Future Systems to Combat Climate Change and Pollution

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Abstract

Climate-induced flooding is causing a huge displacement of people in developing countries. In 2041, people will need to adapt to life on water due to insufficient habitable landmass. This report uses foresight techniques such as STEEP to discuss social, technological, economic, environmental, and political factors that in turn contribute to this projected 20-year scenario.

The most significant findings from the main literature review showed that there will be no infrastructure to deal with future waste. Furthermore, the isolation of communities on water only worsens the communities' problems regarding access to clean drinkable water, food security and energy supply. It was important to define what the future of waste would be, and possible emerging techniques that could utilise waste as a resource in the scope of a 20-year timeline. The research found that communities in LEDC's would only be mainly outputting organic waste by 2021.

Following on from the research section, expert interviews were conducted to validate concepts in more depth. Three product service systems were proposed to address the unique design engineering opportunity of designing a new waste management system. This report concludes that a product service system to address the circularity of waste management in this community must also address the water, food, and energy scarcity using organic waste as a resource.

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1 Contextual Studies

1.1 Introduction

Even if climate change mitigation is successfully implemented now, sea levels will continue to rise. Under a high emission projection, it is indicated that up to 630 M people will live on land below the projected annual flood levels for 2100 (1). This means by 2041 people will need to start adapting to life on the water. The overarching topic of this paper is the effect of global climate change and its implications on the circular economy of waste in 2041. More specifically looking at future scenarios in less economically developed countries. This is crucial as studies reveal that tens of millions of people in the developing world are likely to be displaced by sea levels rising within this century (2).

The main question that will be addressed is how a circular economy of waste might be successfully implemented in developing communities that have been displaced due to flooding. The points this report will discuss are a contextual analysis of the predicted environment for 2041, the main problems that these communities will face in 2041, what circular system design will need to solve in this scenario and finally how such a system will be designed and integrated into a community. The concluding aim of this report is to cultivate an innovative design engineering opportunity that will address themes including circular economy, emerging technology, sustainability, human behaviour, and critical climate change within the scope of a 20-year time frame.

1.2 STEEP Analysis

A STEEP analysis is a speculative design tool that has been used It will improve understanding of the context in which the design engineering opportunity exists. STEEP is an acronym for Social, Technological, Economical, Environmental and Political.

1.2.1 Social

Coastal displacement due to sea-level rise and flooding is predicted to increase to affect hundreds of millions of people worldwide over the next century (3). This will create significant economic, humanitarian, and national-security challenges. However, for centuries, people all over the world people have adapted communities to live on the water in their ever-changing environments. From the Baan Koh Chai settlements in southern Thailand, where communities live in stilted houses among nipa palms and mangroves (4) to Lake Titicaca on the border of Bolivia and Peru where the Uru people live on cultivated reed islands (5), and across the world again on floating gardens in Bangladesh, where crops grown on buoyant weeds that can rise and fall with flooding (6).

Undeterred by a climate-induced decline in quality of life, residents of floating communities in less economically developed countries (LEDC's) are open to change to protect their settlements of cultural heritage (7). Research findings demonstrate that despite people's tradition of perseverance and willingness to adapt, their capacity to do so will be too slow (8), making them most the vulnerable group to climate-induced flooding.

1.2.2 Technological

Technocratic solutions that focus on fighting flooding and staying on land have long been adopted to protect people, but the scope of this type of protection is expensive, limited and can subsequently be even more hazardous when inevitably structures collapse (8). Floating architecture is seen as an effective long-term solution for many low-lying coastal areas all over the world (9). They could be especially effective in LEDC's due to the long history of floating settlements already being accepted and adopted into society. However, as mentioned previously these communities are built with weak structural integrity, and most floating settlements are constantly threatened by several socio-cultural, economic, and environmental factors.

The Netherlands is a more economically developed country (MEDC) that is at the forefront of the innovative technology of floating homes (10). This is due to their high risk of climate-related flooding as over 25% of their landmass is below sea level (11). When extreme flooding occurs, the scale of destruction in the Netherlands is often much less than seen elsewhere despite their geographical disposition (12). Contemporary innovation for climate adaptation in the Netherlands is focussed on developing floating architecture. For example, IJburg, a floating community in development in the Netherlands, which will be discussed in more detail later in the report, when finished, will offer 18,000 homes for 45,000 people (13). The concept of well-designed floating communities can be safer than the alternative of building on land and risking frequent structural damage from floods. Furthermore, they are more sustainable as they are easily adaptable to needs and the environment beyond the scope of a 20-year climate prediction. Furthermore, another benefit is the possibility to safely construct dense communities which would allow for far more efficient energy usage in LEDC's (14).

"In a country that's threatened by water, I'd rather be in a floating house; when the water comes, [it] moves up with the flood and floats," – IJburg resident (10).In the Netherlands, it is viewed that the new flood protection approach should not view water as an obstacle to fight but rather it should be carefully integrated into how people live in the future. This view can provide new methods and innovative tools to bridge the gap between existing floating infrastructure in LEDC's to a safer adaptable community that simultaneously fulfils people's wants to protect their cultural traditions.

1.2.3 Economical

Mainland China, Bangladesh, India, Vietnam, Indonesia, and Thailand consist of the majority of people on land projected to be below average annual coastal flood levels by 2050 (15). Investments in these developing countries are heavily focussed on recovery from flooding related disasters instead of going into enabling the innovation required to protect and adapt to climatic variability (16).

Flooding leads to economic stress and debt for developing countries as it displaces local economies dependent on natural resources situated in vulnerable coastal locations. In developing countries such as Rio de Janeiro, Mumbai, Guangzhou, and Dar es Salaam, large commercial ports are at risk of being flooded by rising sea levels, consequently halting global supply chains (17).

A study done at Stanford University found that climate change has caused economic inequality between developed and developing nations to increase by 25% since 1960 (18). For example, this materialises as an exponentially increasing price of access to safe drinking water in these developing nations. The World Commission on Water estimates that by 2025, one half of the world's population will live in conditions of severe water stress' (19), compounded by a continuous deterioration of water quality in most developing nations. Poorest communities are most heavily affected when water services are compromised. Their main source of income is often dependant on natural resources and the agricultural industry meaning it will be even harder to find opportunities for economic growth.

The projection of sea-level rise will vary depending on the rate of pollutants emitted subsequently so does the future economic losses due to flooding. Predicted protective measures for coastlines and land could cost countries trillions of US dollars per year (20). LEDC's cannot afford such measures and physical damage to buildings and infrastructure will be sustained. This means large land areas will be sacrificed, causing a crucial economic drive for reform of investment policies to focus on capacity building and implementation of floating and amphibious infrastructure (21).

1.2.4 Environmental

Research undertaken indicates that significant land loss, flooding of low-lying coastal areas, accelerated coastal erosion are already occurring in developing countries across the world (22). A major environmental impact from flooding is the destruction of wildlife habitats and farms due to high-velocity water flows. Plants and crops that do survive the initial flood are still likely to die due to being inundated with water, silt, and sediment (23). For example, flooding can cause extensive damage to rice crops (24). This has serious implications for food security in the future as rice is the predominant staple food for at least 33 developing countries (25).

Runoff and sewage discharge can cause significant changes in the water quality of coastal waters, resulting in coral degradation resulting in unstable biodiversity (26). Furthermore, contaminated floodwater can pollute rivers, water sources and subsequently food chains. This causes a detrimental effect on human health as the rate of infectious diseases and epidemics rapidly after extreme flooding events (27).

Furthermore, predictions show that flooding increases the amount of plastic in water systems by 10 times compared to non-flood conditions and in the worst affected areas, "plastic mobilisation increases up to five orders of magnitude" (28). Plastic pollution has been found to significantly affect local economic activities in LEDC's such as fishing and direct transportation across rivers and coastlines, and in some locations again put the availability of clean freshwater at risk, endangering the livelihoods of the surrounding communities (29). The tangible negative direct day to day impact on people's quality of life from plastic pollution will become more prevalent as flooding increases. This shows that in the future communities will be more likely to adopt the use of plastic packaging alternatives to reduce the amount of plastic waste ending up in their water supply.

1.2.5 Political

Facing climactic unpredictability and more frequent flooding governments urgently need to find effective solutions to ensure adequate space for residents in low-lying coastal areas. However, LEDC's effectiveness in responding is often short-lived as political instability is often exacerbated by climate-induced disasters (30). It has been suggested that extreme weather has contributed to conflict and terrorism in politically fragile nations (31) that will lead to more than 143 million people being driven from their homes by conflict over food and water insecurity and climate-driven natural disasters in 2050 (32).

Governmental leadership and resources within the global humanitarian system will be essential to help manage and respond to the increasing flows and movements of people, along with investments to help promote stability and alternative livelihoods for communities that are permanently displaced.

The Netherlands governmental response to flooding and their unique approach to water management can provide imperative flood preparedness for developing countries around the world. Smart innovation in the Netherlands paired with initiatives such as the Green Climate Fund so far have helped build resilience for an estimated 350 million people worldwide (33). The fund was established as a partnership between over 190 countries that sought to help developing countries respond to climate change. The fund has raised over $10 billion since 2014 and has directed resources to projects dedicated to both mitigation and adaptation (34). This shows that countries are working together to combat climate change on a global scale.

By 2041, the cutting-edge technology being developed in MEDC's will be made even more accessible to governments of LEDC's meaning it's feasible to implement this technology into the future scenario.

1.3 Future Timeline

Figure 1 outlines the predicted timeline from 2021 to 2041 in which our product service sys-tem will be implemented.

1.4 Future Scenario

The world is in a volatile condition regarding climate change, so there is a necessary design engineering opportunity to intervene in places that will suffer the most. In less economically developed countries climatic unpredictability is causing weather extremes; sea-level rise, salinisation of soil and water, storms, and floods. By 2041, With the current climate sce-nario, it is predicted that climate-induced flooding and weather extremes will displace between 300-700 million peo-ple (15). This means that a transition to floating communities was a necessity for their survival.

Furthermore, day to day plastic waste is a thing of the past, it has been replaced by organic biomaterials to reduce the dev-astating plastic pollution in LEDC's communities. This means there is an abundance of organic waste resources that needs to be dealt with. People have safe communities on the water to live in however they are still pressing concerns over food security, access to clean water and energy, and proper disposal of organic waste.

2 Project Definition

2.1 Problem Definition

The defined problem of great significance to address: Existing waste management systems (WMS) in developing countries won't be viable for future floating communities.

In 2019 it was reported that 90% of the waste in developing countries was burnt or left in unregulated dumps (35). Open dumpsites and landfills are major sources of pollution as contaminants leak out, namely leachate, infiltrating the groundwater supply (36). For centuries MEDC's have been taking advantage of lenient environmental regulations. The environmentally damaging industry is outsourced, and waste is exported, for example, 75% of global waste has its end of life in developing countries within Asia (37). This was a key driver that further compounded the diminishing amount of habitable land available, alongside the frequency of flooding and the developing world's rapidly growing population (38). Furthermore, the upsurge in flooding events will increase the mobilisation of pre-existing pollutants exponentially meaning landfills will no longer be viable for waste disposal (39). This is a key aspect that shows the urgency for innovation into new WMS for communities living on the water.

The future of day-to-day disposable waste in 2021 is predominantly organic, already comprising 60% of all municipal solid waste (MSW) in developing countries (40). From the social and environmental drivers highlighted in the STEEP analysis, communities have effectively adopted bio-degradable alternatives to day-to-day plastic waste. This is combined with population growth causing an increase in human waste, a rise in crop and livestock production which generates further food waste. All aforementioned factors mean it is feasible to assume that the main type of waste requiring disposal will be organic.

Innovation in floating infrastructure up till 2041 was primarily focused on immediate problems, such as designing enough functional housing that could be implemented safely into the environmental conditions in LEDCs. This caused the development of waste disposal and collection infrastructure to be left behind causing large issues in communities. For the overall environmental, cultural, and sustainable success of floating structures, a new circular WMS will need to be devised.

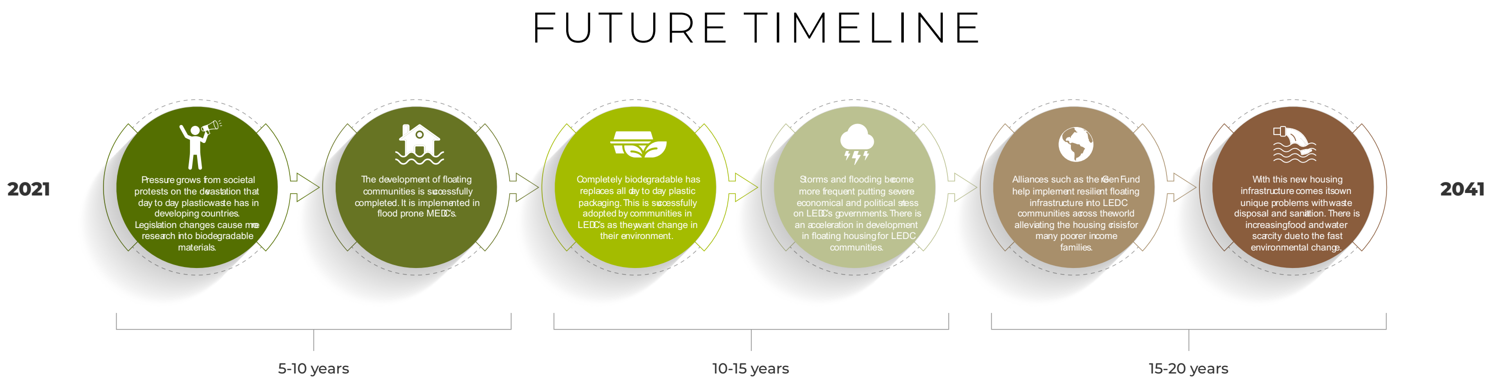

Figure 1: Timeline from 2021–2041

2.2 Design Engineering Opportunity

The design engineering opportunities have been summarised in the following how might we questions:

- How might we design an effective waste service management system, for floating communities in developing countries?
- How might we integrate the system successfully into individuals' lives, designed in a way that enables adoption and routine use?
- How might we output a useful resource/s that can be used by the individual or community directly? For example, clean water, electricity, building materials.
- How might the system be operatable and maintainable by the local people?

Most importantly:

- How might we integrate each functionality of subsections?

2.3 Potential Enablers

Potential enablers for discussion include:

- Disinfection and water purification
- AI and machine learning
- Sustainable energy production
- Genetic engineering and synthetic biology
- Starlink, global internet and autonomy
- Fast analytics and biosensors

3 Design Definition and Discovery

3.1 Proposed Design Engineering Product Service System

To address the opportunities a fully integrated circular waste management system has been proposed (Figure 2). This aims to solve the waste disposal problem by processing it into new resources. This acts to further incentivise adoption as resources are put back into the community to mitigate problems such as food scarcity and access to clean water and energy. Furthermore, embracing a circular model essentially reduces the quantity of waste to a more manageable level. This system aims to better enable the collection of organic waste, extraction of value to produce new resources and eliminate physical pollutants; The key objective is to successfully integrate all these features into one system.

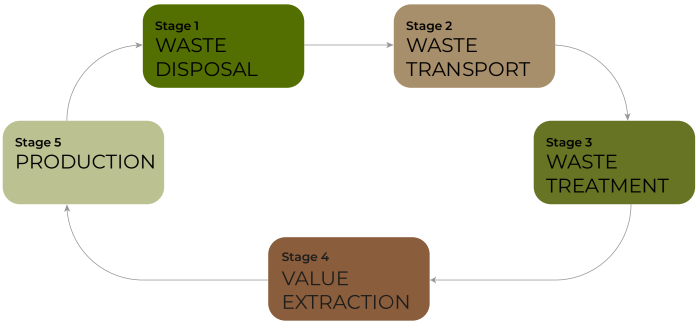

Figure 2: Product-Service-System

3.2 Existing Enablers

This section of the report addresses existing systems and case studies that were analysed to enable the development of the formulated product-service system.

3.2.1 Waste Management Systems

Managing municipal solid waste (MSW) is one of the most essential services to ensure a functioning society, especially in an urban context. Poorly managed waste can contribute to flooding, air and ground water pollution and public health impacts such as respiratory ailments, diarrhoea, and dengue fever. Waste management plays a major role in transforming a linear economy into a circular one where waste is not seen as something to be discarded, but as a resource to be used (41)(42).

3.2.1.1 MEDC Countries

In upper-middle- and high-income countries the waste collection rate approaches almost 100%. These countries have realised that uncontrolled disposal of waste (through open dumping or unregulated burning) causes significantly greater clean-up expenses in the long run than disposing of it in a regulated way. Currently, in high-income countries only 34% of waste is organic, the remainder is solid, recyclable materials. For recycling to work effectively, the segregation of the waste into its different types is crucial. So-called segregation at source is especially important to ensure the separation of organic and dry recyclable materials. This will become less important due to the development of the future of waste that will be discussed later. Recycling rates for high-come countries are high at around 60–70%, followed by waste being incinerated for energy recovery at 30–40% and only a very minor share going to landfills (41)(42)(43).

3.2.1.2 LEDC Countries

In developing countries only as few as 35% of waste is collected. The collection is often carried out by third parties contracted by the government, private companies making their operations profitable by selling the recycled materials or even community-based systems on a very small local level. Additionally, a greater percentage of the waste is organic, around 50%. Barely any waste materials are being recycled or incinerated with 70%–100% of waste going to landfill. In water-based villages, the additional challenge of managing floating and stranded waste arises. Often waste ends up in the ocean blocking waterways, such as in water villages in Sabah, Malaysia (42)(44).

3.2.2 Case Studies: How Floating Communities Work

To better understand the various ways in which waste is handled in the proposed scenario of floating cities, the following case studies of existing and future concepts and technologies were conducted.

3.2.2.1 Case Study: Thai Floating Communities

Historically, Baan Koh Chai settlements in southern Thailand, are where communities have lived in stilted houses for centuries. Settlements have integrated markets for the exchange of agricultural goods and social gatherings and cultural celebrations. Floating communities and markets have gained popularity due to globalisation and the tourism industry (45). Due to increased visitation from tourists, there has been an increase in water contamination through plastic litter, oil seepage, as well as air and noise pollution. Low water quality in these rivers has gotten to such an extent that this water is not fit for consumption by locals. In extreme cases, water quality has caused the markets to close, halting the local economy (46).

Currently, waste is not disposed of sustainably due to improper infrastructure that can't cope with the waste output from locals, let alone the influx from tourism. Subsequently, most waste is often thrown directly into the river (47). Water distribution and toilet infrastructure are basic with simple pipes that run by the rivers, that are susceptible to faults and contamination (47). When looking at the construction of the communities a few measures by locals have been put in place to protect infrastructure from water damage. For example, bamboo, banana, palm trees and plastic bottles are organised as a protective barrier against waves (47). These implementations show the communities foresight and willingness to adapt, however, efforts based on available materials are currently far too fundamental to protect against the dangers of climatic variability and extreme flooding.

3.2.2.2 Case Study of Future Floating Communities: IJburg and Oceanix

As previously mentioned, the Netherlands initiated a construction project called IJburg on the IJmeer sea, which is a floating expansion of Amsterdam. The projects aim is to house more people sustainably by considering Amsterdam's increasing threat of severe flooding. In total there are six artificial islands are set to be built and populated with approximately 19000 homes to harbour more than 45000 inhabitants (48). Currently, in the first phase, construction has largely been done on two of its islands (Steigereiland and Haveneiland), and 61 homes have already gone to sale (49). The islands will be interconnected and connected to land via a network of bridges. The second phase was initiated in 2013 with the construction of Centrumeiland, and it is planned to be a residential area for professionals and students upon completion (49).

Oceanix proposes concepts that transfer sustainable living on the water to more to harsher conditions such as in the North Sea. The envisioned cities would be many times larger than communities in Amsterdam, producing their own electricity, food and no waste (50)(51). Oceanix' floating communities are based on a modular concept designed to grow and adapt organically over time. Triangular modules each housing 300 citizens are clustered to form neighbourhoods of 1,650 people which are then combined to a city structure with a population of 10,000 (52)(53). They also propose closed-loop waste processing system will turn waste into energy, agricultural feedstock, and recycled materials (54).

These case studies showcase the technological feasibility of how quickly stakeholders are planning and already facilitating a transfer to floating communities due to the threat of climate-related flood risks.

3.2.3 Case Study: Gates Foundation Sanitation

With clean drinking water and electricity being two of the biggest developing world needs, the Bill and Melinda Gates Foundation has funded two main projects (55) (56). The first is called the Janicki Omniprocessor that makes use of human waste for sanitation and energy generation and the second is a toilet that can feasibly be implemented into LEDC's that have no existing sewerage infostructure (57).

The Janicki Omniprocessor takes a mixture of faecal matter, biosolids and other wet waste streams and heats them to 100°C (58). The dry matter is used in the combustion chamber for fuel and the by-product is bio-ash, which can be used to make bricks (59). The exhausts given off in the burning process are filtered to meet government regulations. The combustion chamber heat is used to generate high-pressure, high-temperature steam that is used in a steam turbine to generate electricity. This energy is used to power the machine and any surplus can be sold back to the grid or other local processes. The steam is then directed back over the heat exchanger surfaces to transfer heat back and aid in the drying process. As it transfers heat, it condenses and can be used again in this cycle. Water from the inputted wet waste is captured, filtered, and condensed to drinkable water (58). A pilot project was run in Senegal to test the technology on a community of 100,000. There, manual cleaning of latrine pits and poor sanitation methods had resulted in fast pathogen-spreading (59). There were shown to be many benefits such as improved community health, clean water supply, electricity generation with lower CO2 emissions and no toxins contamination(60).

The second concept is the toilet redesign brief. This was required to protect people by removing harmful pathogens from human waste and recovering valuable resources such as energy, clean water, and nutrients. The concept in development costs less than US$.05 per user per day. Furthermore, it operates "off the grid" without connections to water and sewer systems (61). These factors indicate that this technology is a feasible solution to human sanitation treatment in remote LEDC communities.

3.3 Future Enablers

The following section of the report addresses future systems and technology that were researched to further evolve the formulated product-service system.

3.3.1 Waste as a Resource

3.3.1.1 The Future of WMS

The rise of climate change awareness has driven demand for new sustainable economic models. The most prominent of these is the Circular Metabolism Model (Circular Economy), specifically concerning urban environments (62).

The Circular Urban Metabolism (CUM) model consists of three main principles: designing out waste and pollution, keeping products and materials in use, regeneration of natural systems (63).

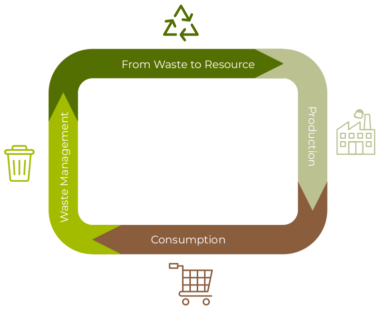

Figure 3: Circular Economy

This transition from a linear to a circular economy will require an associated paradigm shift in existing WMS.

3.3.1.2 The Future of Organic Waste

Looking into societal trends the primary sources of organic waste are predicted to be: The agricultural industry, the food and beverage industry, the paper industry, household, and businesses waste (64).

These streams will produce five main categories of organic waste: Food waste (animal and vegetal), human waste, paper waste, garden bio-waste and biopolymers (64).

Bioplastics are an emerging organic waste source due to the rising demand for biodegradable alternatives to single-use plastics. Wide-scale adoption is being driven by the packaging industry with bioplastics being used for garbage bags, food packaging and shipping materials (65). This is enabling more sustainable consumption without altering consumer habits.

3.3.1.3 Emerging Waste Management Technologies for Organic Waste

Waste can be broken down into two fundamental resources: materials and energy. Most emerging waste management technologies are building upon anaerobic digestion (AD), attempting to improve biogas yield, cleanliness and find additional uses for solid and liquid effluent.

Development Stage

LARGE PILOT SCALE

Anaerobic Digestion: the oxygen void biological breakdown of waste. It recovers energy through biogas production and generates fertiliser in the form of digestate (66).

PILOT SCALE

Pyrolysis: the thermal treatment of waste at 600-650°C in an oxygen void environment to convert waste to syngas, bio-oil, and biochar. Able to recover material resources and energy from waste (66).

LAB SCALE

Plasma arc: plasma reactor to create a super-hot environment, between 5,000-14,000°C, to convert waste into a gas containing its chemicals and heat energy. Opportunity for higher energy and heat recovery, however, there are environmental concerns over the by-products of plasma technology (66).

PILOT SCALE

Bioreactor technology: control of moisture content levels, to their field capacity, to accelerate the decomposition of waste. This greatly increases the quantity of methane gas generated from waste breakdown. Allows a higher volume of waste disposal compared to landfill alone, however requiring pre-processing of waste(67).

LAB SCALE

Thermal hydrolysis: pre-treating waste sludge to increase its biodegradability by heating to 150-165°C at a pressure of 7 bars. As the pressure is rapidly released cells present in the waste rupture making the waste more digestible to microbes during AD. Opportunity for additional ethanol production during the process (66).

LAB SCALE

Conversion of solid wastes to protein: use of cellulolytic bacteria in aerobic conditions to convert the insoluble cellulose contained in plant waste. The bacteria are harvested with a protein content of 50-60% directly converting waste to nutrients (67).

LARGE PILOT SCALE

Vermicomposting: also known as worm farming, involves using Tiger Worms to break down organic substances into compost. There is research showing how this technique can be used on human faeces for high-quality fertiliser (68). When soil composition is 30-50% vermicompost, crop yields can increase by 26% (69).

LARGE PILOT SCALE

PILOT SCALE

Formation of new, value-added materials: utilising fully separated waste streams to enable better fabrication of new materials. Production of new products from novel sources such as food preservatives from orange peels (70), water filter media from seashells (71), thermal insulation for packaging from feathers (72).

LAB SCALE

Extraction of bioactive compounds: freeing and isolating beneficial bioactive compounds from biological materials to produce food supplements, chemical production, and pharmaceuticals. Extracting polyphenols and polysaccharides from tea waste to use in the feed industry promotes numerous health benefits (73).

LARGE PILOT SCALE

Fungus: breaking down organic matter to produce mycelium and mushrooms. This has been implemented on a larger scale to utilise ground coffee waste from cafés.

LARGE PILOT SCALE

Supplementing existing manufacturing: using solid AD effluent's high fibre content in manufacturing to act as filler material. Examples include particleboard construction, animal bedding and cement aggregate (66).

3.3.2 Energy Production Methods

The most widespread method of biogas production is the anaerobic digestion of organic matter by complex microbial communities in reactors. Multiple waste types, such as manure, food waste, wastewater biosolids, crop residues, etc. can be combined in one digester for co-digestion. This produces two outputs: biogas and digestate. Biogas is composed of 50% – 70% of methane, 30% - 40% of carbon dioxide, as well some traces of other gases like hydrogen sulphide and water vapour (74). Digestate is a mixture of liquid and solid residual material after digestion. It is handled by separating the different phases, and each is treated to have added value for different applications. Solids can be used as a foundation for bio-based materials, compost, soil amendment, or animal bedding, whereas the liquids can be denitrified and produce clean water for crops and drinking water (75), and can be combined with solids to make nutrient-rich fertiliser.

Throughout the processing of organic waste, heat is generated and dissipated into the environment. This results in energy inefficiency, which must be minimised to have a circular floating ecosystem, let alone produce enough energy to meet a community's needs. Waste heat can be recaptured from its sources by fitting in a heat exchanger, reusing the escaping heat for any applications within (digestate preheating, pasteurisation) or outside of the biogas reactor that needs it (heating homes, livestock infrastructures). With a HRS digestate pasteuriser, captured heat can save more than 40% of efficiency savings (76), with the manufacturer claiming up to 60% heat regeneration and up to 70% increased efficiency compared to traditional pasteurisers (77).

There is an emerging trend in utilising the growing potential of algae in a sustainable ecosystem. Algae can process lipids into biodiesel, carbohydrates into ethanol, and can break down organic materials into protein, which can have application in producing lab-grown food, nutrients, or other biomanufacturing applications (78). It can be a notable replacement for current biofuel producers, in the form of artificial photobioreactors with a much higher production volume. However, its high operating cost can hinder its accessibility to everyone (79). Algae can also produce much cleaner biohydrogen than current production methods, which is an alternative source of biofuel (80).

3.3.3 Genetic Engineering

For future applications of biogas in floating communities, the main goal is to use floating reactors to produce high rates of energy efficiently as the community's main energy source. It has been shown that higher methane yield by the microbiome is associated with their exposure to appropriate hydrogen levels. This can be assured by adding genetically modified bacteria with enhanced hydrogen production (C. saccharolyticus and E. cloacae) into the reactor (81). Therefore, novel biotechnology methods such as synthetic biology can create microorganisms that can optimise the production of biogas in floating reactors.

Biotechnology has consistently been the driving force to increase crop yield. With ground-breaking genetic engineering methods being developed such as CRISPR Cas9, Directed Evolution, it is now possible to design lifeforms to streamline their functions to specific needs. Not only can it be used to pinpoint and modify DNA regions that affect desired phenotypic traits (quantitative trait loci - QTL) to increase yield over the density of crops (82), it can also design plants that grow in environments that it would naturally not be able to grow. For example low pH environments, amphibious climates, and diseases resistance (83). Current experiments on salt-tolerant rice do not produce optimal yield yet, but at the rate of development, it can be expected to be successfully achieved within the next 20 years (84).

3.3.4 Water Purification Methods

As discussed in the case study of the Janicki Omniprocessor there are proven ways to purify the most contaminated organic waste sources. Figure 5 shows emerging technological trends that are impacting the wastewater treatment industry for different applications.

Electrocoagulation is an electrochemical process that can simultaneously neutralise and remove pollutants from wastewater through flocculation caused by the electro-dissolution of a soluble anode (87). Flocculation refers to the process by which fine particulates are caused to clump together into a floc and therefore are easily removed (87). The assessment concluded that on average the cost of a small-scale facility handling 3000 Litres (l) wastewater per day would amount to $3 per 1000 l (88). This amount of water treatment is feasible for a small to medium size developing community as people are not used to accessing piped water, hence out of habit would use it more sparingly. Due to its compact design(90), electrocoagulation could be easily implemented as a sustainable and cost-effective wastewater treatment into a service system to address water scarcity in communities.

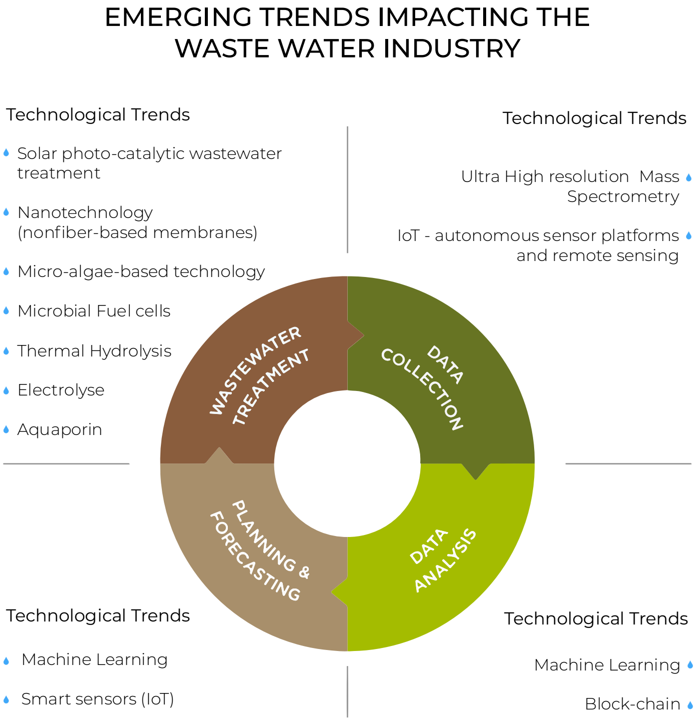

Figure 4: Emerging Trends for Wastewater Purification (86)

Aquaporins facilitate water transport between biological cell membranes. Embedded in polymeric materials it can filter water for drinking and home uses or saltwater desalination (90). This biomimicry-based approach to filtration highlights the shift in the wastewater industry towards developing traditional techniques into innovative new methods. By 2030 evidence suggests that aquaporin-based water filters will be efficient enough to be used by NASA in space applications (91).

Furthermore, the emergence of novel utilisation of ultrahigh-resolution mass spectrometry is notable. As a biomonitoring tool, it will help assess the exposure to toxins, biomarkers and help mitigate the spread of disease through water (92).

4 Concept Development

This section of the report goes on to explain initial product-service systems, how they were evaluated and developed into a singular final concept. Furthermore, the scope for development in the next stage of the project is identified.

4.1 Concept Ideation

Figure 5: Possible Visualisation of Floating Communities and Farms

4.1.1 Service System 1: Addressing Water and Energy Access

This concept envisions that all floating houses circle the main community centre, and everything is connected via walkways. Mimicking current WMS models in developed countries waste is stored in decentralised bins, with regular collection from a community waste disposal company. Waste will be collected into a single main digester where it'll be processed further. This reduces the number of system steps better enabling self-management by local communities. Integrated treatment in toilets will pre-process human waste to a non-hazardous level so it can also be collected into this system.

Figure 6: Bin with Biogas Nozzles

The centralised floating biogas reactor has optimised bacterial cultures produced via genetic engineering enabling faster and more efficient waste processing. The waste is digested anaerobically, producing biogas, solid digestate and liquid effluent. The extracted gas is then combusted, powering mechanical turbines to provide electricity for the whole community. Heat dissipated from anaerobic digestion is captured and converted to electricity via heat exchangers fitted inside the digester. The solid residue will be processed into nutritious fertiliser to be used on floating crop fields. Liquid effluent is further purified through electrocoagulation to produce potable water.

Heat dissipated from AD can be captured and converted to electricity via heat exchange fitted at heat source(s). During AD, the temperature can reach up to 60°C – 70°C in 4-5 days (93), so collecting this heat can save a considerable amount of energy in the long run.

4.1.2 Service System 2: Addressing Water and Food Scarcity

This concept envisions a decentralised WMS with waste processing occurring in every individual's home. Each kitchen sink would be fitted with a food waste disposal (FWD) unit, crushing food waste to create a pulp. This reduces waste volume by 80-90% (94) and extracts water from the solid waste. This water is then purified through Aquaporin filters to produce potable drinking water for the household.

The remaining solid waste is vermicomposted to convert into nutritious compost for crop production. This method facilitates the continuous addition of further organic waste into the bin, without disrupting the treatment process, crucially important to enable better sanitation. Tiger worms are used since they can process most types of organic waste, from crops and food to human and animal faeces. Maintenance is relatively simple to greater enable adoption since the worms are self-sufficient and self-replenishing (95).

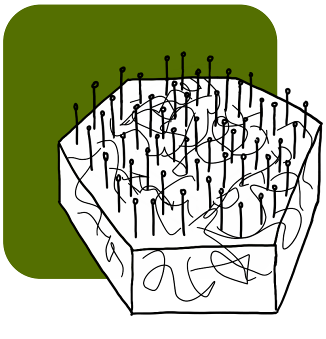

Figure 7: Hexagonal Mycelium Farm Tile

This compost is inoculated with aquatic fungus to produce a mycelial cake (96). Mycelium makes the nutrient mix buoyant, purifies saltwater and breaks down any toxins present in the waste (97). Genetic engineering enables the combination of all these fungi properties into one fungus species. Genetically engineered crops for increased salinity tolerance can be planted into these cakes before being placed onto the water to operate as a floating farm. These farms will produce mushrooms and crops for the household to consume helping alleviate food scarcity.

4.1.3 Service System 3: Sustainable Ecosystem

This concept envisions individuals bringing their waste to a community waste management facility, where they get electricity and heating credits in return for providing waste.

Food waste will be compressed to extract its water for use in plant irrigation systems. Water will be extracted from other wastes (primarily human waste) using a similar infrastructure outlined in the Janicki Omniprocessor. This water can again be used for plant irrigation or human consumption.

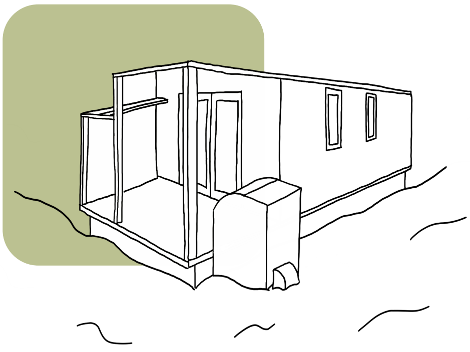

Figure 8: Floating Waste Collection Bin

Dry anaerobic digestion will be used to break down organic waste into digestate and biogas. Solid digestate derived from food and farm waste will be used to cultivate algae (98). Algae will be used in artificial photobioreactors to produce hydrogen, a cleaner biofuel than methane. Algae also capture toxins and heavy metals in the wastewater (99), further purifying the waste water, although still not to a potable level (100). At the end of their lifecycle, dead algae are collected and transformed into nutritious pellets that can be fed to fish to help promote healthier ocean ecosystems (101).

4.2 Concept Validation

4.2.1 Interviews

Two experts in the field of water supply, sanitation, and coastal engineering from the Department of Civil Engineering at Imperial College London were interviewed. Both gave their professional opinion on the scenario, research, and possible service system concepts.

Dr Ioannis Karmpadakis is a lecturer in Coastal Engineering, focusing on the design of coastal structures and sediment transport processes regarding complex hydrodynamics, and modelling coastal flooding. Professor Michael Templeton is a Professor of Public Health Engineering, researching water supply and sanitation solutions. He has undertaken the Gates Foundation 'Reinvent the Toilet' challenge, collaborating with medics in providing a viable sanitation solution for developing countries in Africa.

Regarding waste collection and transportation, Prof. Templeton stated that "sewage tubing would be a problem when constantly exposed to salt water [...] current sewage systems (in developed countries) require fresh water to transport waste, which is a scarce resource." Transplanting the sewage system of developed countries onto floating communities would not be possible. Either localised collection or on-site decomposition of organic waste with vermicomposting bins, taking an example of the vermicomposting toilets that he developed, are favoured. This transforms organic waste into safe and sterile residues that can be applied for other uses. Furthermore, containing waste is a priority, as it would “be a sanitation hazard to have open wells and toilets that let waste float around when there’s a flood”.

Dr Karmpadakis emphasised that current drainage systems are under-designed in mitigating flooding scenarios, furthermore, he also said that piping in floating communities would be unfavourable. He validated the research that current coastal defence methods for flooding are incredibly expensive and, likely, developing countries will simply have to sacrifice large amounts of land mass.

Key insights from these conversations were:

- Pipes are not adequate channels for organic waste to travel through due to the low-pH environment and waste of scarce fresh water, and organic waste can be a sanitation hazard if left untreated and in the open sea.
- There are effective methods to integrate human waste safely into the system without needing to deal with it separately.
- Floating communities are more feasible for LEDCs than current coastal protection methods due to cost.

From our concepts, we selected and combined stages that fulfilled the criteria inspired by what the experts said, to create a final system.

4.2.2 Secondary Research

Further studies have shown that the development of a treatment process that integrates electrocoagulation with biogas pumping. This new method would synergistically combine the filtration of anaerobic digestion effluent and the purification of biogas (102).

4.2.3 Concept Evaluation and Selection

To evaluate which concept aspects should be developed into the final waste management service system, each was assessed in terms of how the design objectives were addressed seen in Figure 9. All concepts address waste management in a circular sense so the concept's impact on food, water and energy scarcity, cost factors and the ease of adoption and acceptance were evaluated.

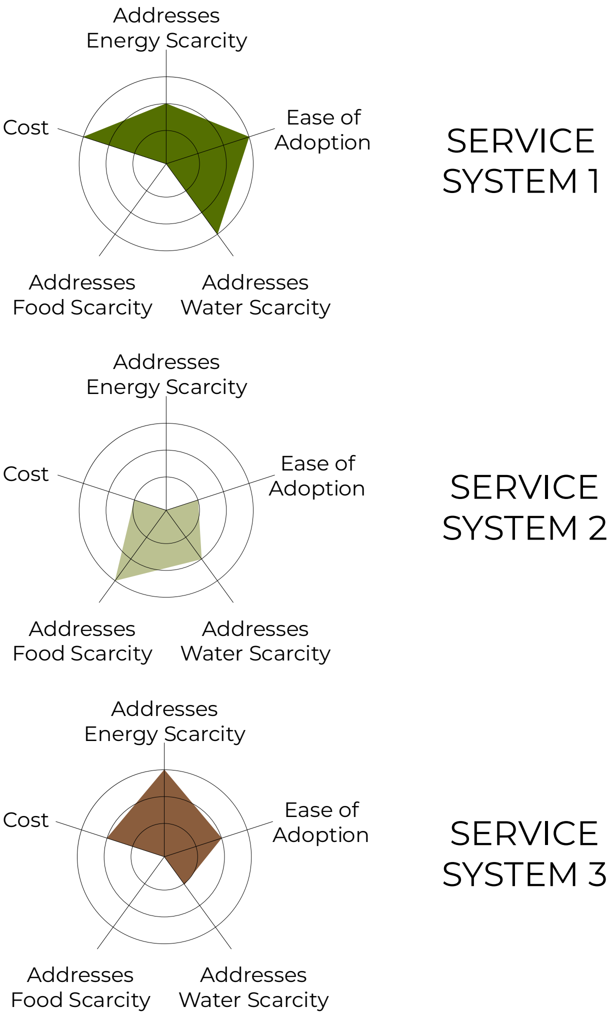

Figure 9: Radar Graphs to Evaluate Service Systems (higher = better/easier/cheaper)

The initial concepts addressed circularity of waste management through the three targeted design objectives, food, water, and energy scarcity, in varying ways however no concepts address all the design variables. Therefore, it was decided to evaluate each substage against each other to find the best possible combination.

Table 1: Weighted Decision Matrix for Subsystem Evaluation (1–5, higher = better/cheaper/easier)

		Cost	Ease of Use	Sustainability	Efficiency	Viability	Safety	Total
	Weight	0.25	0.15	0.2	0.25	0.05	0.1	1
Waste Collection and Transport	Main Composter	3	4	3	5	3	4	3.75
	Decentralised System	2	5	2	2	1	2	2.4
	Transport by Citizens	5	2	5	1	5	1	3.15
Energy Extraction	Biogas	4	4	3	4	5	3	3.75
	Heat Exchanger	2	2	4	3	4	2	2.75
	Vermicomposting	5	4	4	1	2	4	3.4
Water Separation	Electrocoagulation	4	3	4	5	4	3	4
	Aquaporin	2	2	2	3	3	4	2.5
Value Creation	Mycelium Farm	4	4	3	4	4	4	3.8
	Algae Photobioreactors	3	2	4	3	3	4	3.15

As can be seen in Table 1 for waste collection and transport the main composter with local bins scores highest, as a completely decentralised system is hard to implement and transport by citizens could be a health hazard. Biogas stands out for energy extraction and will therefore be integrated into the final concept. Tiger worms produce the best nutrients, but the waste cannot be used afterwards for fuel extraction and a heat exchanger is more expensive than biogas production and needs specific unattainable conditions in the scenario environment to work efficiently. Furthermore, it has been found that aquaporin does not work well scaled up and is not circular due to regular replacement of the filters and non-reusable or sustainably disposable aspects of their design. Water purification will therefore be done via electrocoagulation as it has the higher score for this section along with its compatibility with anaerobic digestion. As the mycelium farm scores higher than the algae photobioreactors it was decided to scale this up into a centralised farm attached to the composter facility.

4.3 Final Concept Summary

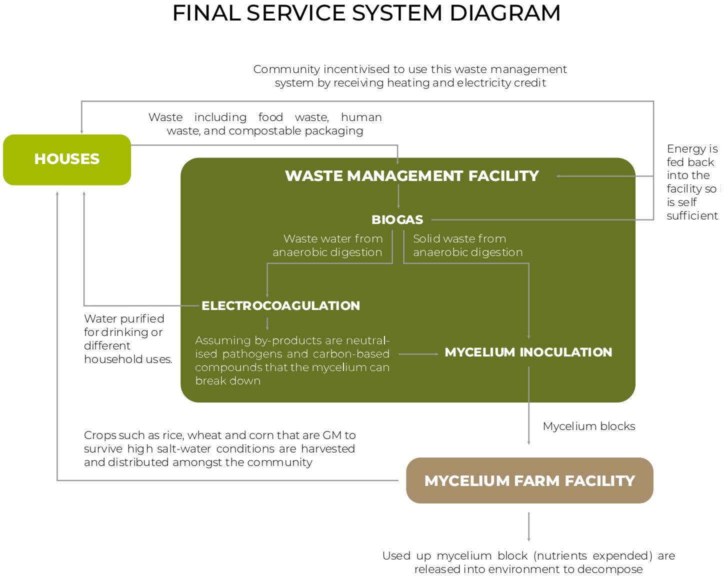

Figure 10: Final Service System Diagram

The final chosen concept integrates aspects from all three initial concepts. The system requires each household to dispose of and store their waste in bins, which are then collected by a waste disposal service and the waste is transported to the main treatment facility. Human waste will also be somewhat treated by the toilet system so that it can be transported and handled safely on the way to and at the facility. At the treatment facility, the waste will undergo a synergistically combined process of anaerobic respiration process to produce cleaner biogas and electrocoagulation of effluent to produce drinkable water for the community. The biogas is then combusted to produce electricity from a high-pressure high-temperature steam turbine system. The electricity will not only run the facility but also power homes. The heat produced can also be transported to houses used with the mycelium farm for faster growth. The final solid waste will be used to create farming blocks with the implementation of mycelium. These hexagonal blocks allow plants to grow on them and will float on the seawater. The specific plants of interest will be rice, wheat and corn that have been genetically modified to survive in these salt-water conditions. This farming operation will be carried out centrally from a secure facility. After the farming blocks have been expended of all their nutrients, they will be released into the ocean where they will be able to decompose without causing harm to the environment.

From research, it is clear some people are not willing to move from their current areas of inhabitancy but are willing to adopt technologies or infrastructure that allows them to stay and keep their culture and tradition alive. We will try to adopt an aesthetic that matches the general styles of these houses in the developing world by using materials like wood and glass. This will result in the system being more easily accepted by the communities currently living there if they feel 'more at home' in these new structures.

5 Conclusion

This document depicts the development of a service system implemented into the future of climate change and pollution in developing countries. The detailed analysis for the scenario prediction has been used to create design engineering opportunities to address problems associated with waste management infrastructure in 20 years. An iterative approach was taken to concept development taking the most efficient subsystem aspects to create a final design. This final concept simultaneously addresses all design objectives. Moving forward development will need to focus on the integration of each step within the system, this is to ensure a circular waste disposal system and cultural acceptance of the proposed design. The refined system will alleviate communities from crippling water and food insecurity, access to energy and environmental waste management.

6 Moving Forward

Design Engineering Opportunities of Focus:

With such a large system design and time constraints for the project, the group have decided to explore the following design engineering opportunities in more depth:

- Feasibility of integrating the different technologies into one facility.
- Designing for effective behavioural change for seamless adoption of our concept.

The group plans to explore these further by conducting more interviews with specialists in the field to gain a better understanding of the technologies and infrastructure that would be required to build Infrastructure such as the one we are proposing. The team has already contacted Dr Weston Baxter, an expert on Contaminated Interaction, to learn more about human behaviour surrounding these waste items and whether incentives are the best approach. Professor Geoff Kelsall, Professor Adam Hawkes, Prof Alexander Bismarck, and Prof Adrian Butler, experts in the electrocoagulation systems, biogas systems, mycelium farming and saltwater crops respectively, will also be contacted to validate our concept and help us understand how they can be integrated. Lastly, the group will explore other system technologies such as AspenTech (103), to identify how to optimise our system design and performance.

Collectively, the group have created a Gantt Chart, Risk Mitigation Table and have allocated members with specific researchers to contact to start the next term with interviews lined up.

7 Project Management

7.1 Project Management and Meetings

Team meetings are done at least once a week, most of the time in hybrid mode, most team members come together in person, some join online via video call. The meeting minutes are recorded and updated onto a centralised platform, called Notion, after each session by a designated secretary. They are named and listed in chronological order. A chair position would be assigned to someone to stay on track and cover all meeting points. Positions are chosen before the next meeting. All the meeting notes and action plans are linked to each other, and relevant people are notified about assigned action points. We rotate roles for each session, practising chairing meetings, writing notes, and assigning action points to appropriate members. Absent members state their reason for absence and are briefed on the meeting notes and actions.

7.2 Resource Management

The scope of the project theme requires a structured design process. From the start, we made sure that each of us had an opportunity to take all the roles during each meeting by rotating secretary and chair positions. Task allocation was done and recorded at the end of each meeting, entrusting responsibilities to each team member. Preparation and research are done before each meeting, where we all brief in our progress. Meeting duration and frequency varies depending on the subject and priority. Each of us has different expertise and preferences, so we allocated research themes to whoever is most knowledgeable. Mutual support and help are always done online and offline to ensure that everyone is on the same page, and we actively share relevant resources. Weekly meetings were arranged with our tutor for feedback on progress done. We seek expertise within the fields of waste management and marine structures to gain key insights for our concept development, ensuring that the project is on the right track.

7.3 Risk Mitigation

To prepare ourselves for the remainder of the project, the group have reflected on issues that have arisen and have predicted events that could hinder our performance in the upcoming term. We have done this by creating a risk mitigation table and implementing an impact probability risk matrix to access the risk of each event. We have marked each event with a likelihood and impact score scaling from 1 to 5, where 5 is the event being most likely to happen or most impactful on the project. This is then used to determine a final risk rating of High, Medium, or Low using a risk matrix (104). For low-risk events, the group will observe how operations unfold, but not much action will be needed. For medium-risk events, the group will monitor the event and carry out any measures to try mitigating these before they escalate and cause more issues down the line. For high-risk events, the group will actively try to control the situation by making these areas the priority to keep the momentum going and prevent the team from falling behind on deadlines. This is then used to determine a final risk rating of High, Medium, or Low using a risk matrix (104). For low-risk events, the group will observe how operations unfold, but not much action will be needed. For medium-risk events, the group will monitor the event and carry out any measures to try mitigating these before they escalate and cause more issues down the line. For high-risk events, the group will actively try to control the situation by making these areas the priority to keep the momentum going and prevent the team from falling behind on deadlines.

7.4 Reflection

Looking back on the development of this project, there are key strengths and weaknesses to our group's response to the problem. As a group, it was hard to stick to any idea or scenario and a lack of decisiveness led to time being wasted on building many different scenarios instead of ideating. Furthermore, some of our design methods were not effective. For example, to begin with, each member conducted their research and scenario building, which led to many very different ideas and not many coherent scenarios. The group changed methods and used a series of mind maps, boards and drawing sessions to come back onto the same page and save more time. The group were very supportive of these requests and worked around them. All members have suggested tools for research, and report writing to enable members to improve communication skills and get ideas across easier, using drawings and mood boards.

Table 2: Risk Mitigation Table

Risk Event	Likelihood	Impact	Risk Level	Mitigation Plan
The concept could be too large a problem to solve in our given timeframe, which could result in a final product that lacks detail or clarity	3	3	Medium	The team will set a clear focus of the project by outlining a certain design engineering opportunity of the system they wish to solve (e.g., how the different technologies will integrate).
The team put off deliverables to the last week and rush the final deliverable. This will result in errors being made and not reflecting the team's abilities or best work.	3	3	Medium	Regular, smaller deadlines will be set throughout the term in order so the team can give relevant feedback earlier on and not waste time on and rush final deliverables.
Difficulties finding experts to help design system infrastructure or validate our ideas	2	4	Medium	With the clear design engineering opportunity set and decided, relevant researchers and professors in the relevant fields will be contacted early on to allow enough time for scheduling meetings and then validating ideas. The team will make use of their network to see if there are more effective ways to reach out instead of cold e-mailing. Conduct further research in worst-case scenarios to validate ideas.
Team Members not attending meetings	4	1	Low	Team members that are not present during meetings will have the opportunity to read over meeting notes and catch up. Recordings will also be available if that is preferred.
Group meetings not given clear focus or direction beforehand	2	2	Low	At the end of each meeting, clear actions will be set for each member, and these can be referred to in meeting notes. This will ensure members do not overlap research topics and are more efficient with time.
Meetings with tutors not being made as effective	1	2	Low	Team members will meet before every tutor meeting to go over research conducted and what they would like to get out of the meeting with the tutor.

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