADTO | YONGYAN G Steel | 1.0 | 1.0 | A=B |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 1.0 | 2.0 | B |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 1.0 | 2.0 | B |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 1.0 | 2.0 | B |
| 10 | YONGYAN G Steel | SIP panels from ZHONGJIE | 1.0 | 2.0 | B |
| 11 | YONGYAN G Steel | Fiber cement MgO board | 1.0 | 2.0 | B |

| Comparisons | | | Ease of assembly | | Easier |
| --- | --- | --- | --- | --- | --- |
| # | A | B | A | B | |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 1.0 | 2.0 | B |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 2.0 | 2.0 | A=B |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 2.0 | 2.0 | A=B |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 2.0 | 2.0 | A=B |

Table 48

*Judgment Ease of Assembly/Assembly Time Worksheet*

| # | Better Subject | Intensity |
| --- | --- | --- |
| 1 | A=B | 1 |
| 2 | A=B | 1 |
| 3 | B | 5 |
| 4 | B | 5 |
| 5 | B | 5 |
| 6 | A=B | 1 |
| 7 | B | 5 |
| 8 | B | 5 |
| 9 | B | 5 |
| 10 | B | 5 |
| 11 | B | 5 |
| 12 | B | 5 |
| 13 | A=B | 1 |
| 14 | A=B | 1 |
| 15 | A=B | 1 |

Table 49

*Calculation of Decision Matrix AHP- Ease of Assembly/Assembly Time*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 1.00 | 1.00 | 0.20 | 0.20 | 0.20 |
| Light Steel Villa/ ADTO | 1.00 | 1.00 | 1.00 | 0.20 | 0.20 | 0.20 |
| YONGYANG Steel | 1.00 | 1.00 | 1.00 | 0.20 | 0.20 | 0.20 |
| SIP panels from ZHONGJIE | 5.00 | 5.00 | 5.00 | 1.00 | 1.00 | 1.00 |
| Fiber cement MgO board | 5.00 | 5.00 | 5.00 | 1.00 | 1.00 | 1.00 |
| EPS cement sandwich wall | 5.00 | 5.00 | 5.00 | 1.00 | 1.00 | 1.00 |
| Total | 18.0 | 18.0 | 18.0 | 3.6 | 3.6 | 3.6 |

Table 50

*Normalized Score of Each Product- Ease of Assembly/Assembly Time*

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| Light Steel Villa/ ADTO | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| YONGYANG Steel | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| SIP panels from ZHONGJIE | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 |
| Fiber cement MgO board | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 |
| EPS cement sandwich wall | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 51

*The Global Priority of Each Product-Ease of Assembly*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.33 | 4.8 | 0.00192 |
| Light Steel Villa/ ADTO | 0.33 | 4.8 | 0.00192 |
| YONGYANG Steel | 0.33 | 4.8 | 0.00192 |
| SIP panels from ZHONGJIE | 1.67 | 23.8 | 0.00929 |
| Fiber cement MgO board | 1.67 | 23.8 | 0.00929 |
| EPS cement sandwich wall | 1.67 | 23.8 | 0.00929 |
| Total | 6.00 | 100.0 | 0.04 |

Table 52

*The Global Priority of Each Product-Assembly Time*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.33 | 4.8 | 0.00192 |
| Light Steel Villa/ ADTO | 0.33 | 4.8 | 0.00192 |
| YONGYANG Steel | 0.33 | 4.8 | 0.00192 |
| SIP panels from ZHONGJIE | 1.67 | 23.8 | 0.00929 |
| Fiber cement MgO board | 1.67 | 23.8 | 0.00929 |
| EPS cement sandwich wall | 1.67 | 23.8 | 0.00929 |
| Total | 6.00 | 100.0 | 0.04 |

**Maintenance Costs**

The author assumed that no matter which products the German government chose, the maintenance routine would be the same, including the security, routine check, and electricity cost. Table 53 shows the maintenance costs for each comparison which was provided by each company's suggestion, then input the judgment into Table 54. The intensity of difference in table 54 was divided by each other. When the judgments in Table 54 were entered, the AHP calculated the data by Excel (see Table 55) then showed the priorities for the seven products with respect to maintenance costs in Table 56 and Table 57.

Table 53

*Comparisons Worksheet-Maintenance Costs*

| Comparisons | | | Maintenance Costs/per year | | Better Price |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 600.0 | 650.0 | A |
| 2 | Andy Steel | YONGYANG Steel | 600.0 | 675.0 | A |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 600.0 | 500.0 | B |
| 4 | Andy Steel | Fiber cement MgO board | 600.0 | 450.0 | B |
| 5 | Andy Steel | EPS cement sandwich wall | 600.0 | 400.0 | B |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 650.0 | 675.0 | A |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 650.0 | 500.0 | B |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 650.0 | 450.0 | B |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 650.0 | 400.0 | B |

| Comparisons | | | Maintenance Costs/per year | | Better Price |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 675.0 | 500.0 | B |
| 11 | YONGYANG Steel | Fiber cement MgO board | 675.0 | 450.0 | B |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 675.0 | 400.0 | B |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 500.0 | 450.0 | B |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 500.0 | 400.0 | B |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 450.0 | 400.0 | B |

Table 54

*Judgment Maintenance Costs Worksheet*

| # | Better Subject | Intensity |
|---|---|---|
| 1 | A | 0.92 |
| 2 | A | 0.89 |
| 3 | B | 1.20 |
| 4 | B | 1.33 |
| 5 | B | 1.50 |
| 6 | A | 0.96 |
| 7 | B | 1.30 |
| 8 | B | 1.44 |
| 9 | B | 1.63 |
| 10 | B | 1.35 |
| 11 | B | 1.50 |
| 12 | B | 1.69 |
| 13 | B | 1.11 |
| 14 | B | 1.25 |
| 15 | B | 1.13 |

Table 55

*Calculation of Decision Matrix AHP-Maintenance Costs*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 0.92 | 0.89 | 0.83 | 0.75 | 0.67 |
| Light Steel Villa/ ADTO | 1.08 | 1.00 | 0.96 | 0.77 | 0.69 | 0.62 |
| YONGYANG Steel | 1.13 | 1.04 | 1.00 | 0.74 | 0.67 | 0.59 |
| SIP panels from ZHONGJIE | 1.20 | 1.30 | 1.35 | 1.00 | 0.90 | 0.80 |
| Fiber cement MgO board | 1.33 | 1.44 | 1.50 | 1.11 | 1.00 | 0.89 |
| EPS cement sandwich wall | 1.50 | 1.63 | 1.69 | 1.25 | 1.13 | 1.00 |
| Total | 7.2 | 7.3 | 7.4 | 5.7 | 5.1 | 4.6 |

Table 56

*Normalized Score of Each Product-Maintenance Costs*

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.14 | 0.13 | 0.12 | 0.15 | 0.15 | 0.15 |
| Light Steel Villa/ ADTO | 0.15 | 0.14 | 0.13 | 0.13 | 0.13 | 0.13 |
| YONGYANG Steel | 0.16 | 0.14 | 0.14 | 0.13 | 0.13 | 0.13 |
| SIP panels from ZHONGJIE | 0.17 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 |
| Fiber cement MgO board | 0.18 | 0.20 | 0.20 | 0.19 | 0.19 | 0.19 |
| EPS cement sandwich wall | 0.21 | 0.22 | 0.23 | 0.22 | 0.22 | 0.22 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 57

*The Global Priority of Each Product-Maintenance Costs*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.82 | 11.8 | 0.00470 |
| Light Steel Villa/ ADTO | 0.82 | 11.7 | 0.00469 |
| YONGYANG Steel | 0.82 | 11.7 | 0.00470 |
| SIP panels from ZHONGJIE | 1.05 | 15.0 | 0.00601 |
| Fiber cement MgO board | 1.17 | 16.7 | 0.00668 |
| EPS cement sandwich wall | 1.31 | 18.8 | 0.00751 |
| Total | 6.00 | 100.0 | 0.04000 |

**Comfort/ Appearance**

The author used the customers' reviews to compare each product's comfort/appearance, then input the judgments for each comparison into Table 58. Table 59 is the judgment sheet. The intensity of difference was divided into three levels. If the difference was 0~10, it was indicated as level 3. If the difference was 11~20, it was indicated as level 5. If the difference was 20~30, it was indicated as level 7. When the judgments in Table 59 were entered, the AHP calculated the data by Excel (see Table 60) then showed the priorities for the seven products with respect to comfort in Table 61 and Table 62. The priorities of appearance are shown in Table 63.

Table 58

*Comparisons Worksheet-Comfort/Appearance*

| Comparisons | | | Customer's Review | | Better Strength |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 85.0 | 95.0 | B |
| 2 | Andy Steel | YONGYANG Steel | 85.0 | 98.0 | B |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 85.0 | 75.0 | A |
| 4 | Andy Steel | Fiber cement MgO board | 85.0 | 80.0 | A |
| 5 | Andy Steel | EPS cement sandwich wall | 85.0 | 80.0 | A |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 95.0 | 98.0 | B |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 95.0 | 75.0 | A |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 95.0 | 80.0 | A |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 95.0 | 80.0 | A |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 98.0 | 75.0 | A |
| 11 | YONGYANG Steel | Fiber cement MgO board | 98.0 | 80.0 | A |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 98.0 | 80.0 | A |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 75.0 | 80.0 | B |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 75.0 | 80.0 | B |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 80.0 | 80.0 | A=B |

Table 59

*Judgment Comfort/Appearance Worksheet*

| # | Better Subject | Intensity | Disparity |
|---|---|---|---|
| 1 | B | 3 | 10 |

| # | Better Subject | Intensity | Disparity |
|---|---|---|---|
| 2 | B | 5 | 13 |
| 3 | A | 3 | 10 |
| 4 | A | 3 | 5 |
| 5 | A | 3 | 5 |
| 6 | B | 3 | 3 |
| 7 | A | 5 | 20 |
| 8 | A | 5 | 15 |
| 9 | A | 5 | 15 |
| 10 | A | 7 | 23 |
| 11 | A | 5 | 18 |
| 12 | A | 5 | 18 |
| 13 | B | 3 | 5 |
| 14 | B | 3 | 5 |
| 15 | A=B | 1 | Equal |

Table 60

*Calculation of Decision Matrix AHP- Comfort/Appearance*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 0.33 | 0.20 | 3.00 | 3.00 | 3.00 |
| Light Steel Villa/ ADTO | 3.00 | 1.00 | 0.33 | 5.00 | 5.00 | 5.00 |
| YONGYANG Steel | 5.00 | 3.00 | 1.00 | 7.00 | 5.00 | 5.00 |
| SIP panels from ZHONGJIE | 0.33 | 0.20 | 0.14 | 1.00 | 0.33 | 0.33 |
| Fiber cement MgO board | 0.33 | 0.20 | 0.20 | 3.00 | 1.00 | 1.00 |
| EPS cement sandwich wall | 0.33 | 0.20 | 0.20 | 3.00 | 1.00 | 1.00 |
| Total | 10.0 | 4.9 | 2.1 | 22.0 | 15.3 | 15.3 |

Table 61

*Normalized Score of Each Product- Comfort/Appearance*

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.10 | 0.07 | 0.10 | 0.14 | 0.20 | 0.20 |
| Light Steel Villa/ ADTO | 0.30 | 0.20 | 0.16 | 0.23 | 0.33 | 0.33 |
| YONGYANG Steel | 0.50 | 0.61 | 0.48 | 0.32 | 0.33 | 0.33 |
| SIP panels from ZHONGJIE | 0.03 | 0.04 | 0.07 | 0.05 | 0.02 | 0.02 |
| Fiber cement MgO board | 0.03 | 0.04 | 0.10 | 0.14 | 0.07 | 0.07 |
| EPS cement sandwich wall | 0.03 | 0.04 | 0.10 | 0.14 | 0.07 | 0.07 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 62

*The Global Priority of Each Product-Comfort*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.79 | 11.31 | 0.00339 |
| Light Steel Villa/ ADTO | 1.54 | 22.04 | 0.00661 |
| YONGYANG Steel | 2.56 | 36.57 | 0.01097 |
| SIP panels from ZHONGJIE | 0.23 | 3.31 | 0.00099 |
| Fiber cement MgO board | 0.44 | 6.24 | 0.00187 |
| EPS cement sandwich wall | 0.44 | 6.24 | 0.00187 |
| Total | 6.00 | 100.0 | 0.03 |

Table 63

*The Global Priority of Each Product-Appearance*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.79 | 11.31 | 0.00113 |
| Light Steel Villa/ ADTO | 1.54 | 22.04 | 0.00110 |
| YONGYANG Steel | 2.56 | 36.57 | 0.00332 |
| SIP panels from ZHONGJIE | 0.23 | 3.31 | 0.00033 |
| Fiber cement MgO board | 0.44 | 6.24 | 0.00062 |
| EPS cement sandwich wall | 0.44 | 6.24 | 0.00062 |
| Total | 6.00 | 100.0 | 0.01 |

**Resale Value**

The resale value inputted into each product at Table 64 was provided by Table 4. Table 64 is the judgments number of resale value entered for each comparison, then input the judgment into Table 65. The intensity of difference in Table 65 was divided into three levels. If the difference is 10~25, it was indicated as level 3. If the difference was 35~45, it was indicated as level 5. If the difference was more than 50, it was indicated as level 9. When the judgments in Table 65 were entered, the AHP calculated the data by Excel (see Table 66) then presented the priorities for the seven products with respect to the resale value in Table 67 and Table 68.

Table 64

*Comparisons Worksheet-Resale Value*

| Comparisons | | | Strength | | Better Strength |
|---|---|---|---|---|---|
| # | A | B | A | B | |
| 1 | Andy Steel | Light Steel Villa/ ADTO | 75.0 | 75.0 | A=B |
| 2 | Andy Steel | YONGYANG Steel | 75.0 | 50.0 | A |
| 3 | Andy Steel | SIP panels from ZHONGJIE | 75.0 | 75.0 | A=B |
| 4 | Andy Steel | Fiber cement MgO board | 75.0 | 75.0 | A=B |
| 5 | Andy Steel | EPS cement sandwich wall | 75.0 | 10.0 | A |
| 6 | Light Steel Villa/ ADTO | YONGYANG Steel | 75.0 | 50.0 | A |
| 7 | Light Steel Villa/ ADTO | SIP panels from ZHONGJIE | 75.0 | 75.0 | A=B |
| 8 | Light Steel Villa/ ADTO | Fiber cement MgO board | 75.0 | 75.0 | A=B |
| 9 | Light Steel Villa/ ADTO | EPS cement sandwich wall | 75.0 | 75.0 | A=B |
| 10 | YONGYANG Steel | SIP panels from ZHONGJIE | 50.0 | 75.0 | B |
| 11 | YONGYANG Steel | Fiber cement MgO board | 50.0 | 75.0 | B |
| 12 | YONGYANG Steel | EPS cement sandwich wall | 50.0 | 10.0 | A |
| 13 | SIP panels from ZHONGJIE | Fiber cement MgO board | 75.0 | 75.0 | A=B |
| 14 | SIP panels from ZHONGJIE | EPS cement sandwich wall | 75.0 | 10.0 | A |
| 15 | Fiber cement MgO board | EPS cement sandwich wall | 75.0 | 10.0 | A |

Table 65

*Judgment Resale Value Worksheet*

| # | Better Subject | Intensity | Disparity |
|---|---|---|---|
| 1 | A=B | 1 | Equal |
| 2 | A | 3 | 25 |
| 3 | A=B | 1 | Equal |
| 4 | A=B | 1 | Equal |
| 5 | A | 9 | 65 |
| 6 | A | 3 | 25 |
| 7 | A=B | 1 | Equal |
| 8 | A=B | 1 | Equal |
| 9 | A=B | 1 | Equal |
| 10 | B | 3 | 25 |
| 11 | B | 3 | 25 |
| 12 | A | 5 | 40 |
| 13 | A=B | 1 | Equal |
| 14 | A | 9 | 65 |
| 15 | A | 9 | 65 |

Table 66

*Calculation of Decision Matrix AHP- Resale Value*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 1.00 | 1.00 | 3.00 | 1.00 | 1.00 | 9.00 |
| Light Steel Villa/ ADTO | 1.00 | 1.00 | 3.00 | 1.00 | 1.00 | 1.00 |
| YONGYANG Steel | 0.33 | 0.33 | 1.00 | 0.33 | 0.33 | 5.00 |
| SIP panels from ZHONGJIE | 1.00 | 1.00 | 3.00 | 1.00 | 1.00 | 9.00 |
| Fiber cement MgO board | 1.00 | 1.00 | 3.00 | 1.00 | 1.00 | 9.00 |
| EPS cement sandwich wall | 0.11 | 1.00 | 0.20 | 0.11 | 0.11 | 1.00 |
| Total | 4.4 | 5.3 | 13.2 | 4.4 | 4.4 | 34.0 |

Table 67

*Normalized Score of Each Product-Resale Value*

| Subject | Normalized Score Andy Steel | Normalized Score Light Steel Villa/ ADTO | Normalized Score YONGYANG Steel | Normalized Score SIP panels from ZHONGJIE | Normalized Score Fiber cement MgO board | Normalized Score EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Andy Steel | 0.23 | 0.19 | 0.23 | 0.23 | 0.23 | 0.26 |
| Light Steel Villa/ ADTO | 0.23 | 0.19 | 0.23 | 0.23 | 0.23 | 0.03 |
| YONGYANG Steel | 0.08 | 0.06 | 0.08 | 0.08 | 0.08 | 0.15 |
| SIP panels from ZHONGJIE | 0.23 | 0.19 | 0.23 | 0.23 | 0.23 | 0.26 |
| Fiber cement MgO board | 0.23 | 0.19 | 0.23 | 0.23 | 0.23 | 0.26 |
| EPS cement sandwich wall | 0.03 | 0.19 | 0.02 | 0.03 | 0.03 | 0.03 |
| Total | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Table 68

*The Global Priority of Each Product- Resale Value*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 1.35 | 19.3 | 0.00193 |
| Light Steel Villa/ ADTO | 1.12 | 16.0 | 0.00160 |
| YONGYANG Steel | 0.51 | 7.3 | 0.00073 |
| SIP panels from ZHONGJIE | 1.35 | 19.3 | 0.00193 |
| Fiber cement MgO board | 1.35 | 19.3 | 0.00193 |
| EPS cement sandwich wall | 0.31 | 4.4 | 0.00044 |
| Total | 6.00 | 100.0 | 0.00100 |

**Decision Matrix**

Finally, the global priorities for each product was recorded in the AHP decision as Table 69. The grand total was 1.000, which is identical to the priority of the goal. Each sample was given a global priority grade depending on the judgments of assumption for the German government on all eleven aspects.

It was found that the structural steel frame house from YONGYANG Steel, with a global priority of 0.20, contains the panels with the highest recommendation for the wall panels specific to the needs of the German government. The SIP panels from ZHONGJIE was in second place, with a priority of 0.15. The other samples had a lower priority than those two. In descending order, they were EPS Cement Sandwich Wall, Fiber Cement MgO board, Light Steel Villa/ ADTO and Andy Steel.

Table 69

*Final Decision Matrix for German Government*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Price per Shelter | 0.03110 | 0.02404 | 0.00487 | 0.01243 | 0.04826 | 0.05945 |
| Weight | 0.00611 | 0.00481 | 0.00329 | 0.01541 | 0.02931 | 0.02187 |
| Maintenance costs | 0.00484 | 0.00477 | 0.00475 | 0.00578 | 0.00626 | 0.00751 |
| Resale value | 0.00203 | 0.00177 | 0.00067 | 0.00203 | 0.00203 | 0.00041 |
| Durability | 0.00308 | 0.00461 | 0.02574 | 0.00911 | 0.01172 | 0.02574 |
| R-value | 0.03562 | 0.03562 | 0.04478 | 0.06372 | 0.03550 | 0.03550 |
| Strength | 0.03612 | 0.06078 | 0.11526 | 0.01470 | 0.00755 | 0.01470 |
| Ease of assembly | 0.00192 | 0.00192 | 0.00192 | 0.00969 | 0.00969 | 0.00969 |
| Assembly time | 0.00192 | 0.00192 | 0.00192 | 0.00969 | 0.00969 | 0.00969 |
| Appearance | 0.00113 | 0.00110 | 0.00330 | 0.00033 | 0.00062 | 0.00062 |
| Comfort | 0.00339 | 0.00661 | 0.01097 | 0.00099 | 0.00187 | 0.00187 |
| Total | 0.12790 | 0.15014 | 0.21814 | 0.14391 | 0.16273 | 0.18721 |

**Application to Another Situation**

This thesis mainly focused on the refugees and homeless people in Germany and may not apply to other countries due to the differences in environmental and cost constraints. However, due to the flexibility of AHP, this model for choosing the ideal wall construction could be easily adapted into different situations. In other words, this research has developed an AHP model that could help decide between optional materials or building methods for shelters in different situations or environments.

For instance, Brazil was being hit by flooding in 2015, which forced 150,000 people to evacuate ("Flooding 'worst in 50 years'," 2015). If the Brazilian government was going to build shelters for these homeless people due to the flooding, the judgment and criteria would be completely different than for the German government. However, the AHP model that was built as part of this research could easily be adapted to this situation. For example, in this situation, R-value does not need to be considered at all, because the temperature is relatively higher than Germany's climate. The assembly time becomes a very important factor to the Brazilian government because they want to quickly settle displaced people before they get sick or starve. The preliminary estimates of the various factors and the judgments of priorities were calculated and are shown in Table 70. The evolving factors that need to be considered can be easily added into the judgment criteria later. Changing the priority of these criteria could also change the priorities for the future. The decision for the Brazilian government would still require a reasonable but complex hierarchy to describe. To ensure this research's AHP works for the housing needs in Brazil, a comparison of criteria is still necessary.

Table 70

*Priority of Judgment for Brazil Example*

| Priority order | Percent of Importance |
|---|---|
| Assembly Time | 0.21 |
| Price per Shelter | 0.20 |
| Durability | 0.15 |
| Strength | 0.15 |
| Comfort | 0.10 |
| Appearance | 0.10 |
| Ease of Assembly | 0.05 |
| Maintenance Costs | 0.04 |
| Total | 1.00 |

For the flood situation in Brazil, the AHP result would indicate different products than in the German situation due to the very different environment and needs. However, to show how the AHP model works, the author used the same products but only varied the criterion value. The criteria of assembly time are in Table 71.

Table 71

*The Global Priority of Each Product in Brazil Example-Assembly Time*

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Andy Steel | 0.33 | 4.8 | 0.00913 |
| Light Steel Villa/ ADTO | 0.33 | 4.8 | 0.00913 |
| YONGYANG Steel | 0.33 | 4.8 | 0.00913 |
| SIP panels from ZHONGJIE | 1.67 | 23.8 | 0.04565 |

| Subject | Normalized score sum | Percent ratio scale of priority | Global priority |
|---|---|---|---|
| Fiber cement MgO board | 1.67 | 23.8 | 0.04565 |
| EPS cement sandwich wall | 1.67 | 23.8 | 0.04565 |
| Total | 6.00 | 100.0 | 0.02100 |

After all the data was entered into the new comparison, the AHP model could easily export the global priority of numerous comparisons. The decision matrix for the Brazilian flood example is shown in Table 72. The decision result changed due to the differing decision factors. However, since these products in the AHP comparison are picked for the German situation, it is highly possible that they are not the best choice for the Brazil flood example. A further study is necessary for choosing products judged to be more suitable for that scenario.

Table 72

*Final Decision Matrix for Brazil Example*

| Criteria | Andy Steel | Light Steel Villa/ ADTO | YONGYANG Steel | SIP panels from ZHONGJIE | Fiber cement MgO board | EPS cement sandwich wall |
|---|---|---|---|---|---|---|
| Price per Shelter | 0.02590 | 0.02590 | 0.03249 | 0.04678 | 0.02599 | 0.02599 |
| Maintenance costs | 0.00484 | 0.00477 | 0.00475 | 0.00578 | 0.00626 | 0.00688 |
| Durability | 0.00308 | 0.00461 | 0.02574 | 0.00911 | 0.01172 | 0.02574 |
| Strength | 0.02057 | 0.03490 | 0.06562 | 0.08210 | 0.00428 | 0.00821 |
| Ease of assembly | 0.00286 | 0.00286 | 0.00286 | 0.01429 | 0.01429 | 0.01429 |
| Assembly time | 0.00913 | 0.00913 | 0.00913 | 0.18160 | 0.18160 | 0.18160 |
| Appearance | 0.01315 | 0.02500 | 0.03866 | 0.00661 | 0.00661 | 0.00661 |
| Comfort | 0.01315 | 0.02500 | 0.03866 | 0.00661 | 0.00661 | 0.00661 |
| Total | 0.06374 | 0.10372 | 0.11021 | 0.18566 | 0.17422 | 0.20229 |

## Conclusion

The Analytic Hierarchy Process indicated that the steel frame house from YONGYANG Steel best satisfies the criteria and judgments for the Syrian refugee crisis in Germany. The German government could purchase these steel frame panels to build shelters to provide housing for both refugees and homeless Germans. However, because of the flexibility of AHP, the German government could also use the AHP template created to refine the decision. If the German government disagrees with any of the assumption or judgments, or even the criteria, they can change it and re-evaluate this in the AHP. The final choice will change depending on the different judgments.

This thesis used the German scenario as a case study, developing an AHP to compare products for use in Germany. The AHP template is flexible and the model that was developed for the German scenario can be applied to differing emergent situations in other parts of the world. This AHP template can help the decision maker, like the German government, to see clearly the decision-making process. The companies that produce wall panels can also use this template to benchmark with competitors and to improve products based on customer's needs.

### Further study

Based on this research, it is probable that a specific-need design based on requirements would be more cost effective than using products that currently exist in the market. Further studies could be done to design and test purpose-specific panels that could be used to respond rapidly to the needs of temporary housing requirement.

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