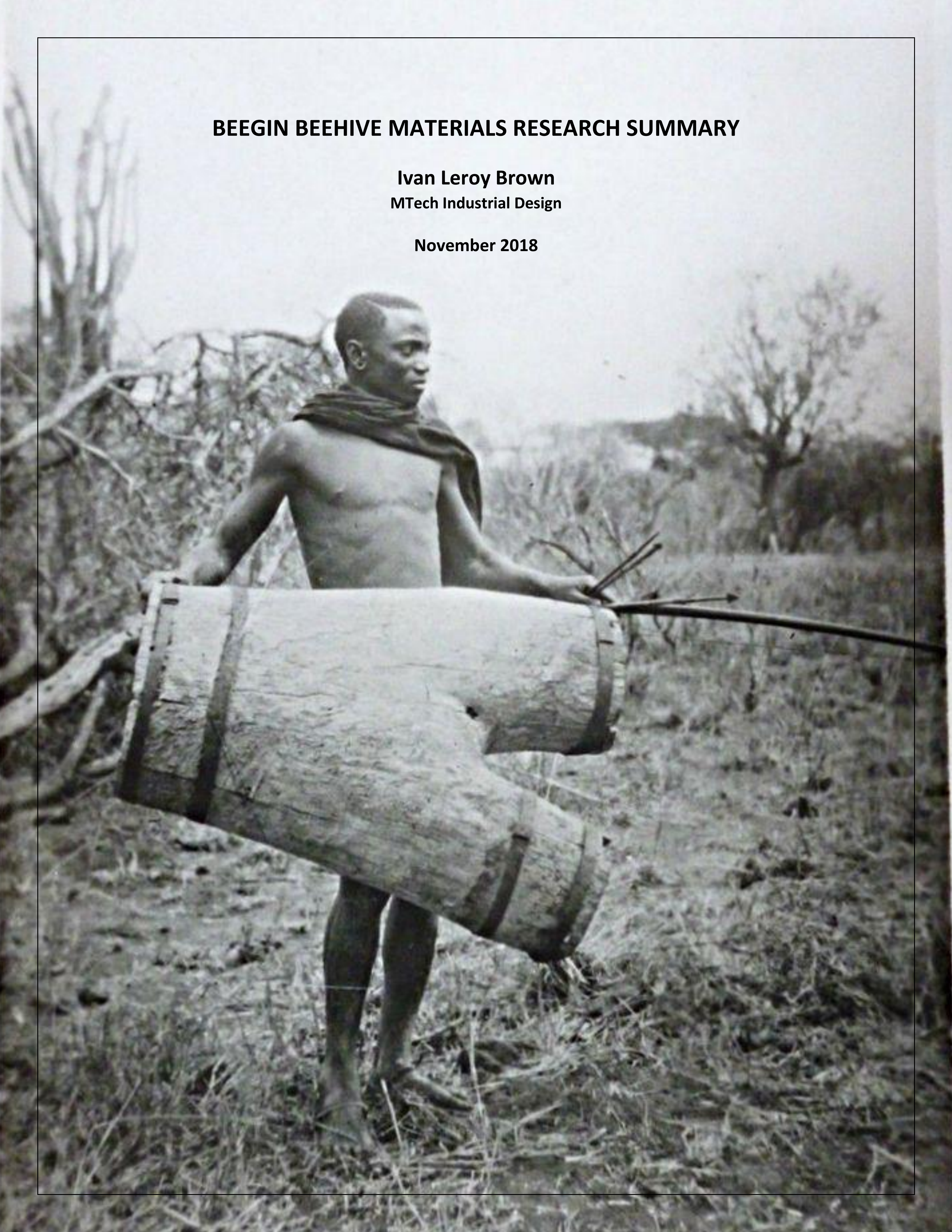
BEEGIN BEEHIVE MATERIALS RESEARCH SUMMARY

Ivan Leroy Brown
MTech Industrial Design

November 2018



Contents

1. INTRODUCTION

1.1. SUMMARY

The beekeeping industry is riddled with problems, not least of which is the high attrition rate of beehives. Beekeepers regularly have to replace or fix their hives due to damage or loss caused by, among other things, weathering, fires, theft, vandalism, pests, animals and floods. The standard wooden beehives have also created hurdles for small scale, rural beekeepers who lack equipment and skills to produce and maintain the equipment. There are a variety of materials that can be used to make beehives, some of which have properties that may solve the various problems. The goal of this study was to either confirm or disprove wood as the best material. By identifying certain categorical requirements of a beehive on the material it is made of, I was then able to test 18 different materials and categorically determine their suitability to the application. Through comparatively analysing the results, lightweight concrete and regular, dense concrete emerged as more suitable materials than wood, leading to the development of the Beegin appropriate beekeeping technology.

Figure 1: Beehives destroyed by flooding, badgers and fire (left to right).

1.2. BACKGROUND

This is a summary of the findings of an ongoing study into the suitability of different materials for beehive construction. The research began in 2015 as my Master's research project, titled *An Appropriate Technology System for Emergent Beekeepers: Field Testing and Development Towards Implementation,* at the University of Johannesburg and has been continued, and expanded, under the commercial company Beegin (created to deliver the research outcomes to market). The focus of the research has been on developing and implementing an improved beekeeping system for beekeepers in Southern Africa and abroad. This report focuses specifically on the core research and findings that have driven the success of the Beegin project so far.

Although the Beegin project has involved solving problems across various areas (sustainability, business, mould design, manufacturing, etc), the entire project is based, at its foundation, on a design research study into the viability, feasibility and desirability of alternative materials for constructing beehives. The purpose of this summary (presented here as an article) is to explain the research and findings to the broader public in a simple and consumable manner. This is not an academic paper, although some sections are taken from my published work.

Two other areas of study are also critical to the Beegin research and development process:

- The Problems Beekeepers Face and Their Innovative Solutions
- Concrete Moulding Tools and Mix Design

These will also be released as summarised articles to be read in conjunction with this article. I have separated these studies out from one another to make it easier to read, and faster to write.

1.3. RESEARCH QUESTION

What material should beehives be made from to support sustainability and growth in the beekeeping industry?

1.4. HYPOTHESIS

Although wood is the most common material used to make beehives, it is not the most suitable or appropriate material.

1.5. AIM

Determine the most suitable and appropriate material for making beehives.

1.6. PROCESS

I used the following basic research method:

1. Identify different categories of requirements on material by beehive application.
2. Identify different materials for beehive construction.
3. Conduct research and experimentation to measure the materials competence in each area.
4. Compile the results and information into a ranking system.
5. Analyse the results.

1.7. CONTEXT

Firstly, this study has been primarily focused on, and conducted within, South Africa. Although much of the literature used to inform the research process originated from other African countries, and from some other continents, the findings are influenced by the locality. I believe that the categories of material requirements identified during this study, as well as the properties of the materials, are universal and can be applied to beehive design anywhere. However, the thinking that informs my analysis and conclusions may have been different had I lived in China, or Canada, where several other contextual considerations may have been present.

Secondly, I am not a scientist, etymologist or engineer. For this reason, my physical resources in terms of equipment, and theoretical knowledge in areas like honeybee biology or thermal conductivity of materials were limited. Where possible I relied on literature and advice from experts in other fields, but for the most part this study was structured around my expertise – industrial design. Industrial design is a discipline of design focused on creative problem solving, mainly through manufactured products and systems. My area of focus is on a field of Industrial Design called Appropriate Technology (AT). AT consolidates the technological value with economic, cultural, political and social contexts, to develop new technologies that ensure implementation, uptake, usage, self-sustainability and minimal cultural disruption (Conteh, 2003, p. 4). The criteria for AT development were combined by Ian Smillie (*Mastering the Machine Revisited: Poverty, aid and technology*, 2008, p. 91) as follows:

- It meets the needs of the majority, not a small minority, of a community;
- It employs natural resources, capital and labour in proportion to their long-term availability;

- It is ownable, controllable, operable and maintainable within the community it serves;
- It enhances the skills and dignity of those employed by it;
- It is non-violent both to the environment and to the people;
- It is socially, economically and environmentally sustainable.

Examples of AT typically demonstrate an appropriation and simplification of a Western technology – appropriated to meet the requirements of developing nations. Often the hybridised and pirated outcome demonstrates healthier, more sustainable or more efficient ways of solving the problem, and the solutions make their way back into the Western technology. Such has been the case with water pumps, nut shellers and vehicle manufacturing.

Figure 2: Appropriate Technology innovations designed and implemented by industrial designers. Concrete nut sheller (left) and sheet metal water pump (right).

Thirdly, and in answer to the question I get asked most frequently, yes, I am a beekeeper. I have kept my own bees since 2015 and my mother kept several beehives on the farm I grew up on. Although I am a small-scale beekeeper (30 hives at the time of writing) I have a developed a deep knowledge for apiculture and would consider it my alternate profession. I harvest and process honey, wax and propolis from all my hives and I manage several permanent hives that pollinate farms.

2. MATERIAL REQUIREMENT CATEGORIES

Beehives are used to house a swarm of bees, allowing a beekeeper to easily harvest honey and inspect or maintain the health of the bees. The most common beehive, the Langstroth hive, is a series of wooden chambers with lids and bottoms, and removable inserts called frames. Although almost all beehives are based on the same standardised system, no two beekeepers' beehives are ever quite the same. Every beekeeper has different requirements and contexts. There are hobbyists, pollinators, commercial farmers, researchers, migratory, sedentary and many more types of beekeeping strategies, that each require slightly different things out of their beehives. The challenge here was to distil the myriad requirements into a few key areas that were universally important to beekeepers. Through intensive research I isolated six key areas where the properties of different materials will cause advantages or disadvantages when used for a beehive – regardless of the beekeeping style or hive design.

2.1. DURABILITY

Req.: The beehive lasts long.

Beehives are routinely exposed to forces that deteriorate the material, which leads to two issues:

- The beekeeper must spend time, resources and money on maintaining or replacing the beehive.
- The structure of the hive becomes compromised and can cause harm to the colony housed within.

The main forces are fire; weather (rain, flooding, sun, wind, etc.); pests (various insects, mainly moths, beetles, ants and termites); animals (bears, badgers, baboons, etc); humans (vandals, thieves and occasionally competitors); wear and tear (from regular usage by beekeeper & bees). The durability of a beehive directly affects cost/price - the longer the hive lasts, the cheaper it becomes. Therefore, a more expensive beehive can only be justified if it will last much longer than a cheaper one. In this category I asked the question *'how does the material cope with exposure to these forces?'*. A material that coped better would score higher in this category.

Figure 3: Left – Beehive parts destroyed over 1 month period for commercial beekeeper. Top right – wax moth damage to wooden super. Bottom right – fire burnt hive.

2.2. WEIGHT

Req.: The beehive is light… but not too light.

This category deals with the ergonomic properties of the material. Beekeeping (specifically the field activities of inspections and harvesting) is laborious muscle work. The components of a beehive are each lifted and put down several times per hive. The hive also contains honey and brood that can add 20kgs to each chamber. The work is also done wearing a heavy protective suit, gloves, boots and a veil, adding complexity. Beekeepers do have systems and practices for avoiding injuries, mistakes and extra strain. Like pairing up, using the frame-by-frame method of harvesting, using leaf blowers and operating small fork lifts. However, at a small-scale it is often a single person working on their own, with no added equipment.

You may think, 'lighter = better' for the purposes of the beekeeper. However lighter weight also produces a negative consequence – the beehive becomes easier to steal. There are other benefits to heavy weight, like protection from winds, but with light hives natural threats are easily overcome with a clever stand. With human threats there is no solution outside of making it harder for the person to steal or vandalise your hive. If someone really wants to steal or destroy a light beehive, as much as you try to secure it, there will be tools to unsecure it. Whereas, with weight it is possible to deter a lot of theft, simply by making the beehive a little too heavy to carry away.

So, for this category the scoring was more complicated. A heavier material would get both a good and bad score. Obviously, all the scores would level out at 5/10. So, in this category, I decided to focus on the lighter = better argument. Then at the end, when compiling the results, I weighted this section slightly lower than other sections to account for the benefit/drawback issue.

Figure 4: Wooden beehives are light and can be loaded on trucks efficiently for migratory beekeeping (left), but they must also be protected from theft (right).

2.3. INSULATION

Req.: The beehive is well insulated.

Bees need to maintain a temperature of around 32°C inside the beehive. When the external temperature is too hot or cold, they control the internal temperature of the hive by fanning their wings to either circulate air and cool the hive or create friction and warm the internal air. As it goes:

WORK = ENERGY = CALORIES = FOOD

Bees consume honey to generate the energy needed to fan their wings so vigorously. It is well known that in consistent tropical climates beehives produce more honey. It is also well documented that honey yield can be increased in climates with varying temperatures by insulating the beehive. In this category I asked the question *'how does the material affect the bee's ability to control the interior temperature of the beehive?'.* Material that assisted internal temperature regulation scored higher in this category.

Figure 5: Bees in cold climates expend a lot of energy heating the hive (left snow covered hives) and in hot climates – to cool the hive (right bees bearding to reduce heat).

2.4. TOXICITY

Req.: The beehive is not harmful.

Materials, and the chemicals used to make and treat them, can be harmful to people and bees. People that work with hazardous materials risk harming their health, and as great as a material may be, the value of human life is always of paramount concern in design. Likewise, when we select a material to house bees within, we are inadvertently exposing the insects to a range of chemicals and environmental factors that are not natural to their evolutionary, biological make-up. Insects are much smaller than us and more susceptible to micro-hazards, that may not affect humans, but can cause huge problems to a colony. It was important to develop an understanding for honey-bee biology and colony activities for many areas in this study, not least of which this category.

The process of making, using and discarding materials also has an impact on the environment. Some materials produce more wastage, higher costs to biospheres, larger carbon footprints and cannot be recycled effectively. Sustainability is of similar importance to designers and this is where it comes in to play. The more benign the material in all areas, the higher it would score in this category.

Figure 6: Left – beehives being burnt to kill bacterial contamination. Right – bees dead outside beehive due to poisoning.

2.5. MANUFACTURING

Req.: The beehive is easy to make.

In this category I asked two questions of each material: '*how is the beehive made?*', and '*what does the manufacturing process mean?*'. For example:

- Wooden beehives are made using carpentry tools, locally sourced semi-machined raw material and wood working skills. This means that wooden hives exclude people without access to these resources but do allow for relatively small-scale production.
- Plastic beehives are made using high-tech, large-scale, mostly imported and expensive - equipment, tools and raw materials. This means that plastic hives require huge capital outlay, excluding small-scale producers, but producing high quality end-products extremely quickly.

This category deals with several ethical, moral, economic, social, metaphysical and fundamental questions in the modern world. Such as the debate between industrialisation versus decentralisation. There are good arguments for each worldview and I don't attempt to satisfy everyone in the choice of the one that forms the basis for this study. Appropriate Technology (AT) was chosen as a theoretical framework for this study because it fits in with the South African context, so before accepting the findings of this study you may want to ask yourself if it fits in with your world view and context. Nonetheless, AT values the democratisation of manufacturing above all else. So, when it comes to production concerns, the material that favours local, low-tech production over mechanised, mass-production would score higher in this study.

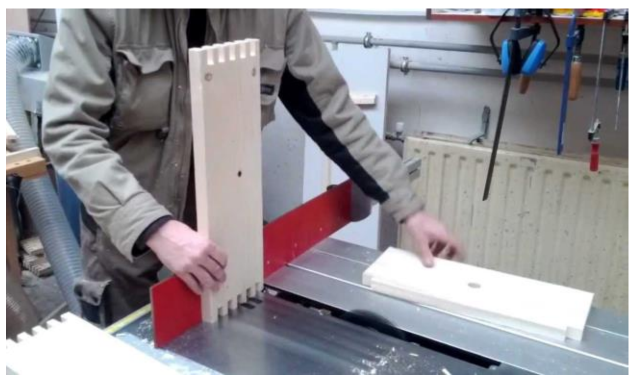
 

Figure 7: Beekeepers in rural areas use natural materials and recycled plastic to make cheap beehives (left). Beekeepers in developed areas rely on precision manufacturers to make their high quality hives (right).

2.6. COST/PRICE

Req.: The beehive is cheap.

Costing is calculated based on the price of raw materials, labour, equipment amortisation (recuperation of capital outlay for tools etc.), transport and business expenses (marketing, admin, design, sales, etc.) that go into producing and delivering a product to market. The price of a product is typically set at 200% of cost to produce a profit that a business can use to expand, or a price point that can be negotiated and discounted from. So, price and cost are directly proportional.

A single beehive may not cost much, but beekeepers require hundreds of them to generate an income. As soon as the price of the individual hive becomes too expensive, the beekeeper's business becomes unsustainable. The higher the cost/price the worse the material performs in this category.

Figure 8: Left - Flow Hive at a price of $750. Right - Beehaus at $790.

3. MATERIALS

In industry (industrial) materials are inputs into production processes. A material is a chemical substance or combination of substances that can be constituted to form an object (design). There are thousands of materials that can be used in the production of objects, so to begin with I narrowed the focus down to those materials most commonly used for products of this nature (feasibility study excluded). The materials are separated into 4 main categories:

3.1. METAL

- Mild steel sheet
- Cast iron
- Aluminium sheet

3.2. WOOD

- Pine
- Plywood
- Marine Plywood
- Paper & Cardboard

3.3. POLYMERS

- Foam - polystyrene
- Foam - polyurethane
- Rotation moulded plastic (ABS, HDPE, LDPE, PP, PET, HIPS)
- Injection moulded plastic (ABS, HDPE, LDPE, PP, PET, HIPS)
- Composite (fibre-glass & polyurethane resin)

3.4. SAND & STONE

- Clay (unfired)
- Clay (fired)
- Stone
- Brick & mortar
- Concrete
- Lightweight Concrete


Figure 9: Left - Sheet steel beehive chamber. Right - unfired clay hive.

Figure 10: Top left & right – polystyrene foam beehive.

Middle left & right – Rotation moulded plastic beehive.

Bottom left – Polyurethane foam hive chamber.

Bottom right – cardboard paper beehive.

4. RESEARCH & TESTING

4.1. DURABILITY

For all the materials I was able to find mechanical property data on their compressive, tensile, shear and torsional strengths. This data came with insights into the stiffness, resilience, elasticity, brittleness and plasticity of each material. For some materials I did my own experimentation (see figures 9-10), because often materials can be made more durable through clever design and production techniques. Foams and plastics can have UV stabilisers added to extend their life expectancy. Concrete can be reinforced with fibres to prevent brittleness. Wood can be treated and coated to minimize deterioration. Unfired clay can be coated with ash and lime to protect it from rain. You name it, I tried it. Most of the time I did block tests (making cubes of the material and experimenting on it), and occasionally I constructed whole beehives. I had a great deal of fun breaking, freezing, wetting, burning and pounding the various materials.

4.2. WEIGHT

The data found in 4.1 also provided specific mass information for each material. What the data mostly did not provide was any help in determining the happy middle point between weight and durability. For most materials thickness is directly proportional to durability. Similarly, weight is also directly proportional to thickness. For each material there would exist a point where the material would be extremely durable, but impossibly heavy – and extremely light but impossibly weak. In the end I used the strength and mass data to calculate the weight of each material if I were to make them each to be the same strength. So, for wood 30mm thickness would be roughly equivalent to 2mm of mild steel sheeting.

4.3. INSULATION

The insulation of the materials has been tested several times, with my experiments becoming more sophisticated each time. Initially, I used pre-existing material data to determine the insulation coefficient of each material. This information, that is available in several engineering manuals, helped predict which materials would be good insulators. To confirm the predictions, I built small blocks and boxes from each material and measured their surface temperatures and internal air temperatures in different climates. I simulated different climates by taking measurements on the materials when placed in an oven, left at room temperature and in a freezer room. Finally, I have been testing the materials when used as beehives. To do this I use a recording device to measure the change in outside temperature over 24 hours, as well as the temperature inside an empty beehive (control) and the temperature inside a beehive full of bees (brood chamber and super chamber). I have been recording data for over 2 years, taking measurements on cold, hot and average days. I also record honey production from the different beehives and use the figures as anecdotal evidence of better or worse temperature insulation capability.

There are intrinsic problems with using the information gathered on the temperatures of the live hives here. The problems are as follows:

- The beehives made from different materials are mostly different designs (shape, form, structure, etc). The different designs can mean that some hives seal more effectively or have better ventilation. My original lightweight concrete beehive was designed to be as similar to a wooden beehive as possible (see figure 11) for this very reason.

- The swarms are all different. I try to use very similar size, age and strength swarms in each of the beehives. However, there is no way to ensure the swarms are perfectly matched, and so a more consistent temperature in one beehive may be attributed to a slightly better colony. Or a higher honey yield may be the result of hard-working bees more than temperature regulation.

In the end I must exclude the data from the live testing from any conclusions drawn about the insulation of the materials and focus only on the baseline material data in this study. If the material is a better insulator naturally, then it will be easier and cheaper to design a beehive that is effective at insulating. Plain and simple. If I talk about the design development of the Beegin lightweight concrete beehive (another article altogether), then I can talk about how well it insulates when compared to other beehive designs, not materials.

Figure 11: Left – block testing concrete and wax temperature insulation. Right – live hive temperature recording with concrete ad wooden hives.

4.4. TOXICITY

Toxicity is also multi-faceted. We could look at the environmental impacts of the material before, during and after its life, the impact of the manufacturing process, the impact of the material on the user or even the impact on the continued trade of the material on developing nations economies and how that contributes to other toxic contributions. Toxicity also relates to food safety – beehives hold honey that is consumed by people and must not be contaminated by toxins. So, I did, and I rated all the materials in each area based on as much current information as I could find. Data on the toxicity, or harmfulness of the materials was widely available, as well as the harmfulness of their production and disposal process'. As part of the research done for 'Manufacturing' I compiled information on the carbon footprint and environmental impact of using the various materials. Where I did spend much more time, and weight the final scores much more heavily, was the impact the material has on the bees that are housed within it.

4.5. MANUFACTURING

For each material I went through the process of creating a business plan for producing a minimum-viable-product (simple beehive) from it. I sourced prices, expert insight and quotes on equipment, facilities, resources, labour and skills required to process the various materials. For all the materials there existed a variety of possible production strategies, with more initial capital investment usually translating to faster and cheaper end products. So, part of the calculation involved determining the most reasonable level of production for each material. To do this, I calculated how many beehives would have to be produced, and at what speed, to sustain the business and how many of these businesses the beekeeping industry could sustain.

To calculate the material and equipment figures correctly I needed to have a rough design for each beehive. To do this I needed to use the findings from the first 4 categories to design a simple beehive from each material. So, each beehive was designed to provide maximal insulation and durability, while achieving minimal weight and toxicity. For most of the materials it was straight forward to determine their score in this category. If the MVP production was highly complex, required lots of expensive machinery and was reliant on technical skills that weren't easy to replicate, then the material scored low.

Figure 12: Manufacturing testing of concrete beehive moulding tools with small scale farmers.

4.6. COST/PRICE

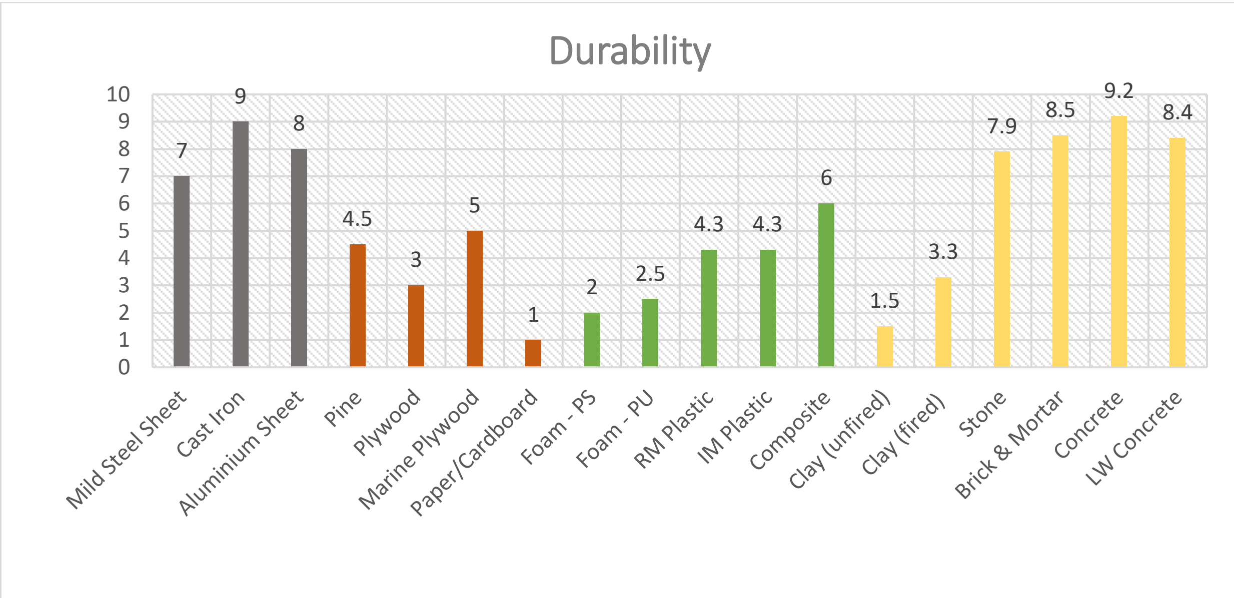
Where hives already existed (made from the material) their market price was used to calculate the average cost, or manufacturers were contacted or interviewed to verify the costs. With materials that are suited to mass manufacture the cost was fairly calculated based on the larger scale manufacturing requirements. For the capital required to set up and produce the hives see Manufacturing above.

Figure 13: Manufacturing of low-cost beehives for rural community in Ethiopia.

5. RESULTS

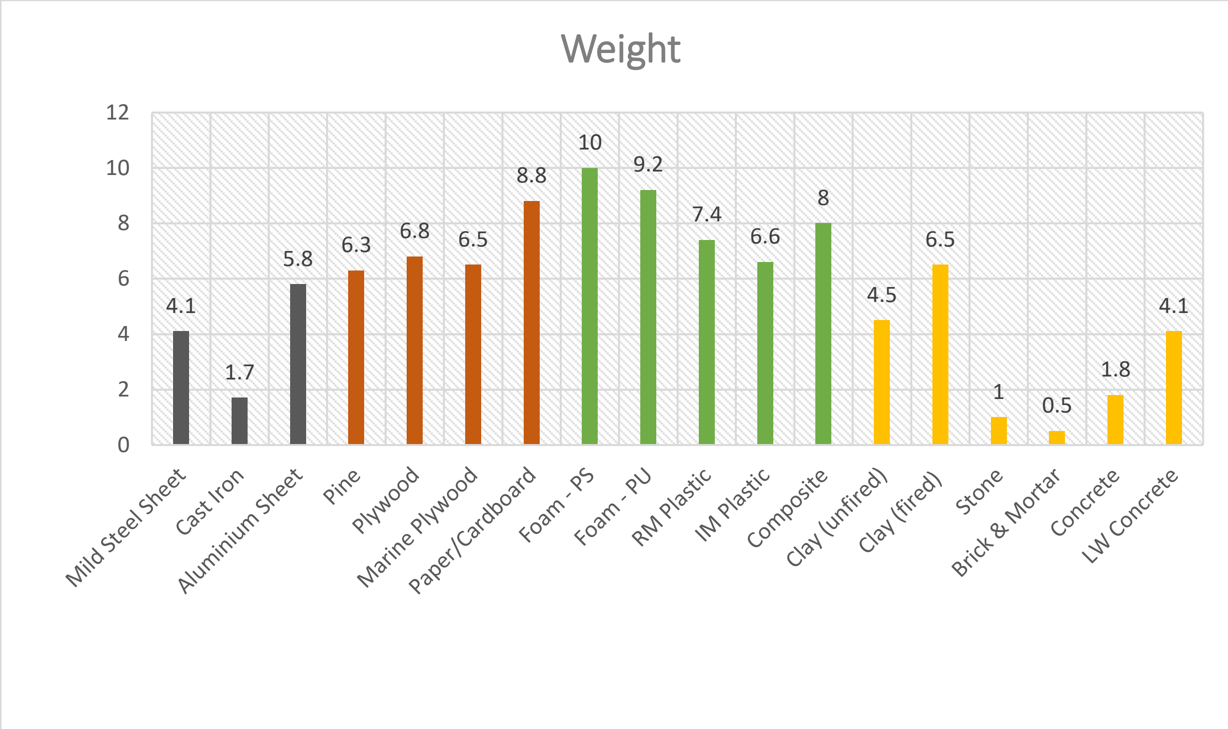
The outcome of the research and experimentation was a lot of data. I have gone about summarising the findings into six easy to read charts with a short paragraph of anecdotes explaining the subtler results. I have then also summarised all the data into a final table which explains my final choice of material.

5.1. DURABILITY



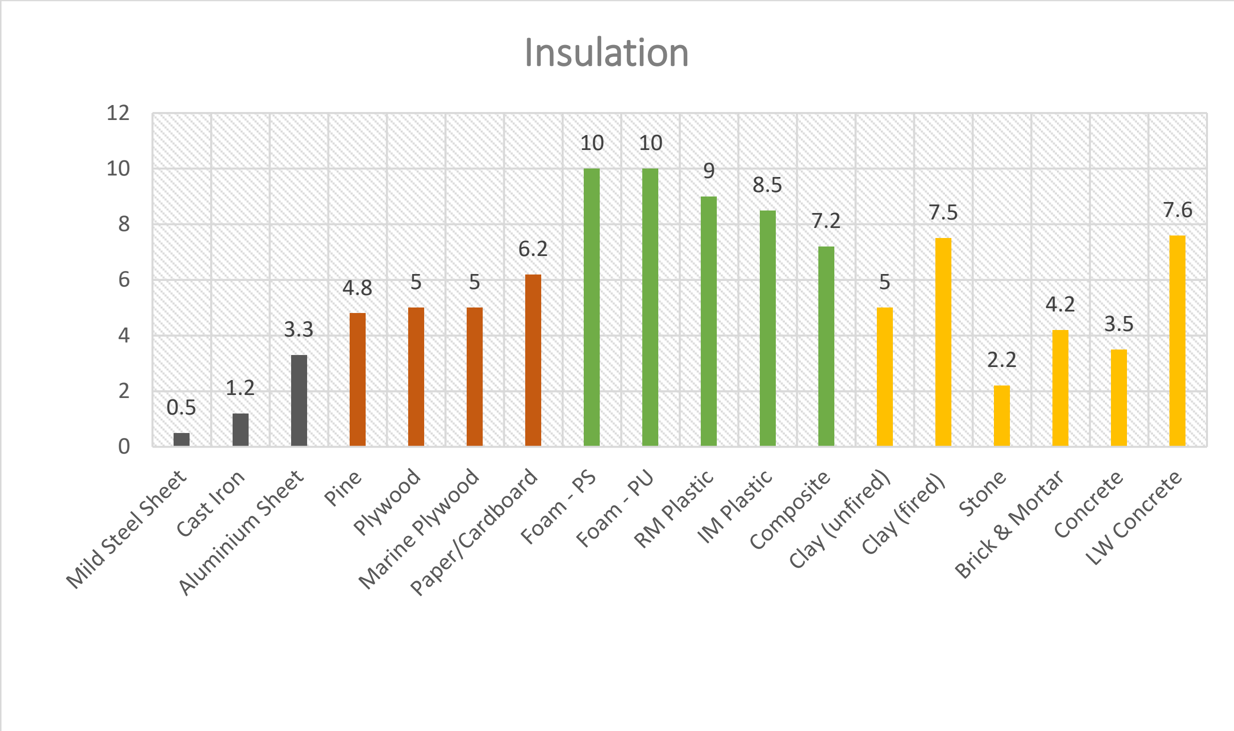
- Although plastic and foam represent a marked improvement from wood in that they are resistant to weathering from water, they must be treated for UV protection in similar ways to how wood is treated for water protection. Then there is the problem of fires, where wood, plastic and aluminium are no match.
- Several companies that make plastic hives advertise the durability of the hive in relation to bacterial diseases. They claim that with a plastic beehive, users can treat the material with chemicals to kill any residual bacteria before re-swarming the hive. This is mainly focused on American and European Foul-Brood, that, if found in a wooden beehive, require the beekeeper to burn the entire unit – loosing a swarm and a hive. What I thought when I heard this was 'and then what do you treat the plastic with to neutralise those chemicals?'. Most plastics are porous and would absorb some amount of the chemicals used on them. The next swarm, although safe from diseases, would experience some exposure to a toxic chemical. I found very little useful information on this, probably because plastic hives are rare and AFB treatment is rarer. Anyway, I gave plastic a little credit for this point, and used this logic to apply the same credit to other materials that would not have to be destroyed during bacteria treatments. For instance: lightweight concrete can be treated using fire to kill bacterial residue.
- Although materials like steel and cast iron are extremely durable, they cannot be given a perfect score. The value of metal as a recyclable material will make the beehive more attractive to thieves. Also, those hives would experience greater weathering in coastal areas.
- Stone is very durable, yes. But in order to make a beehive it must be made into a thin enough layer, where it will become brittle and crack if dropped. Concrete is more absorbent of impacts.

5.2. WEIGHT



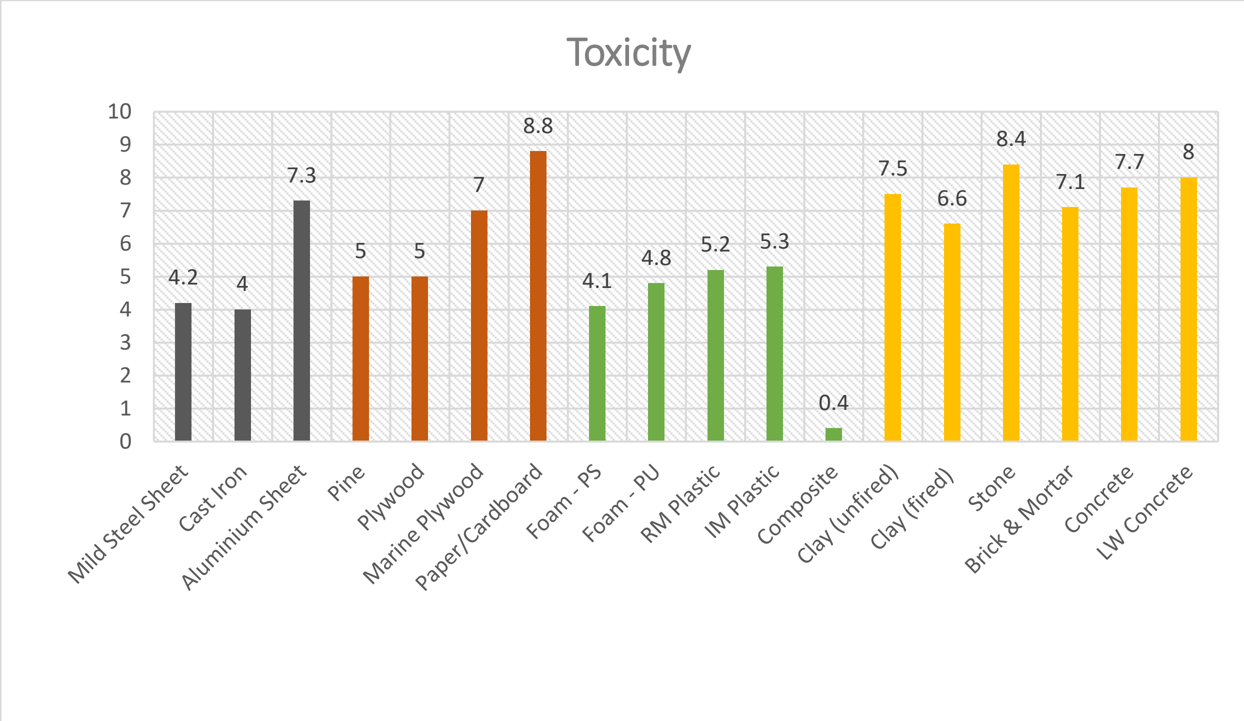
- Mild steel sheeting is much heavier (7.85 g/cm³) than concrete (2.4g/cm³). However, for concrete to be at an effective strength the thickness must be 60-100mm, compared to sheet metal which is strong when 2-5mm thick.
- Pine is a soft wood with a density of about 0.5g/cm³, which is lighter than injection moulded HDPE plastic which is about 0.9g/cm³, or ABS which is about 1.2g/cm³. Again plastic is much stronger than wood and can be used at thicknesses of les than half that of wood to achieve the same strength. So, their scores are similar.
- Foam is a tricky substance, with Polyurethane foam ranging from 0.08-0.8g/cm³. The heavier/denser the type used, the stronger it is. Polystyrene can be anywhere from 0.02-1.3g/cm³. We looked at the types of these foams used already for beehive making and found that Polystyrene was favoured for lighter and stronger properties. Either way, both foams achieve incredibly low weights even when used in massive thicknesses to achieve adequate strength.

5.3. INSULATION



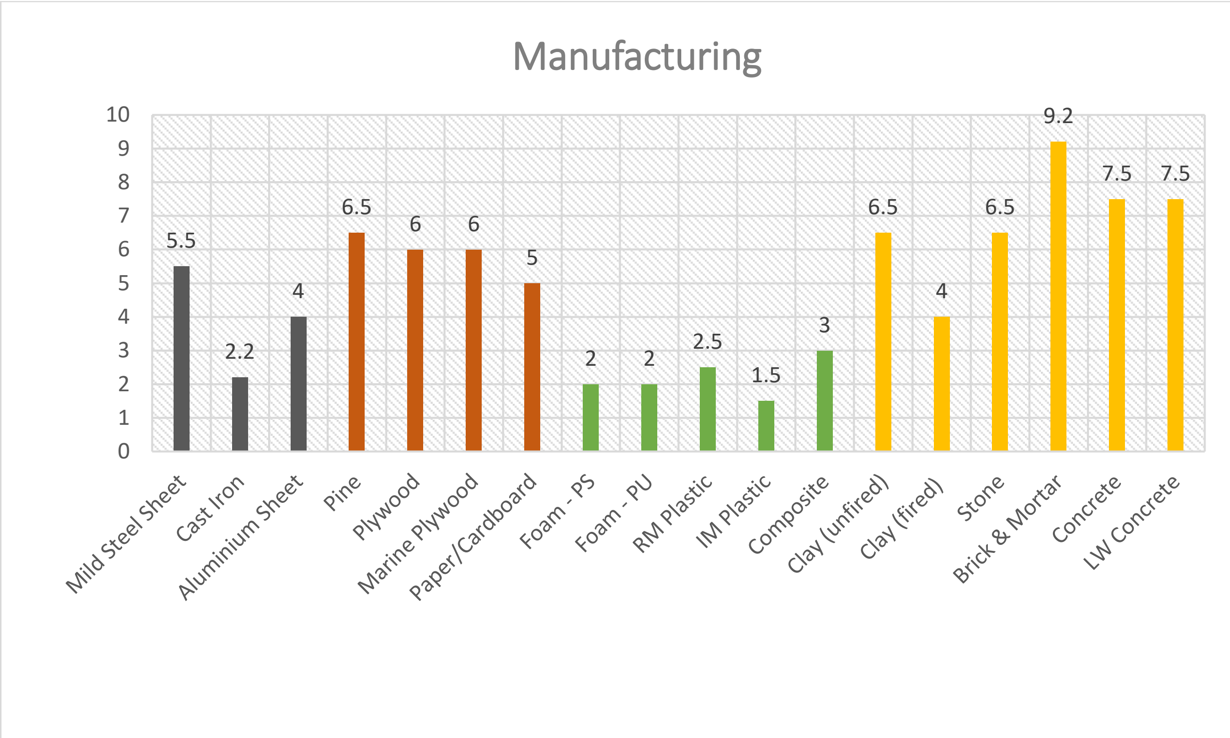
- Polymers are naturally non-conductive and so retain a consistent, neutral temperature. Foams (aerated polymers) literally have air (another great insulator) trapped within them, which makes for incredibly effective insulation.
- Lightweight concrete comprises up to 75% of aggregates that retain air and are non-conductive. The shift from aggregates like stone that are highly conductive translates to a doubling in insulation. Regular concrete is slightly insulating, mainly due to the sand aggregate.
- Although polymers are good insulators, I also found a lot of research and data on humidity issues. The plastics often cause problems with condensation inside beehives. This category is not about humidity, but we did measure humidity in the hives we tested and found some definite issues with plastic hives. Most plastic hives incorporated a mechanism or vent to release moisture from the top, but even so there was an issue with water collecting in the hives. This was not scored here but instead moved to Toxicity.
- Wood is generally a good insulator, however I identified two key issues with its ability to create a beehive that is well insulated. Firstly, the wood must be treated (ideally soaked and boiled) in a chemical that permeates the porous layers of the wood and binds the fibres together to keep moisture out. This treatment effectively halves the insulation capacity of wood. Secondly, it is difficult to find a wooden hive, and harder to make on, that seals properly. Compared with plastic and concrete, wooden hives will generally have gaps and holes that let in air. Although the bees will typically seal these gaps up, a great deal of literature explains that insulation is critical when a swarm is first developing in a new hive and hasn't had time to seal up the gaps. This same issue is true of steel and ceramic hives.

5.4. TOXICITY



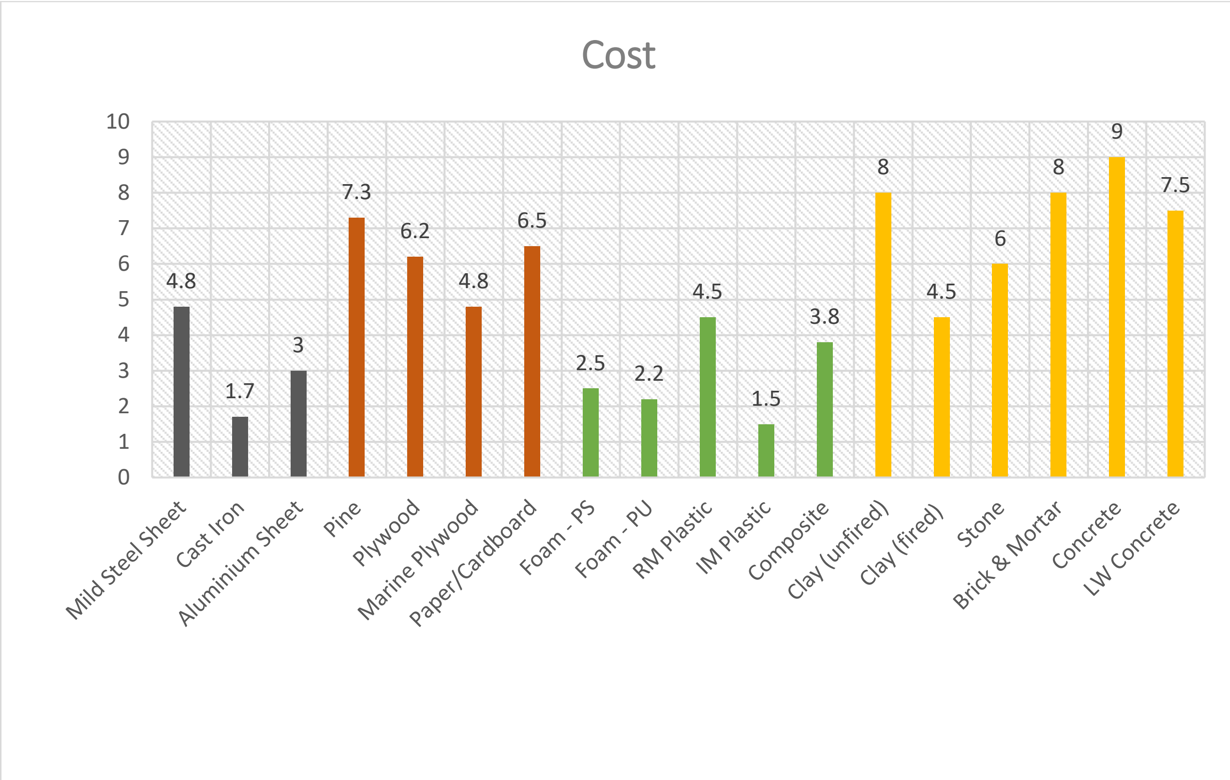
- Several of the materials were innocuous in their main-use state and raw form, which they scored high for. For instance, wild bees are commonly found living in wood or in/on rock. They also have a penchant for brick and mortar cervices, plastic compost boxes and fibre-glass pool pump houses.
- Although wooden hives represent the bee's natural tendencies, the wood used to make beehives is treated with chemicals that take it about as far from an old tree as it can be. Pine and plywood scored low due to the chemicals required to treat it, and metals lost points due to their large carbon footprint during production. Marine plywood is pre-treated and fairly safe, although that comes at a price.
- Materials like stone, concrete and composite plastic lost points due to the potential harm they could have on the persons working with their aggregates to make the beehives.
- Polymers scored low for their impact on the bees through humidity, chemical exposure and electro-static disruption, not to mention their carbon footprint and environmental risk factor. There was a great deal of evidence that bees struggle to survive in plastic beehives, attributed mainly to humidity control issues or electro-static disruption to their communication and activities.
- Steel rusts over time, more so when exposed to the levels of humidity present inside beehives. Rust can be toxic and harmful to bees, and is a contaminant if honey is exposed to it.
- Aluminium and cardboard are highly recyclable materials.

5.5. MANUFACTURING



- Mild steel and wood are similar in terms of manufacturing. The flat materials come in standard sizes, which are then cut and joined using a variety of hand operated tools and machines. Because these materials are so common, the skills for working them are widely available. Aluminium sheet is a similar material, but the skills required to form it are scarce.
- Clay, unfired, is very easy to produce. One can use a variety of clay sources of any quality and grade. The material is cheap and requires almost no tools. However, when you want to fire clay to make a ceramic, the clay must be high quality, free of impurities and one will need a kiln.
- Foam and other polymers are easy to produce products with, but only once a large amount of capital has been outlaid to make tools, moulds and purchase machine time to run batches of the parts. The manufacturing can only be done by certain factories and is largely mechanised. Rotation moulding tools are much cheaper and more labour intensive.
- Cast iron also requires expensive tools and forge equipment that uses huge amounts of energy.
- Fibre glass composite is not easy to work with, requiring technical skills and experience usually from the boat and automotive industries. The material must be formed over a mould which will require some initial investment.
- Brick, concrete and stone are common building materials and the skills and knowhow for forming with them is more common. Concrete usually requires some moulding tools and material knowledge, but it is low-tech and easily transferable.
- In this category I also looked at the quality of the products that are produced with each material. For example: unfired clay is generally hand formed and the accuracy of parts is difficult to maintain. Moulded plastic has extremely high quality between parts.

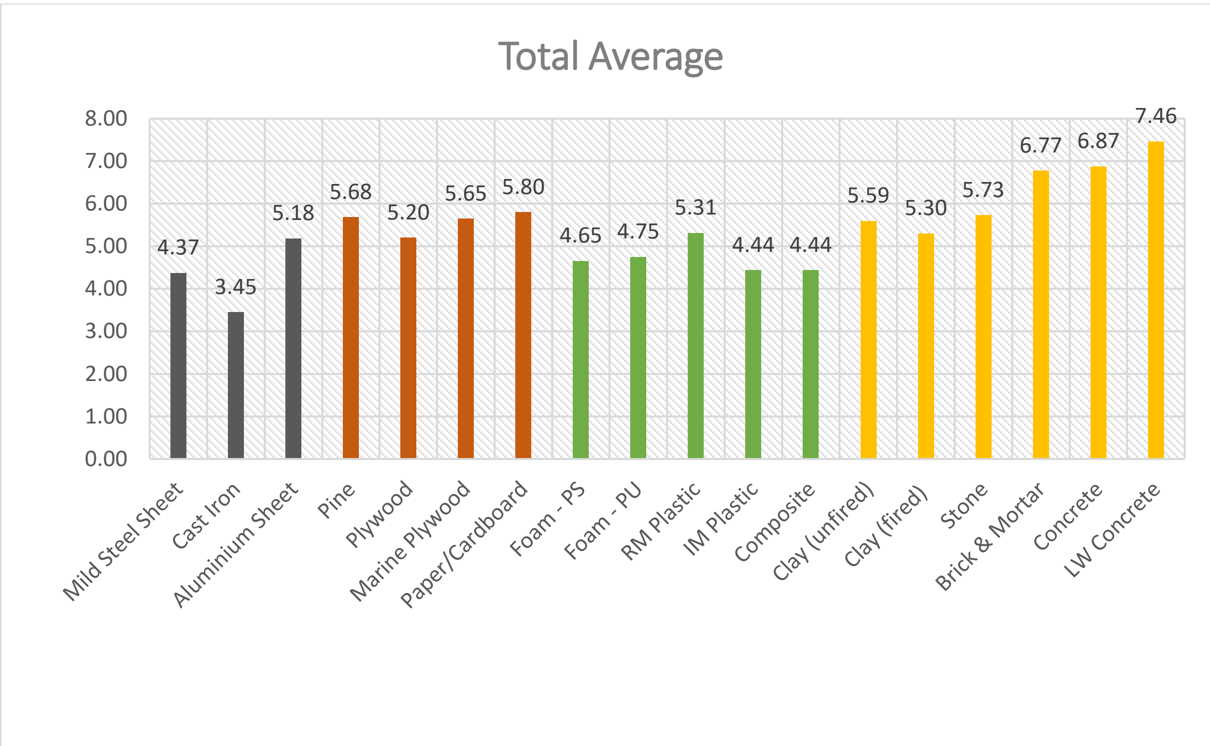
5.6. COST



- Although materials like plastic and cardboard are cheap when made into mass produced products, they require large capital outlay to produce tools to form the materials.
- Cardboard is also a cheap material, but to produce products from it at a cheap and efficient rate die cutting tools must be purchased. These tools are not prohibitively expensive.
- Marine plywood and mild steel sheeting cost almost the same to produce beehives from and work with. Whereas regular pine is much cheaper but requires similar tools to form.
- Clay is relatively cheap. However, it is not always available everywhere. This is often a problem with materials like wood, steel, plastic and cardboard. In a study of material availability that I conducted in this section, I found that bricks and concrete are the most readily available materials in most areas.
- Then there are the small manufacturing cost details that account for certain discrepancies. For example: brick and mortar take longer to make a beehive with than concrete. Concrete is mixed and poured into a mould. Bricks require concrete to be mixed and then used to join the ceramic blocks, which are usually coated afterwards in another cementitious layer.

6. ANALYSIS

The average scores were calculated with the Weight category weighted half as strong as all the others. This was to account for the positive and negative benefits of lighter weight of the materials. I toyed with the idea of increasing the weighting of Durability because I believe it is a crucial aspect above all other, but in the end left it as is because the results already spoke for themselves. Perhaps some categories are worth more to different beekeepers than others, and then they can look at which materials scored higher in those specific areas. But for the majority, I believe the results are accurate in pointing out the right material for the job.



In order of best to worst:

1. Lightweight Concrete
2. Concrete
3. Brick & Mortar
4. Paper/Cardboard
5. Stone
6. Pine
7. Marine Plywood
8. Clay (unfired)
9. RM Plastic
10. Clay (fired)
11. Plywood
12. Aluminium Sheet
13. Foam – PU
14. Foam – PS
15. IM Plastic
16. Composite
17. Mild Steel Sheet
18. Cast Iron

Lightweight Concrete comes out at the top. It is low-cost, easy-to-make, durable, insualtive, non-harmfull and the weight can be controlled to suit the application perfectly. All other materials lack in some or other areas. Several are better than Lightweight Concrete in one area, or two. Nevertheless, the generally high score Lightweight Concrete recieves is a testament to its appropriateness as an improved material for beehive manufacture.

Paper/Cardbaord came out higher than wood as well. This led me to experiment further with an entry-level cardboard hive design. My design process eventually led me to focus on the concrete beehives ad moulding tools (will be discussed in another article), although I do still believe there is potential for an ultra-low-cost, disposable cardboard beehive (there are a number already on the market as trap/catch-boxes) shown below.

Figure 15: Initial prototypes of carboard and lightweight concrete beehives for testing.

Figure 14: Ongoing field testing of lightweight concrete and wooden beehives.