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Design and Development of a House with Recycled and Renewable Materials

Ms. Hannah Lynn Johnson,
Dr. Ulan Dakeev, Sam Houston State University

Dr. Ulan Dakeev is an Assistant Professor in the Engineering Technology Department at Sam Houston State University. His areas of research include Virtual & Augmented Reality, renewable energy (wind energy), quality in higher education, motivation, and engagement of students.

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Abstract

This paper aimed to examine the use and implementation of recycled and renewable resource building materials to construct residential houses. The central hypothesis is that building a house using completely sustainable materials is attainable through the use of renewable and recycled materials while keeping costs low.

In today's world, as the demand for alternate sustainable power sources is continuously growing, the need for long-lasting, energy-efficient power systems and building supplies which are recycled, durable, and affordable has also been increasing. By making more environmentally-conscious decisions on the utilization of resources, future generations will continue to advance technology while reducing cost with adoption. This concept will bring about a catalyst with a normalization toward the alternate power and sustainable-design building options for a world that can no longer rely on non-renewable resources.

A computer automated design (CAD) construction model has been designed. A building material cost report have been created as an estimation to compare the pricing of building a residential house through standard commercial methods. This helped determine the feasibility of utilizing these building materials in today's market. Research has been done on the recycled and renewable resources to compare the efficacy to common building materials such as insulation, plywood boards, cement, asphalt, and roofing. Lastly, a small, physical model was created through 3D printing for demonstration purposes.

Introduction

In this ever-changing world, the need for alternative power systems and building supplies has been increasing. Future generations will benefit from those who make more environmentally-conscious choices on how they leave their footprints on Earth. One way to be more environmentally conscious is to build sustainably, whether through ethically sourced minerals, recycled plastics, reusing items that would otherwise be deemed single-use, or even using industrial waste products to build a structure. While sustainable development's primary goal is to rationalize the use of natural resources, utilizing other materials that are considered waste is also living sustainably. Through this, the social and environmental issues are minimized [5]. Humans produce a high quantity of waste with any manufacturing process. Much of the waste can be recycled and reused into other products with a little extra effort and steps in the process. Therefore utilizing industrial waste is a promising solution to reduce environmental pollution from waste dumping and to reduce material costs when building structures [5]. Through these material alternatives, it is possible for a house to be designed out of what the average person thought was just waste to be thrown into a landfill or somewhere else polluting a stream.

The physical composition of a house is simply a combined pile of materials assembled from widely scattered sources created through multiple processing steps. Some of the steps and materials are easily replaced with renewable or recycled materials without disrupting the process since they undergo different kinds and degrees of processing in large numbers of places through many different techniques and materials [6]. This paper researched alternative methods and materials for the currently used construction industry standards. Some alternatives mentioned are oil shale, rice husk, shredded textiles, and paper sludge. Included are a cost estimation and comparison report, Creo 3D models, and Revit model plans.

Literature Review

Over several decades, many universities worldwide have been researching new materials and methods for building a modern home. For example, Jilin University in China, Brunel University in the UK, University of Perugia and Pavia in Italy, University Moulay Ismail in Morocco, and University of Nizwa in Oman just to name a few. are multiple materials that go into constructing a house. The construction of a house consists of a standard process: typically, first, the foundation is laid before moving onto the studs, siding or bricks, roof, insulation, and lastly, the partition walls in a simplistic order of operations.

Fly Ash and Oil Shale for Concrete and Asphalt Materials:

The first part of building a residential neighborhood is either using concrete or asphalt to pave the roads and driveways. An alternative additive for concrete is fly ash instead of sand. Its favorable qualities are that the concrete requires less water, is dense with a smooth surface, and does not crack as often or easily [15]. By using concrete mixtures that include fly ash, waste from electricity production plants will be reduced due to the ash being a byproduct of burning pulverized coal in electricity production plants. Fly ash mixed with lime and water creates a cement similar to Portland cement [15]. Since the concrete is smoother, it makes it easier to pump to locations when building a structure.

In the past decade, one of the main focuses of sustainability research has been to use environmentally friendly materials in asphalt pavement engineering to improve pavement performance [5]. Utilizing a full or partial adaptation to alternative components with one of the most widely used building materials can be more cost-effective upfront and more durable thus also being cheaper over time when repairs are needed.

Oil shale is found naturally within the Earth's crust. It formed from collected dead plants and animals over many millions of years ago [15]. Commonly extracted oil is created through a similar, natural process. The definition of oil shale is a solid combustible argillaceous rock whose color ranges from light gray to dark brown, and its ash content is higher than 50% [5]. It can be processed through oil refineries to make petrol, diesel, and many other fossil fuels. "Many petrol, diesel, and chemicals are extracted from shale oil and processed again, making it an important replacement for the 21st century" [5]. Since carbon shale can be carbonized into oil shale, it is a suitable replacement for anything petroleum-related. If all the oil shale in the world were extracted all at once, it would amount to over twice as much as oil reserves [5]. Since oil is processed into many different products and fuels, the waste can be reused and transformed into many other products. Currently, oil shale is only used in some agriculture applications and building materials, but its benefits are much more significant than merely that. It can be used as a fine aggregate in asphalt, concrete, and to produce asphalt shingles for roofing.

Rice Husks for Particle Board and Partition Walls:

An alternative material for particle board or partition walls are compressed and glued together rice husk panels. They are the shell that goes around the actual rice grain and is a waste product of rice production and distribution. Rice husks make excellent fertilizer due to its high nitrogen content and can be manufactured into composite decking. According to a study by C. Buratti et al., [2], rice husk can be used for the fabrication of panels for building applications: its acoustic and thermal behavior is comparable to typical particle board and insulation foam panels. The study was based on the acoustic and thermal capabilities with rice husks glued together into 2.9 and 10cm diameter wafers for acoustic testing and 300 x 300mm squares for thermal testing. It was conclusive that the rice husk wafers were above par compared to the other tested materials. The other tested materials were cork scraps, granulated tires, coffee chaff, waste paper pressed and glued with polyethylene fibers mat, waste paper pressed and glued together with wool fibers. These were all produced by a similar compression and gluing process. Ground rice husk powder can also be used instead of sea sand in concrete.

Recycled Textiles for Insulation:

The current understanding is that fibrous insulation materials perform well by controlling temperature and moisture for buildings. Insulation is a low-density fibrous material that behaves like a semi-transparent medium that remains entirely capable of both absorbing strongly scattering and emitting thermal radiation throughout a building. Typical insulation is created of fiberglass or foam boards. High-quality insulation is vital to the cost and energy efficiency of any structure. A study done by A. Tilioua et al. [18] focused on using recycled textiles as an insulation material. The researchers found that using recycled fabrics, such as used jeans, could very well be an alternative to current methods and materials. Currently, home improvement stores provide another alternative to fiberglass insulation that is made out of denim fibers.

Paper Sludge for Partition Walls, Insulation, Cement/Concrete, and Clay Bricks

Paper waste known as paper sludge is another option for partition walls and insulation in a board form. Since concrete is one of the most widely used building materials, the ability to make it substantially more durable and cheaper is highly desirable to both builder and buyer. Cement and concrete, as the most widely used construction building materials, are produced at around 4,200 million metric tons every year, and most has been consumed for buildings and other structures [4]. The researchers from the University of Jinan investigated the influence of paper sludge on clay brick properties. The result stated that paper sludge could improve the thermal and acoustic insulation of clay mixture used in house building [4].

It was calculated that around a blend of 30-55% of paper sludge with concrete not only reduces the greenhouse emission during the fabrication of cement but also lessens future management costs [4]. This material can also create calcium silicate boards that easily replaces the currently used gypsum boards for walls and ceilings. It is above par in thermal and acoustic insulation, fire and water resistance, and mechanical strength than the gypsum boards used today. Strength, water resistance, and other factors are dependent on the ratio of the components and the production process.

Methodology

This project investigated the cost of building a house made with as many recycled and renewable materials as possible. A 3D model of the house was constructed using Revit and Creo Parametric. A building material cost report has been created as an estimate to compare to the pricing of building a residential home through standard commercial methods. This helped determine the feasibility of utilizing these building materials in today's market. Lastly, a small, physical model based on the Creo parametric design was 3D printed.

A 3D house model was created in Revit, shown in Fig 1.

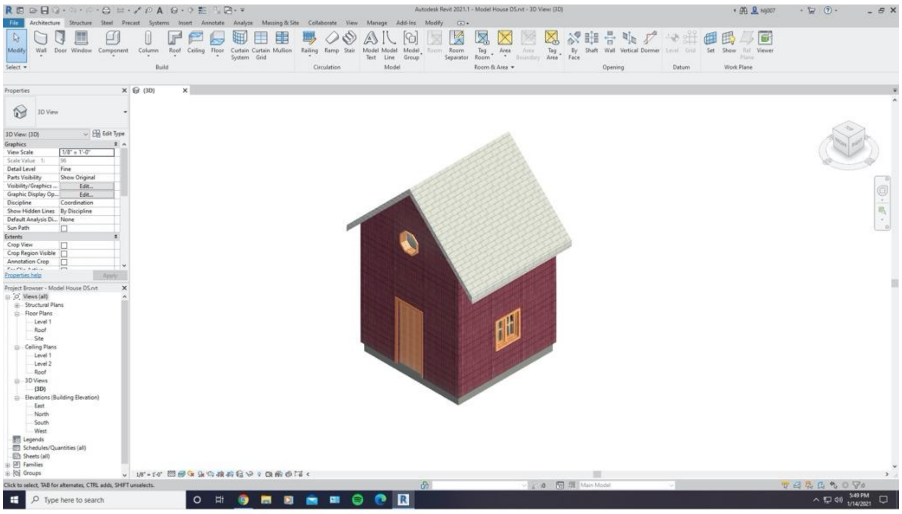

Figure 1. Full model idea of the house in Revit 2020.

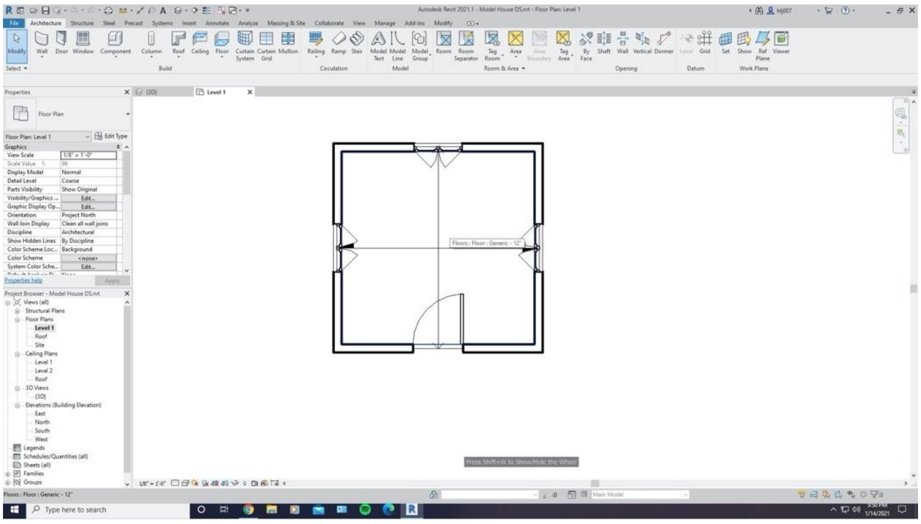

Figure 2. Level 1 floor plan in Revit 2020

The 3D printed model house is designed to be 10”(L) x 10”(W) x 10”(H). It features three square windows, one round window, and a door.

Creo parametric model of separate pieces for 3D printing purposes.

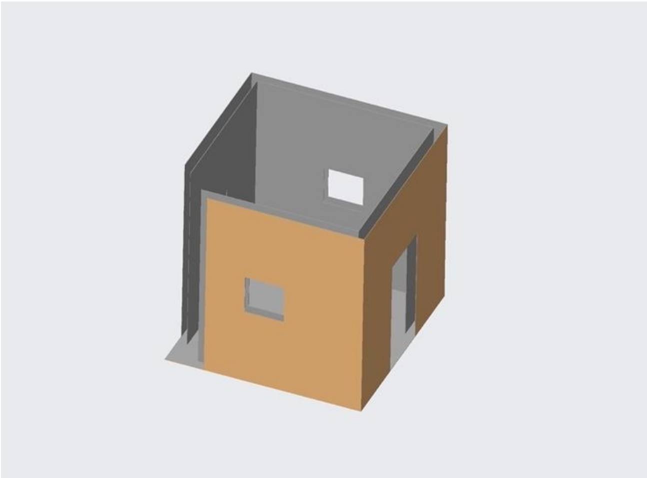

Figure 3. Part one of 3D house design for 3D printing. Created in Creo 6.0

Part uploaded to the Makerbot software for 3D printing. The process took almost two days.

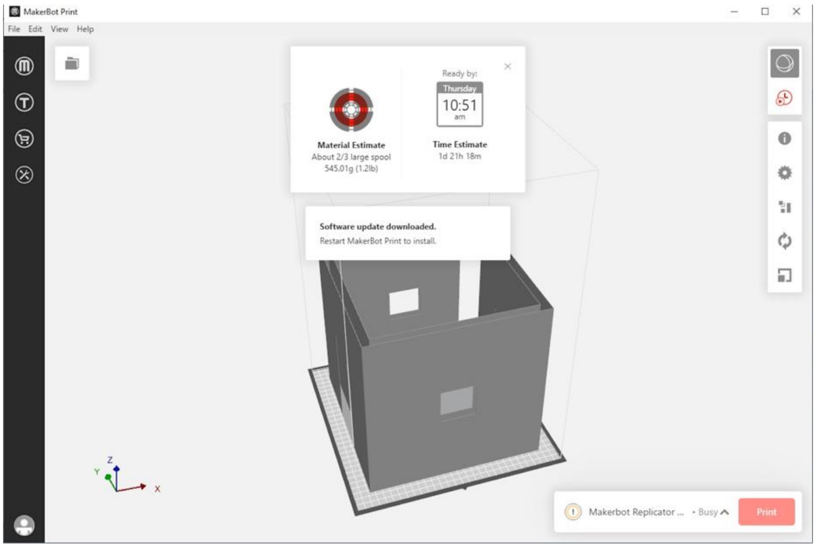

Figure 5. The physical model ready to print with a Makerbot 3D printer.

After the print was done, its edges were cleaned up. Next was to measure the windows, door, and heigh and length of the walls to make similar cutouts of the insulation material.

Figure 6. The insulation chosen and it cut into panels for the model. Pieces are labeled for each one has a different weight and volume.

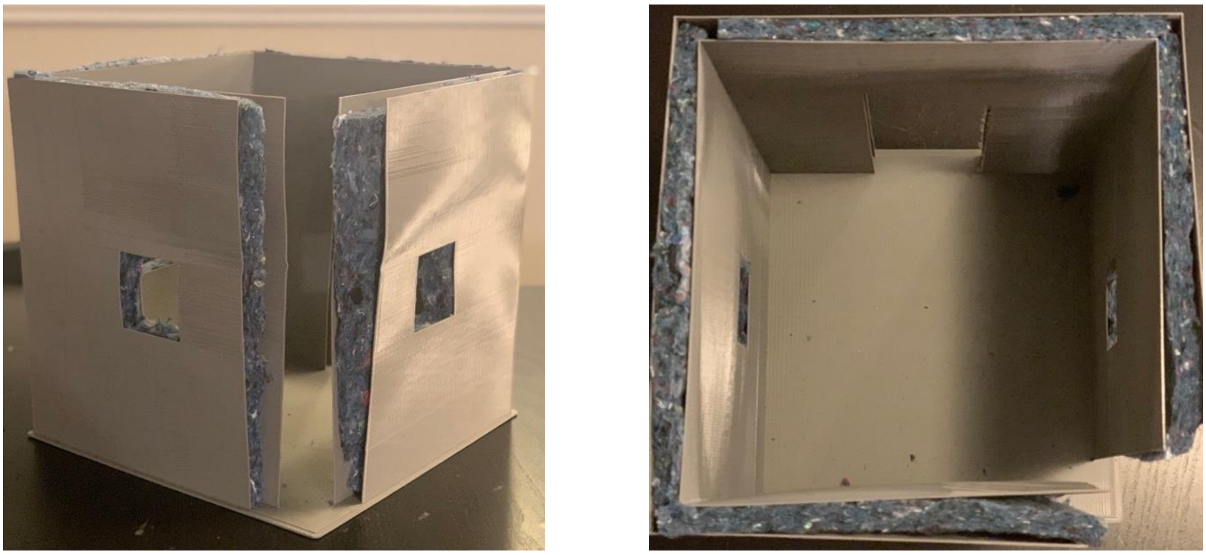

Figure 7. The 3D printed model stuffed with the insulation in two views. A chopstick aided in making sure it was filled entirely.

Data Analysis

Data was collected and calculated through other researcher's papers pertaining to recycled or renewable resources to replace common building materials.

Average materials needed to build a 1,700 square foot, single-family home, and their costs. The materials were then compared to the researched materials to determine the cost between the two. Asphalt shingles were not included in the later calculated total. Since oil shale can be made into asphalt shingles, the data was included.

Material	*Unit*	*Amount Needed*	*Cost (USD)*
Plywood	Square feet	243	$296.76
Concrete	Cubic yard	55	$14,107.50
**Asphalt Shingles*	Square feet	1,992	$1,882.68
Insulation	Square feet	2,500	$2,996
Partition Wall	Square feet	6,484	$1,718.26
Asphalt	Ton	15	$6,990

*Figure 8. Materials needed to build a 1,700 sq. ft., single-family home and the costs based from Home Depot. (Materials Needed to Build a House, 2019). *Not calculated in the grand total. [17], [16], [10], [13], [9]*

Asphalt mixture type	***AC-16***	***Cost USD***
OAM	417.8 (¥/t)	$4.03
SBS	544.8 (¥/t)	$5.25
ORM	404.6(¥/t)	$3.90

Figure 9. Oil shale: Best asphalt mixture costs converted to USD [5]. Sold by the ton.

Oil Shale	***Amount Per***	***Price per***	***Total***
Asphalt mixture ORM	1 ton	$3.90	$58.50

Figure 10. Cheapest asphalt mixture from [5]. Total calculated from average driveway size of 24' (W) x 20'(L) 5"(H), which amounts to 15 tons needed.

Fly Ash	***Amount Per Package***	***Price per Package***	***Total***
Fly Ash Concrete Mix	50lb	$5.25	$4,872.66

Figure 11. Concrete mix with fly ash cost [14]

Rice Husk	***Amount per Package***	***Price per Package***	***Total***
Rice hull	50lb	$42.39	$100.95
Polyurethane Glue	144 oz	$141.99	$283.98

Figure 12. Costs for rice husk panels [8], [1]

Textiles	***Amount Per Package***	***Price per Package***	***Total***
Denim Insulation	8 bags	$759.31	$3,796.55

Figure 13. Insulation made out of shredded denim cost [7]

Paper Sludge	***Size***	***Price per Board***	***Total***
Calcium Silicate Board	12"x12"x1/2"	$15.81	$102,512.04

Figure 14. Calcium Silicate board costs. [3]

Material	Replacement	Total Cost
Oil Shale	Asphalt	$58.50
Fly Ash	Concrete	$4,872.66
Rice Husk	Plywood Board	$384.93
Textiles	Insulation	$3,796.55
**Paper Sludge*	Partition Walls	$102,512.04

*Figure 15. Material cost totals based on calculations from figures 9-14. *Not included in calculations*

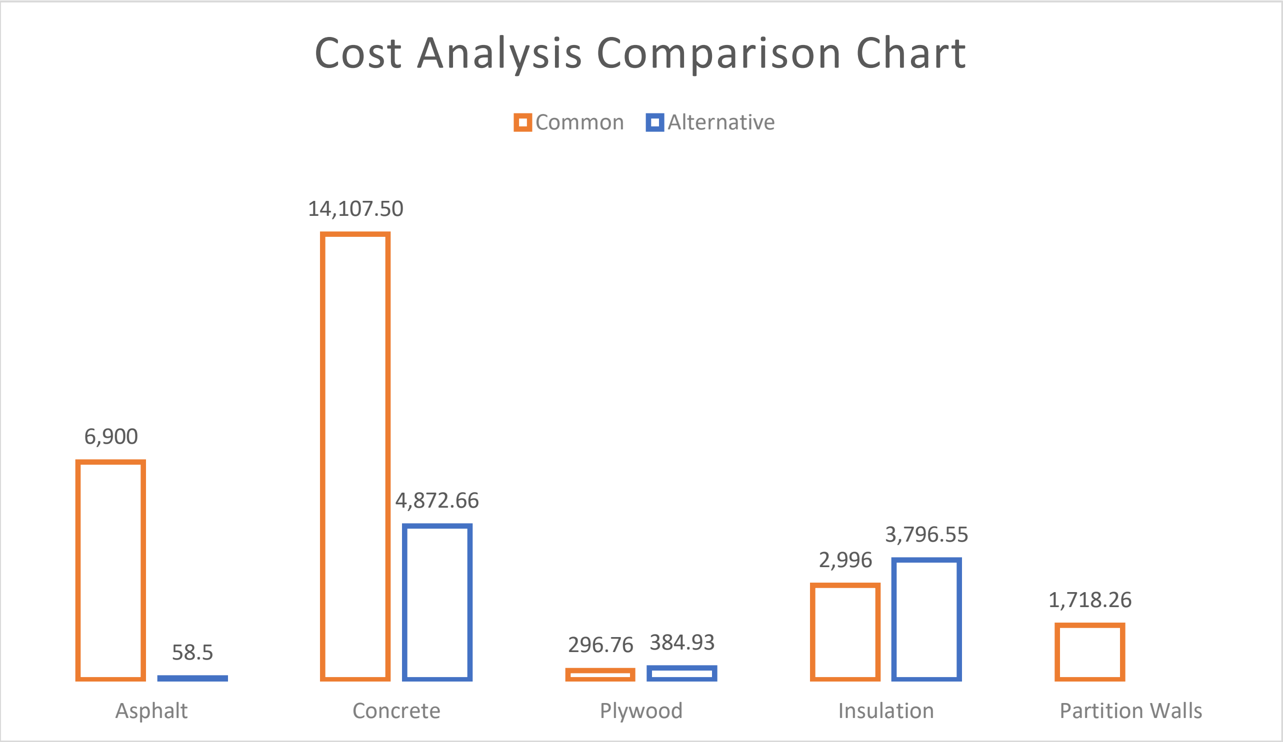

Figure 16. Cost analysis and comparison chart. The calcium silicate board data was omitted due to it being a large number that would make the other data points too small to compare.

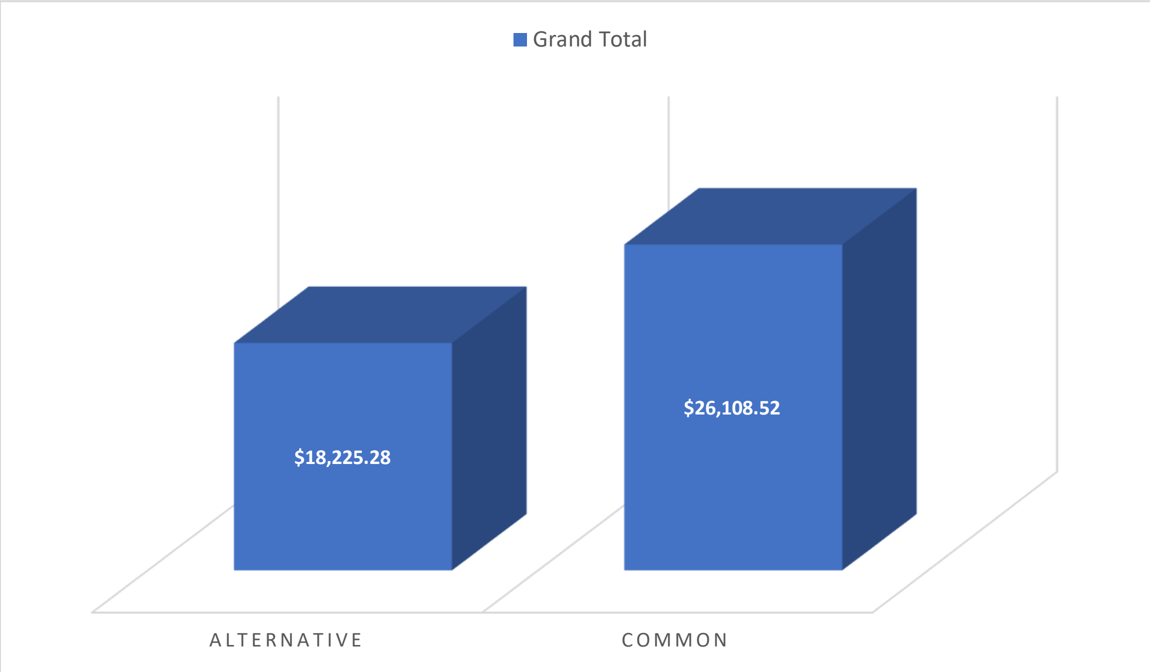

Figure 17. Grand total comparison chart of an average home

The windows and door volumes are subtracted from the total since no insulation will go in those sections. The slice is part of the cross section that is removed from the model on a corner. The total is the calculated volume that was filled with insulation.

3D Model	***Calculated Volume***
Inside Wall Volume	2,026.99 cm^3
3 Windows	43.2 cm^3
Door	64.8 cm^3
Slice	142.56 cm^3
Total	1,776.43 cm^3

Figure 18. Calculated volume of the 3D model using measurements of the wall space.

Denim Insulation	***Dimension***	***Weight***	***Volume***
1 Package	*40.6cm x 122cm x 1cm*	*305g*	*4,953.2*cm^3

Figure 19. Dimension, weight, and volume of the package of denim insulation.

Insulation	***Weight***
Used	*126g*
Left over	*177g*
Trimmings	*2g*

Figure 19. Weight of the insulation that was used, left over, and trimmed from the pieces.

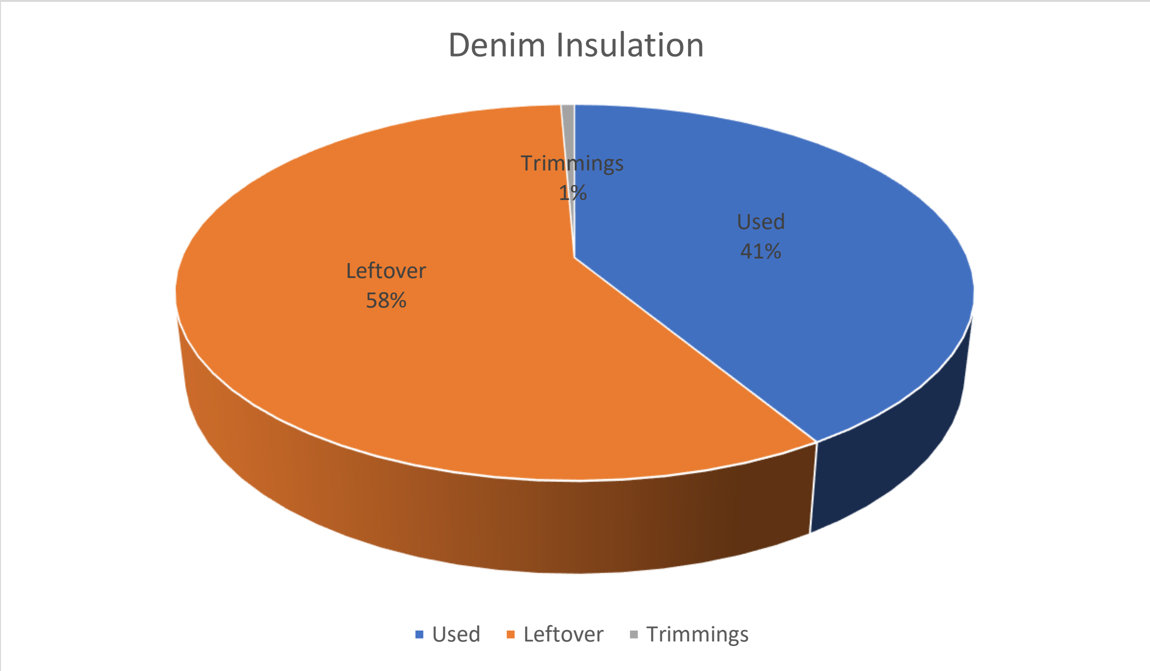

Figure 20. Pie chart of the insulation used and what was left over. Almost two and a half models can be made from one insulation package.

Panel Number	***Dimensions***	***Volume***
1	*16.5cm x 19.8cm x 1cm*	*326.7* cm^3
2	*18.5cm x 19.8cm x 1cm*	*366.3* cm^3
3	*18.5cm x 19.8cm x 1cm*	*366.3* cm^3
4	*16.5cm x 19.8cm x 1cm*	*326.7* cm^3
	Total	*1,278* cm^3

Figure 21. Panels with their respective dimensions and calculated volumes. The volumes from figure 18 of the windows and door are subtracted from the volume total.

Material	***Conventional Cost Per Unit (Total)***	***Quantity Needed***	***Alternative Cost Per Unit***	***Quantity Needed***
Concrete	*$9.50 ($890.62)*	*94 80lb bags*	*$5.25 ($787.50)*	*150 50lb bags*
Plywood	*$9.77 ($1,740.70)*	*14 2'x4'x 7/16" panels*	*$ 184.38 ($184.38)*	*100 ft^2*
Insulation	*$58.98 ($58.98)*	*1 15"x93" (11 batts a bag)*	*$9.29 ($174.65)*	*16"x48" roll*
Walls	*$8.48 ($101.76)*	*12 4'x8'x1/2" panels*	*$15.81($5,612.55)*	*355 1'x1'x1/2" boards*
Total	*$2,792.06*		*$6,759.08*	

Figure 22. (Owen's Corning)

Summary and Conclusion

This research provided data for how feasible it is to build a house with alternative materials. Consequently, some of the study materials proved to be cheaper—all the materials except insulation costs significantly less. A simple replacement of asphalt, concrete, and plywood is substantially less expensive than its ordinary counterpart. Insulation costs are negligible, for the price is roughly an $800 difference.

As for scaling up the 3D printed model to life size, using the alternative materials is 1/3 of the cost than using conventional materials. Therefore the hypothesis is correct that replacing standard building materials with recycled and/or renewable resources is possible and is significantly cheaper.

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