Fig. 1: Flying into Funafuti, Tuvalu
Abstract

The climate is shifting and this shift brings with it a number of effects. Perhaps the most devastating of these effects is sea level rise and its impact on low-lying island nations. One of these nations; Tuvalu, may have to face the very real possibility of mass migration as the situation progresses. But Tuvaluans do not want to abandon their homeland; to do so would be to abandon their cultural identity.

This research project explores an alternative to mass migration, an architectural solution that addresses current and future challenges, improves self-sufficiency, and strengthens cultural identity. This solution revolves around integrating traditional Pacific Island design principles with a number of contemporary strategies and technologies. The result draws upon the past and the future in order to tackle the problems of the present.
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“The patient accretion of knowledge, the focusing of all one’s energies on some problem in history or science, the dogged pursuit of excellence of whatever kind -- these are right and proper ideals for life.” - Michael Dirda
1.0 INTRODUCTION
Fig. 2: Tuvalu location
Tuvalu is a small Pacific Island nation with a population of 10,000, making it the third smallest nation in the world. The country is comprised of three reef islands and six atoll islands, all of which are low-lying with an average elevation of only 1.5m above sea level. The low elevation of Tuvalu's islands makes them susceptible to flooding caused by sea level rise, especially during annual king tide events and storms. Sea level rise has been a persistent trend for decades and it is expected to continue beyond the end of this century, with a rise of up to 2m projected by 2100.\(^1\) The islands of Tuvalu are in danger of being completely inundated, which could result in Tuvalu becoming the first nation of climate change refugees.

“We don’t want to leave this place. We don’t want to leave, it’s our land, our God given land, it is our culture, we can’t leave. People won't leave until the very last minute.” – Paani Laupepa, former assistant secretary at Tuvalu’s Ministry of Natural Resources, Energy and Environment.

Tuvalu, along with other low-lying nations including the Maldives, Kiribati, and Tonga, has been in the international spotlight over the past decade as a prominent example of the effects of climate change and sea level rise. This comes on top of a number of other compelling issues. One of Tuvalu’s islands in particular, Funafuti, is facing poor living conditions and a high level of dependency on the importation of key resources. There is a disconnect between the people and their island as a resource base - they no longer exist in a past where traditional customs ensured continued survival, nor in a future where sustainable technologies and new practices could allow on-going survival. They are somewhere in the middle, where western forms of architecture and infrastructure have only increased their level of dependence. They rely heavily on imported food, diesel, and construction materials. The people of Funafuti will need to look to contemporary technology as well as their traditional design principles in order to improve their self-sufficiency and successfully adapt to the accelerating effects of climate change.

1.2 RESEARCH QUESTION

How can sustainable architecture and technology ensure the inhabitants of the Funafuti island a continued existence in the face of severe climate change?

1.3 AIMS AND OBJECTIVES

The aim of this project is to explore ways in which the people of Funafuti can continue to live in their homeland as sea levels rise and extreme weather events become more common, whilst simultaneously improving living conditions and returning to a self-sufficient way of living. I aim to achieve this through the integration of green technologies with an architecture which is more adaptable and resilient and thus suited to the current and future challenges. This architecture will also be more reminiscent of traditional island living and therefore be more apt to preserve their cultural identity.

Project objectives:

i. Ensure the survival of the inhabitants of Funafuti and the island itself.
ii. Maintain and strengthen cultural identity.
iii. Improve living conditions and social connections.
iv. Present an economic and sustainable solution.
The focus of the project is the role of architecture and design in the relationship between the people of Funafuti and their homeland. The challenge is to design a living typology which adapts to the issues associated with living on an isolated, low-lying island in the grip of climate change. The outcome of such a challenge has the potential to give the people of Funafuti the confidence to face future uncertainties and the capability to be self-sufficient and resilient.

**FOCUS AND CHALLENGE**

The approach was to identify and fully analyse the issues faced by the people of Funafuti and seek to design a sustainable framework which draws upon traditional customs and design principles as well as modern and future technology. Site visits were not possible so analysis was based on extensive government reports on the various issues.

Because the problem is a significant one and carries with it considerable real world implications it is important to develop solutions which are both economic and practically viable. With this in mind I constantly assessed my proposals based on these criteria throughout the design process. This resulted in early proposals being loose and abstract, with subsequent iterations refined towards a potential real world solution. A cyclical process of assessing viability, deepening understanding, and proposing alternatives was used throughout the project.

**METHODOLOGY**

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Fig. 3: Funafuti Atoll
2.0 EXISTING KNOWLEDGE
Sea levels are rising and will continue to rise at an increasing rate for a long time to come. The rise is caused by the thermal expansion of the oceans and the melting of polar ice sheets due to global warming. The nations which will be most affected are not the world’s largest emitters of greenhouse gases but small, low-lying island nations such as the Maldives, Kiribati, and Tuvalu. These countries are facing complete inundation due to sea level rise and stand to be wiped off the map by the end of the century if they cannot find a way to adapt.

The IPCC’s (Intergovernmental Panel on Climate Change) Fourth Assessment Report released in 2007 projected a sea level rise of 0.18-0.59m by 2099. This projection was well on the conservative side as the IPCC chose to exclude contributions to sea level rise from ice sheet melt, largely because it was still unknown how the ice sheets would react to global warming. Instead, the IPCC based their projection on contributions to sea level rise caused by thermal expansion alone. The US National Research Council (‘NRC’) released a study in 2012 updating the IPCC’s 2007 projection to include the latest data on polar ice-cap melting and concluded that global sea levels will rise by 0.5-2m by 2100, with near term rises predicted of 0.10-0.35m by 2030 and 0.20-0.65m by 2050.

The biggest unknown in projecting future sea level rise is how ice sheets will react to global warming and just how much they will contribute to the rise. It has long been believed that the leading contributor to sea level rise has been, and will continue to be thermal expansion. However, the latest advances in satellite measurements indicate that ice sheet loss had a greater contribution to global sea level rise than thermal expansion over the period of 1993 to 2008.

In the recently released draft for the IPCC’s Fifth Assessment Report thermal expansion is again argued as the leading cause of current and future sea level rise with a rise of 0.28-0.97m projected for 2100. The IPCC’s projections have continued to predict higher and higher end limits as they have been released over the years leading many climate change experts to claim that their projections are too conservative. One expert in particular, James Hansen, proposes a much more extreme scenario. He asserts that a rise of up to 5m by 2100 is possible if ice sheets react in an unpredictable way and trigger exponential loss. He refers to ice loss which occurred at an accelerated rate about 14,000 years ago resulting in a rise of 20m over 400 years.

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3 NOAA, Global Sea Level Rise Scenarios, 12.
4 Ibid., 2.
7 Ibid.
Currently the most widely accepted projection is a rise of 0.5-2m by 2100. That projection will be subject to revision as methods of data collection advance and more is understood about global warming and the contributors to sea level rise.

Funafuti is already susceptible to flooding and a small rise in sea level coupled with king tides and extreme weather events will exacerbate the issue. Any rise in sea level within the range of recent projections will have a devastating effect on the island.

Tuvalu has been in the international spotlight recently as one of the imminent victims of global warming. There is an opportunity for the nation to implement a creative solution to the problems they are facing, which could influence other island nations around the world who are also facing an uncertain future due to the effects of global warming.

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Funafuti is one of many coral atolls scattered across the Pacific Ocean and one of six atolls within the nation of Tuvalu. Atolls mark places where coral reefs grew around volcanic islands which once stood above the ocean surface. As the volcanic islands slowly sank below the ocean the reefs continued to grow upwards and eventually formed atolls, owing their distinctive lagoon shape to the sunken rims of their volcanoes.9

A coral reef consists of a thick limestone base with a living coral layer on top. The limestone base is the accumulated skeletons of generations of living coral polyps. These polyps produce their skeletons through the uptake of calcium and bicarbonate ions from the water and the secretion of a calcium carbonate deposit. These deposits build upon those before it eventually resulting in the impressive reef structures we see today.10

Coral Atolls are among the most vulnerable island environments on Earth. Thousands of them have been submerged in the past when they were unable to grow fast enough to keep pace with rising sea levels.11 Many atolls around the world show evidence of periods of rapid growth followed by periods of back-stepping as sea levels have fluctuated over the millennia. They are at the mercy of the ocean and modern atolls owe their current elevations to the rapid sea level rise which occurred after the last ice age about 20,000 years ago. As the oceans rose and submerged the atolls the coral grew towards the surface sunlight which feeds its growth. When sea levels became more stable and even began receding about 5000 years ago, the atolls once again emerged from the water forming the islands we have today. This process is set to repeat, albeit on a smaller scale, as sea levels have begun rising again with a crossover date for many low lying atolls predicted within the next 50 years.12

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11 Nunn, “Pacific Atolls,” 351.
Fig. 11: Coral atoll composition

Fig. 12: Coral atoll formation
Funafuti is the capital of Tuvalu and the most populated island, with around half of Tuvaluans calling the atoll home.\textsuperscript{13} It has the nation’s only airport with the airstrip being constructed by the USA during World War II. Tuvalu’s only hotel is also located on Funafuti making the island the focal point for tourists. People continue to move there from the other islands in search of employment placing strain on the local infrastructure and increasing governmental concerns about overcrowding.\textsuperscript{14} This increase in population has resulted in a move away from traditional Tuvaluan societal structures resulting in a haphazard approach to architecture and urban design.

\textsuperscript{14} Ibid., 6.
2.3.1 Traditional Societal Structure and Architecture

A traditional Tuvaluan society consisted of communities of about 100 people brought together under a hierarchical social structure. Every family had a particular task to perform for the community and were expected to excel in developing the skills and knowledge of the task assigned to them. Tasks would range from building to fishing to warfare and all knowledge was passed on from father to son. The usefulness of this system is evidenced by its survival with various family tasks still known by many Tuvaluans.

These traditional societies had a very strong sense of community and lived sustainable, low-impact lifestyles. Being a sea-faring people they had contact with and were influenced by other Pacific Island nations, and their architecture reflects this. Traditional Pacific Island architecture is welcoming, practical and sustainable. The typical house, or fale, is a single cell timber pavilion associated with an open space, or malea, which is the dancing ground, assembly place and courtyard used for daily living and ceremonial occasions.

Interior spaces are flexible and undivided. The multi-function open plan of a traditional Tuvaluan house is separated into different areas through the use of floor mats, each representing a different activity occurring within the space. The flexible open plan allows for each activity to borrow space from one another, maximising the usefulness of small spaces. This continues the strong communal philosophy from their overall societal structure down through their spatial layout. Sleeping areas are often separated from main living areas through the use of raised floors which help to define the otherwise undivided internal space.

The traditional island aesthetic favours openness over enclosure, perhaps because on islands enclosure is already provided by the tilt of the horizon and the dome of the sky. Screens, or pola blinds, are suspended from the roof in place of solid walls in order to maximize cross ventilation and allow for an open connection to the adjacent melea space. The pola blinds are usually only lowered when family members are sleeping or during strong winds.

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16 Ibid.
18 Ibid.
2.3.2 Current State

Living on an island is to live in isolation and sustainable practices become essential to survival. In addition to sea level rise, Funafuti is currently facing a number of sustainability issues which threaten its continued existence. The island relies heavily on imported diesel for power generation. Tuvalu has committed to being 100% reliant on renewable energy sources by 2020 but currently only 5% of Funafuti’s energy comes from renewable sources, largely due to the recent installation of photovoltaics on the roof of the sports ground grandstand.

The island also relies on imported construction materials, both internationally and from within the islands of Tuvalu. Historically, all buildings were built from locally sourced timbers, mostly coconut trees which thrive in the local climate. Today, much of Funafuti is built with western materials and in western architectural styles largely due to the arrival of Europeans in the late 19th century and the subsequent conversion to Christianity. This brought the construction of stone and brick churches and the conversion to European architectural styles.

Sources of food and water are also problematic on the island. The porous foundations of coral atolls lead to problems with fresh groundwater quality and rising sea levels bring with them increased soil salinity resulting in decreasing yields. The soil in Funafuti’s three plantation sites is already too saline for reliable crop production. Rainwater is vital to the residents and when it becomes insufficient they must turn to the limited groundwater supplies which are located in the freshwater lens. The freshwater lens is not only vulnerable to salinity intrusion due to rising sea levels but also to local pollution, stemming from Funafuti’s growth in population.

Liquid waste management is also of concern in Funafuti. The most common form of sanitation in households is the septic tank system which was introduced without regard to the geophysical characteristics of Funafuti as a coral atoll. The groundwater table is generally within 1-1.3m of the surface and rarely at depths greater than 2m. Subsequently, any pollutants leaking from septic tanks and soak pits easily move into the groundwater lens and into coastal lagoons. As a result, poor liquid waste management in Funafuti is costing the country half a million dollars a year, mostly due to health problems caused by contaminated water.

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21 Holley Ralston, Britta Horstmann and Carina Holl, Climate Change Challenges Tuvalu (Cologne: Germanwatch, 2004), 12.
Fig. 17: Diesel being imported to Funafuti

Fig. 18: Typical house in Funafuti

Fig. 19: Make-shift sea wall, Funafuti

Fig. 20: Poorly designed septic tank system in Funafuti
Funafuti needs to integrate a range of sustainable services in order to address the issues they are facing. The Tuvalu government has set goals of reaching 100% electricity generation from renewable sources by 2020 and aims to increase employment opportunities through the introduction of “green jobs” connected to climate change mitigation and adaptation. In order to reach these goals sustainable practices and services will need to be heavily integrated. Currently the proposal for reaching electricity generation goals is through the development of solar and wind energy but it appears likely that in order to reach the desired 100% the use of coconut oil-based biofuels will also be required.

Tuvalu has a history with solar photovoltaics (PV) being one of the first countries to attempt rural electrification using solar PV during a period from 1984-1994. However, due to the collapse of the Tuvalu Solar Electric Cooperative Society and the subsequent installation of diesel grids in 2000 the solar installations were mostly taken out of service. Nevertheless, the country’s solar resource potential has been proven sufficient and there is a great opportunity to take advantage of photovoltaic technology in Funafuti.

Wind power is a less attractive solution. A 30m meteorological mast near the Funafuti airport has recorded highly irregular wind speeds over an extended period, often below the speed necessary to economically produce electrical energy. However, there is sufficient data to indicate that a wind farm could be economically viable along Funafuti’s east coast, north of the port.

Biofuels offer the largest potential for petroleum import reduction of any renewable energy resource available in Tuvalu. Coconut trees present attractive opportunities for bioenergy solutions as they thrive in Tuvalu’s climate and have a wide range of uses. Coconut husks and shells can be used as a source of biomass for cooking and coconut oil can provide fuel for diesel back-up generators. They also provide a source of food and a traditional and sustainable source of timber. Currently, heavy use of this resource for fuel production is not possible due to limited supply but if the coconut industry is revived by biofuel production it is possible to maintain sustainable levels.

Composting toilets present a number of advantages over the current septic tank system such as eliminating the contamination of water, substantial water savings over flush toilets, and added compost soil benefits. A composting toilet consists of a pan sitting above a collection container or tank, with easy access to the container needed for the removal of the dried compost. The system relies on the use of carbonaceous material such as dry leaves or coconut husks to balance nitrogen in human excreta and provide aeration. The decomposition process produces a soil-like compost which can be used as a fertiliser after sufficient time has been allowed for the destruction of disease-causing pathogens, usually about a year.

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23 International Labour Org., Decent Work Country Programme: Tuvalu, 11.
25 Ibid., 7.
26 Ibid.
27 Ibid., 6.
28 Ibid., 7.
29 Lal, Saloa and Uili, Economics of Liquid Waste Management, 23.
Fig. 21: Photovoltaics

Fig. 22: Coconut tree

Fig. 23: Composting toilet
2.5 PROTOCELL TECHNOLOGY

Funafuti’s sustainability issues can be addressed through the introduction of a number of sustainable practices and technologies, but the issue of sea level rise is paramount and threatens the very existence of the island. The geophysical properties of Funafuti as a coral atoll make it adaptable over the long term, growing and receding with the rise and fall of the ocean over millennia, but it is extremely vulnerable over the short term in the event of accelerated sea level rise caused by global warming. The living coral foundation of the island will be overtaken by the rising ocean sometime within the 21st century effectively making refugees of all its inhabitants.

Protocell technology presents the opportunity to give Funafuti’s inhabitants a greater connection to the island than ever before, giving them control over the atoll’s growth through the introduction a synthetic limestone-like material which can be cultivated through a bottom up approach, bridging the gap between living and non-living matter.

“The protocell is a technology that is native to the 21st century and is likely to define it.”

A protocell is a synthetic cell contained within an oil droplet. It can be programmed through its chemistry to react to its environment and demonstrate living qualities such as movement, growth and self-replication. Though protocells can behave in lifelike ways they are not alive, nor do they have a central biological program such as DNA to guide them. They do not operate within the realms of biological processes that are associated with living systems, but are driven by primordial organising forces – the laws of physics and chemistry. Protocells have technological limitations in that they cannot operate in a dry environment and currently either need oil or water as a medium to function. They are a relatively new technology and are currently models of artificial cells that have some properties of living systems. They have not yet been developed to full “artificial cell” status, although this is expected to happen within the next 5-10 years.

One living quality protocells have demonstrated in the lab is ability to produce solid materials. They do this by metabolizing carbon dioxide and calcium present in their environment and synthesizing a calcium carbonate shell which can then be shed in a process very similar to coral polyps and their skeletal secretion. Unlike coral though, protocells do not require sunlight for the process to take place. When they come into contact with carbon dioxide a simple chemical reaction occurs, producing a calcium carbonate bi-product, a process which can be likened to iron rusting when it comes into contact with oxygen and water.

“This might be a tomorrow’s world that is being prefigured, but it is firmly rooted in the science of today.”

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31 Ibid., 21.
33 Ibid., 145.
34 Ibid., 146.
35 Halen Castle, Editorial in Protocell Architecture, 5.
The significance of this technology to endangered coral atolls is clear; protocells could mimic the growth process of the atoll itself when introduced through a subterranean system to selected sites. The necessary building blocks required for the chemical process to occur already exist amongst the porous atoll foundation and the underground water lens. As the protocells metabolize the carbon dioxide and the calcium in the environment they produce a coral-like solid which will grow over time, raising the elevation of the ground above. The volume of protocells introduced and the subsequent growth attained could be controlled by the atoll’s inhabitants through a facility from which protocells are pumped.

The technology is not yet at a point where this is currently a feasible solution but it is progressing at a promising rate and with the problem of sea level rise extending into the future I view this as a technology that will develop at the right time in order to be implemented in Funafuti. As Tuvalu is already in the international spotlight as a prominent victim of climate change, this is an opportunity for the country to become world leaders through the implementation of a carbon-negative solution to the problem, perhaps influencing larger nations along the way.
2.6 PRECEDENTS

2.6.1 Built
The 5 Lagoons Project in the Maldives is an example of a response to sea level rise which I feel would be inappropriate for Tuvalu. It is a large scale floating islands project headed up by the Dutch architectural firm Waterstudio and consists of a star-shaped hotel and conference centre, a floating golf course, and a range of floating luxury villas. Construction on the project has begun and the first of the floating villas is set for completion in 2014.36

The Maldives has a substantial tourist economy and The 5 Lagoons Project is directed more at maintaining that economy than addressing the issues faced by the Maldivian people and the islands themselves. The approach creates a fundamental disconnect between architecture and island, the people and the land. My research into floating solutions to sea level rise lead me to search for an alternative which would maintain a connection to the disappearing land, allowing me to protect the established lifestyles and customs of the island’s inhabitants, not drastically alter them.

The Omega Centre for Sustainable Living is an educational building for the Omega Institute for Holistic Studies in Rhinebeck, New York. It consists of a laboratory, a water garden, indoor and outdoor classrooms and a yoga studio. The self-sustaining building is powered by roof and wall mounted photovoltaics and incorporates a biological wastewater filtration system through the indoor water garden. The building welcomes visitors and all the sustainable systems are on show for people to learn about.

For the people of Funafuti to adopt the practices and technologies required in order to be self-sustainable it is likely a building of this sort will be needed, a community information centre where people can come to learn about the problems the island is facing and what can be done about them.

The First Light House is a beach house design by architecture students at Wellington’s Victoria University. In 2010 it was taken to the US Department of Energy’s Solar Decathlon where it demonstrated its sustainable design and competed against nineteen other projects from around the world. The house is a modular design consisting of a section running through its centre functioning as a bridge between the natural environment and the indoors with living areas and bedrooms located on either side.\textsuperscript{38}

The aspects of the First Light House which influenced my project were its connection to the outdoors, its economic use of space, its extensive use of sustainable technology and its passive strategies used to control the internal environment.

The Ise Grand Shrine in Japan sits on a simple rectangular site with an identical site adjacent. Every twenty years the shrine is rebuilt as part of the Shinto belief in the transience of life and the impermanence of all things. The rebuilding alternates between the two sites and also serves as a way of passing on building techniques from one generation to the next. The latest rebuild occurred this year and marked the 62nd undertaking of this major event.39

If my project proposes the use of protocells to elevate the ground it will be necessary to have a bare site while the elevation takes place as to not damage building foundations. This process of rebuilding and alternating between two sites is important to my project. As sea levels rise and higher ground is required for a village, protocell growth will take place beneath an adjacent site over a period of years. As this growth is slowly taking place the empty site above can be used for food production, fuel production and the growing of construction materials. When the required elevation is attained the small village will dismantle and rebuild on the higher site, passing on construction techniques and evolving as new technology and knowledge is gained.

2.6.2 Proposed

The village layout typology developed by Tuvaluan architectural graduate Ben Kofe for a proposed migration to Australia by the “Tuvalu 7 C’s” project employs a number of attractive strategies. The central courtyard layout works well with the traditional community-oriented lifestyles of the Tuvaluan people and the use of shared communal buildings reduces the amount of construction required and the overall footprint needed to house people.

Funafuti currently lacks any urban design aimed at fostering the traditional community paradigms seen in the past which were much more sustainable than the westernised paradigms seen today. The island also suffers from overcrowding resulting in the need to import food, diesel and materials for construction. If the population can be compacted into villages which share communal spaces then adjacent land will be freed up for the production of food, fuel, and construction materials.

Fig. 31: Ben Kofe’s proposed village typology

40 “Tuvalu 7 C’s” accessed July 8, 2013, http://tuvalu7seas.com
**Future Venice** is a project which proposes the use of protocells to sustainably reinforce the foundations of Venice. The proposal consists of programming the protocells, through their chemistry, to move away from the light at the surface of the water towards the wooden pile foundations where they would then use dissolved carbon dioxide and minerals to gradually grow an artificial limestone reef under the city. The proposal serves as an alternative way to ‘save’ the city from destructive tides, which are currently being stopped by installing steel floodgates to control tidal movement which environmentalists fear may disrupt the marine ecology.41

This proposal was my initial influence to look into the use of protocell technology as a way to raise the elevation of Funafuti in a sustainable way which emulates the coral atoll’s natural processes, thereby protecting it from flooding caused by sea level rise.

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3.0

DESIGN PROCESS
This project intends to propose a new communal living typology which combines traditional Pacific Island architectural principles with a range of sustainable practices and technologies. These small communities will be built on sites elevated by an underground protocell system in order to protect them from flooding caused by sea level rise. This new living typology will be introduced to the Tuvaluan people through a ‘seed’ community which will be the first of many proposed through an overall island plan.

The ‘seed’ community will include:

i. A community hall and information centre – Encouraging people to come and learn about the new typology, the new sustainable practices, and the new technology.

ii. A central courtyard/malea space – Providing a large outdoor space which can be used for daily living, sports, dance and ceremonial occasions.

iii. 10 housing units/fales – Incorporating a range of sustainable technologies and strategies. Provide an open and flexible living space connected to the central courtyard and a flexible sleeping space with the opportunity for expansion if needed.

iv. A communal kitchen and laundry.

v. A communal nursery/day care.

vi. A green technology repair shop – Providing the first step in creating new employment opportunities through the introduction of ‘green jobs’ and stimulating new ‘family tasks’ within communities.

vii. A communal workshop – To service the repair shop and other members of the community.

The overall island plan will include:

i. A greater master plan outlining the locations of each community and their respective adjacent sites used for the growth and rebuilding cycles – based on areas most at risk of flooding and proximity to the expanding protocell system.

ii. A timeline detailing the protocell growth periods and the construction dates for the ‘seed’ community and each subsequent community.
3.2 SITE SELECTION AND ANALYSIS

Site Selection
I chose the plantation land located in the Vaiaku area of Funafuti as the site for the ‘seed’ community. It is already unsuitable for growing crops due to soil salinity and will continue to get worse as sea levels rise. This large unused plot of land is the ideal location for a number of reasons such as its current vulnerability to flooding, its central location, and its close proximity to the Public Works Department.

The site is beginning to experience flooding during the annual king tide events and this will increase in frequency during extreme weather events coupled with rising sea levels. It is one of the most vulnerable areas on the island making it a fitting place to establish the first protected community site through protocell elevation. Once established, the nearby households who are also located on vulnerable land will move in, freeing up land for the construction of successive communities.

The Vaiaku area of the island is also central and home to key services and amenities, including government offices, the telecom office, the post office, Tuvalu's only hotel, the National Bank of Tuvalu and the Funafuti Airport Terminal. The fact that this is such a busy area means the inaugural community will be more visible and the proposed information centre will receive a lot of traffic. This is important because in order for the proposed living typology to be successful the people of Funafuti will have to learn about what is going on, ‘buy-in’ to the proposal and adopt it.

The site is also near the Public Works Department which looks after the island's amenities and maintains its infrastructure. This is where the proposed protocell facility would be located and operated. Being in close proximity allows for easy installation of the underground system and convenient monitoring of the protocell growth.

Fig. 33: Vaiaku, Funafuti
Site Analysis
The south-western side of the site is the least private. The National Bank of Tuvalu is located on this side and it is also opposite the airport terminal. The road that runs along this side of the site connects up to the hotel, the government offices, the telecom office and some shops. There are opportunities here to extend this busy ‘main street’ through the introduction of the green technology shop and the information centre. There is also opportunity to bring in visitors from the street and tourists from the airport terminal to explore the new living typology and the various sustainable technologies and practices being introduced.

Moving away from the south-western street front, the site becomes increasingly private. The rear corners of the site are bordered mostly by residential land and would be favourable spots for communal buildings which are used solely by the inhabitants of the community such as the kitchen and the day care. There is also an opportunity to create a connection to the sports ground which is opposite the eastern corner of the site, across the airstrip. The sports ground is used often and the airstrip itself is also used for casual sports games by the locals.
The viability of the site as a future inhabitable location is dependent on the successful integration of the system which will introduce the protocells to the coral atoll below, thereby speeding up its growth to contend with the rising sea level. Because the technology is not yet at a point where the specifics of what is required to achieve this form of mass underground growth is known I am assuming three basic facts:

i. The protocells will need to be stored in one location.
ii. That location will need to be connected to the areas designated for protocell growth.
iii. The magnitude of growth will need to be monitored and controlled.

The Public Works Department is the logical place to locate the facilities required to store the protocells, control their release into an underground network connecting to the growth sites, and monitor the growth achieved. The Vaiaku ‘seed’ site will be the first of many to be connected back to the Public Works Department through the underground network.

Researchers assert that the knowledge and technology surrounding protocells will advance significantly within the next 5-10 years.\(^2\) For the purpose of my proposal I am assuming that a date of 2020 will be possible for the introduction of protocells to the Funafuti atoll. With the facilities and underground network in place I am proposing that protocell growth beneath the Vaiaku site will begin in 2020, elevating the site by 700mm over a growth period of five years. This elevation will be sufficient to ensure protection from flooding caused by sea level rise until 2050. Once the growth period is completed the construction of the ‘seed’ community will begin in 2025.

With the ‘seed’ community constructed in 2025 the protocell network will be extended to three nearby sites which are also immediately vulnerable to flooding. The growth process will raise the sites to sufficient elevations in order to protect them and the construction of successive communities will take place in 2030. This process will continue, targeting sites most vulnerable to flooding first, until all of Funafuti’s inhabitants are living in the elevated condensed communities.

An alternative method of elevation is required for the roads as the method of gradual underground growth could compromise their integrity. During WWII the US army excavated coral from large ‘borrow pits’ in order to construct the Funafuti airstrip. These borrow pits were damaging to the local environment and are polluted eyesores today, but a material from which the airstrip could be constructed was needed and on the isolated atoll that was the best option. Construction materials are hard to come by in the middle of the Pacific Ocean so I am proposing a similar method for road construction to that used by the US army in WWII. Through protocells it is possible to grow a solid construction material from minerals found in the ocean. A modern version of the borrow pits could be constructed alongside the Public Works Department, not atoll damaging trenches but large tanks filled with ocean water in which considerable amounts of calcium carbonate solid could be grown through the introduction of protocells. This solid could then be removed and ground into limestone-like gravel and used to construct elevated roads as needed as well as storm surge breakers and sea walls. The isolation of the island amongst the vast Pacific Ocean now becomes less inhibiting when its dissolved minerals can be used to synthesize a construction material.

With this protocell system in place Funafuti will be poised to take advantage of future innovations as the technology advances. Many of the advances in the field of protocells will have architectural relevance which, “by virtue of their environmental connectedness, have the potential to become more than just ‘environmentally friendly’ – a benign state of being – but environmentally remedial – active and subversive.”43 The construction materials of the future will be intelligent and responsive to their environments, capable of adaptation and self-repair.

43 Spiller and Armstrong, Protocell Architecture, 18.
The communal aspect of this new living typology is also integral to Funafuti’s self-sustaining survival. Traditionally, Tuvaluan society consisted of communities of family groups brought together under a hierarchical social structure. Everyone had a particular task to perform for the community and they were expected to excel in developing the skills and knowledge of the task assigned to them. Their knowledge and expertise would then be passed on to the next generation. In the past these tasks would include building, fishing and warfare, but today there are also opportunities to introduce modern tasks such as various technology repair and installation, modern farming techniques, and jobs within the new protocell field. All these are what can be classified as ‘green jobs’, something the Tuvalu government has put emphasis on developing. A solid community framework will better allow for the exchange and development of knowledge and increased self-sustainability through shared resources.

A strong communal arrangement is also something which suits the Tuvaluan way of life. The people of Funafuti are very social; receiving multiple unannounced guests to your house throughout the day is not uncommon and is something that is welcomed. Funafuti has lost the urban design layouts which accommodate this social culture but the individual house designs have not. Many houses consist of a main enclosed area which connects to an adjacent open area, usually a large covered deck space. This is where people will often eat and entertain guests, occasionally even cooking a large meal and offering or selling plates to locals passing by. This connectedness between neighbours and communities is influential to my design.

The sharing and building of knowledge is crucial to developing a sustainable community. It is also important for the people of Funafuti to share and learn about everything involved in this new living typology in order for them to adopt it during its introduction. The ‘seed’ community will be the first of many and will act as the catalyst in raising awareness for the issues faced by the people and what needs to be done in order for them to remain in Funafuti. The information centre proposed for the front of the site will be integral in raising awareness for the issues and demonstrating the various practices and technologies put in place to address them. It will act as a gateway to the site and to the future, encouraging visitors by connecting to the busy front street and the adjacent airport terminal. It will also simultaneously act as a community meeting space, market space, and dance and events space, becoming a central hub for the future of Tuvalu. I see this as being a more permanent building than the others proposed for the site and as such it will need to be constructed 1800mm above the current ground level to ensure a 50+ year existence.

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44 Faaniu, Tuvalu: A History, 22.
By condensing communities through the introduction of shared spaces and communal buildings it is possible to free up land which will be composed into adjacent sites of similar proportions for every community. These adjacent sites will be essential to survival for a number of reasons. They will be used for the production of food, fuel, and fibre through farming and the cultivation of coconut trees for bioenergy uses and construction.

The undeveloped land is also essential to the continued cycle of elevation through protocell growth as sea levels rise. Growth cannot occur beneath buildings due to the risk of damage to foundations but the adjacent sites can be raised over time to the desired elevations and then communities can dismantle and rebuild on the higher site thereby opening up the previous site for cultivation and elevation. This process can continue indefinitely ensuring the permanent existence of the people through the impermanence of their buildings.

The rebuilding process will take place every 25 years and will serve as a valuable way of passing on building techniques to the next generation, much like the Ise Grand Shrine in Japan. It also presents the opportunity to continually improve and evolve as new techniques and technology become available. Just as the reef corals below have grown atop the skeletal remains of their ancestors, keeping close to the surface in order to survive, so too must the people of Funafuti discard their living shells and build upon the knowledge of their ancestors in order to survive.
3.6.1 Initial Concept
My initial master plan worked with the concept of the island as a living organism; a coral atoll which is alive and grows over time. My design sought to carry this concept through to the growth of elevated communities using protocell technology. These communities would develop gradually and arise throughout the island via a connection (protocell vascular system) back to a central protocell pump (heart).

I liked the overall concept behind this master plan but I concluded it would need to be further refined in order to be a viable solution. There were a number of issues that would need to be considered, mostly to do with the transition from the island’s current state to my proposed solution.

Fig. 40: Protocell village concept
3.6.2 Refined Development

The master plan for the island required attentive design as it would outline the locations and construction dates of the communities which would house the people of Funafuti. When developing the master plan towards a viable solution it was important to consider the following:

i. The areas of the island which are most at risk of flooding caused by sea level rise.
ii. The relative proximity to the proposed protocell facility and its underground system.
iii. The current infrastructure layout.

I began by identifying the houses on the island that are most at risk. This was done by cross referencing flooding projections for Funafuti\(^\text{45}\) with a map outlining every house. I concluded that the households most at risk were those located along the western edge of the airstrip as well as those to the west of the Public Works Department.

With the proposed protocell facility located adjacent the Public Works Department and its underground delivery system extending to the ‘seed’ community I concluded the ideal locations for the first round of subsequent communities would be approximately 100m to the northeast and approximately 100m to the southwest of the ‘seed’ community, as well as approximately 200m to the southwest of the Public Works Department. These three communities would be constructed in 2030, five years after the opening of the ‘seed’ community.

Following communities would then be proposed along the western edge of the airstrip, targeting areas most at risk. The boundary of each community site fits within the current layout of the island’s infrastructure. The master plan allows for adjacent sites of similar proportions for every community in order to provide bare land for farming, cultivation, protocell elevation, and the rebuilding process.

Fig. 41: Areas susceptible to flooding and houses most at risk

Fig. 42: Master plan development
When developing the layout of the 'seed' community it was important to refer back to research done during site analysis. There is an opportunity along the south-western side to extend the busy streetscape down to the airport terminal and encourage traffic into the southern corner. Conversely, the rear of the site towards the north is the most private area of the site. These aspects of my site analysis were influential in my positioning of the various buildings that make up the 'seed' community.

The buildings that needed to be positioned on the site were:

i. Information Centre.
ii. Green Tech Shop.
iii. Workshop.
iv. Communal Kitchen + Laundry.
v. Communal Day Care.
vi. 10 Housing Units.

The important aspects to consider during development were:

i. The connections created.
ii. The spaces created.
iii. The circulation through the site.

The connections created between the community and the surrounding areas were the driving force behind locating the information centre on the southern corner. This corner also acts as the main entrance to the site for visitors. I positioned the green tech shop near the eastern corner, next to the existing bike and scooter hire. The communal workshop which services them is located adjacent the green tech shop and the communal kitchen and day care have been positioned in the remaining two corners.

The central courtyard space is an integral part of the site plan. This is the heart of the community and the space where ceremonies, dance, and sports take place. It is also where all circulation throughout the site occurs.

The courtyard is enclosed by the housing units which open out onto decks, which spill into the central space. Privacy is blurred as you move from the centre of the courtyard towards the open decks, into auxiliary outdoor spaces between housing units. The space is large enough to contain a volleyball pitch (a common social sport in Tuvalu) in the centre, with space for seating around it, and circulation space beyond.

I decided to leave the National Bank of Tuvalu located on the south-western side untouched. This building is of solid construction and I see no reason to interfere with it. In the future this building will need to be rebuilt or relocated due to flooding caused by sea level rise but this will not happen for some time.
3.8.1 First Iteration

Early on in the design process I experimented with the possibility of using protocell growth as a building material. This was developed in conjunction with my initial master plan concept which carried the idea of the island as a living organism through to the development of communities and individual housing units. This proposal focused on growth over time. As sites were elevated by underground protocell growth the beginnings of structures would also be grown. These protocell structures could then be built upon using traditional methods.

I concluded that this was not a suitable solution for a number of reasons:

i. The protocell technology would need to advance significantly in order for this structural growth to be possible.

ii. The logistics involved in growing a house over time would likely be too complicated.

iii. The integration of a 'living' building material with traditional construction techniques was problematic.
**3.8.2 Second Iteration**

My second design alternative returned to traditional Pacific Island design principles and aimed to develop a modern fale. I worked with the structural design of a traditional fale and modified it by splitting it down the middle. This split allowed for a distinct separation of the internal space into living and sleeping while maintaining an open and flexible aesthetic. Passive ventilation and connections to the outdoors were also important aspects of this design.

This design iteration led me to establish a number of requirements derived from my research into traditional Pacific Island architecture, sustainability and services, and my precedent studies. Those requirements were:

i. Incorporate traditional design principles and features such as:
   a. Openness; both to nature and to the community.
   b. Connection; to the central courtyard space and between houses.
   c. Simple and flexible interior spaces.
   d. Simple timber post construction for easy disassembly and reconstruction.
   e. Suspended ‘pola blind’ walls for passive ventilation and flexible privacy.

ii. Integrate sustainable services and practices such as:
   a. Photovoltaic systems.
   b. Composting toilet systems.
   c. Green roof systems; to reduce and delay storm water run-off, create cooler internal environments, and provide additional green space to the condensed community.
   d. Sustainable timber (local coconut tree) construction.
   e. Natural ventilation.

iii. Have a small footprint and make economic use of space in order to maximise land area for communal use, farming, and cultivation.

iv. Provide opportunity for expansion to accommodate larger or growing families.

The goal was to combine the requirements above in order to develop a design which responded to a number of issues the people of Funafuti are currently facing and will face in the future while simultaneously fostering a stronger sense of community and connection.
3.8.3 Third Iteration

Based on the design requirements outlined above I developed a third alternative. This design integrated a number of green technologies such as photovoltaics, composting toilets, and green roofs. It also made much more economic use of space making it easier to fit a greater number of units around the central courtyard. The design also opened up the opportunity to create connections between units; when units are positioned next to each other a secondary courtyard space is created connecting their respective living spaces.

The spatial layout is similar to the previous iteration with the flexible living area located at the front of the house, welcoming people in. The living space can be opened up to the central and secondary courtyards by raising the suspended ‘pola blind’ walls. The sleeping space is at the rear of the house divided into 2.4m by 2.4m spaces through the use of sliding screens. This results in a space which can be adapted to suit the particular needs on any given day. Through the rear of the house there are private terraced gardens and access to the composting toilet tank below the house and the roof garden above.

Through the use of a simple grid-like structural layout it is possible to easily extend units to house growing families or connect two units resulting in a double unit which can be shared between extended families. This flexibility is important as it is in line with the social structures of the Tuvaluan people.

Fig. 46: Housing unit - third iteration
The information centre proposed for the corner site of the 'seed' community needed to satisfy a number of requirements such as:

i. Spark excitement and encourage adoption of the new living typology.
ii. Facilitate education and development of practices and technology.
iii. Act as a buffer/gateway to the community.
iv. Act as a flexible community hall space.

Influenced by the Omega Centre for Sustainable Living I made the decision early on that this building would exhibit a number of sustainable technologies to the public. The entrance to the building would be a reception and exhibition space where visitors could view the technology integrated with architecture. This exhibition space would be connected to a seminar space for further learning.

It was also important for this building to be a lively community hub in order to encourage traffic through the building. Through the design development, I proposed two large flexible spaces which could be programmed in a variety of ways. They could be used for community meetings, indoor sports, dance, markets, or as an extension to the exhibition space.

Fig. 47: Information centre development
4.0 DESIGN OUTCOME
I feel the master plan proposed for the island of Funafuti successfully addresses a number of issues pertaining to its future survival. An effort was made to ensure a smooth transition from its current state to the proposed plan. However, it is likely a number of households will be displaced for a period of time as the development progresses; temporary solutions may be required for these households.

While the goal was to promote greater social connectedness within communities I have concerns that the master plan may result in a feeling of disconnectedness between community groups. Being inwards facing and separated by their adjacent servicing sites may result in limited connections between individual community layouts.

This master plan is a rough guideline and is influenced by the current infrastructure and layout of the island. Through the very nature of this project I expect it to evolve and be altered by the people to suit their needs as they arise. I expect my concerns over social disconnectedness will be rectified as community groups naturally conglomerate over the decades through the periodic rebuilding process.
Fig. 48: Master plan - timeline
The ‘seed’ community is the nucleus of Funafuti’s future, acting as an example of the proposed living typology and a prototype for successive developments. In proposing this new typology it is hoped a greater sense of community and a more sustainable way of living would be achieved. I feel the proposed plan would be successful in achieving those goals.

The central courtyard space is essential to the functioning of the proposed plan and as such has been designed to perform a number of functions. Events, spectating, gathering, and circulation can all take place simultaneously. The decision to arrange housing units around the central courtyard space not only helps to facilitate Tuvaluan social dynamics but also their customs and culture. This strengthens their cultural identity, something which was in danger of being lost.

The introduction of communal buildings further helps to strengthen community ties while also improving economy of space, freeing up adjacent land for resource production. The communal buildings have been located in the corners of the site to better contain the internal space.
Fig. 49: 'Seed' community
Since the arrival of European construction materials and methods the people of Tuvalu have favoured western architectural styles over traditional Pacific Island aesthetics. My goal was to develop a design which was modern and attractive to the people while incorporating a number of their traditional design principles and techniques.

The structure is of simple timber post construction similar to traditional styles. This makes use of local sustainable resources and allows for easy disassembly and construction. This is important as communities will be rebuilt every 25 years in order to achieve permanent survival on the island through the impermanence of the buildings.

Functionally, it is a blend of the open and flexible spatial layout of the traditional fale and modern methods of spatial separation. Internal spaces are more enclosed than those of traditional fales but a feel of openness and connection to the outdoors has been maintained. The flexibility of the sleeping space and the ability to easily construct extensions between units facilitates the dynamic social paradigms of the people.

Integrating certain environmental aspects was important in the design of the housing unit. Natural ventilation is important when living in the tropics and my design aims to maximise it through the integration of louvered walls and roofs, ‘pola blind’ walls, and a clerestory above the sleeping space. Roof space is fully utilised with half being used for the installation of photovoltaics and the other half being used as a green roof.

The photovoltaics supply the house with electricity and the green roof helps to passively control the internal atmosphere. A composting toilet system is integrated into the design with adequate space below the bathroom for the collection tank and access to it provided through the rear of the house.

Aesthetically, I am pleased with the outcome. I aimed to blend traditional Pacific Island design principles with modern technology. I find the result to be a modern version of the traditional fale; an aesthetic I think will appeal to the people of Funafuti.
Fig. 51: Housing unit
As with the housing unit my goal for the information centre was to blend traditional design principles with modern architectural styles and aesthetics in order to create a hybrid between a traditional Pacific Island meeting house and a modern recreation centre.

The simple timber post structure is reminiscent of a conventional meeting house but the traditional steep gabled roof style has been replaced by a number of roof planes at reduced angles. This was done in order to maximise the building's solar potential. Glass roofs were also used over selected spaces in order to have the photovoltaic systems on display.

This building is intended to serve a lot of functions within an open and flexible space. Upon entering you are presented with a number of sustainable systems which have been integrated with the architecture and are on display to the visitor. This raises awareness of the issues as well as what is being done to address them. The most noticeable of these systems will be a large 'protocell wall' demonstrating the growth process occurring below ground.

Adjacent to the exhibition space are two large open-plan spaces intended to serve the local community as well as the greater Vaiaku area. These are the traditional community hall spaces in which markets, meetings, sports and events will take place.

Running through the centre of the building is a connection through to the 'seed' community beyond. This opens up the opportunity for the introduction of tours through the community and for the use of the central courtyard space as a ceremonial welcoming area.
This project outlines a first step towards a sustainable future for the people of Funafuti, a future that ensures their continued survival in their homeland in the face of severe climate change. A framework for what happens after this first step has been drafted but the potential for diverse development is great.

There is potential for the people of Funafuti to adapt the proposal to further suit their needs and customs. As they gain knowledge about the issues and develop the methods of addressing them their architecture and community layouts will mature. The requirement for the periodic rebuilding process will help to facilitate this evolution.

With the protocell system in place Funafuti will be poised to take advantage of future technological advances, particularly in the field of ‘smart’ building materials. Further research could be done into utilizing these protocell materials to generate a more sustainable architecture; one which is carbon-negative, more resilient, and adaptable to the dynamic local environment. This protocell architecture could be unlike anything previously experienced on the island, the challenge will be to utilize it in a way which continues to preserve their cultural identity.
Sea level rise is going to make it increasingly difficult for the people of Funafuti to remain on the island. Their self-sufficiency and resilience will be pushed to breaking point unless something is done. This project has presented a solution that aims to strengthen the connection between the people and their island as a resource base. This connection is crucial in ensuring the continued existence of the two.

As conditions continue to deteriorate architecture will play a central role in turning the tide. The combination of sustainable technology and considered architectural design and planning will empower the people and put control of their future back in their hands. Through the introduction of a new living typology and a number of sustainable practices and technologies many of the issues threatening life on the island have been addressed. Traditional low impact social paradigms have also been encouraged through community design and a return to past design principles.

This project presents a framework and a first step towards a sustainable future but the issues the people of Funafuti are facing will persist. The opportunity for future development and adaptation is great and the inhabitants will need to face challenges and make this proposal their own. Future research could further investigate communal layouts and the greater plan for the island. Social connections within communities have been facilitated but connections between communities will also be important. Further research into the application of developing protocell materials will present an exciting avenue to the people of Funafuti, opening up opportunities for environmentally remedial and responsive architecture. This will build upon the foundation established by this project and further strengthen connections to the environment.


During the course of this research project I explored the possibilities of protocell technology and its application to architecture. One of these explorations was into the aesthetic of a protocell construction material; a protocell building skin. I developed the aesthetic by investigating coral growth and identifying a growth pattern called “diffusion limited aggregation” which is essentially a random growth pattern branching from a starting point.

The first step was to emulate this growth pattern. This was done in Grasshopper and yielded a number of images depicting the growth process.

The Grasshopper images were then modified in Photoshop in order to give them depth and make it possible to extract three dimensional models from them.

These modified images were then imported to Rhinoceros 3D and converted to three dimensional computer models through the “height field” surface technique.

The three dimensional computer models were then run through a CNC machine which carved them out of large polystyrene blocks.
7.2 ‘SEED’ COMMUNITY MASSING MODEL
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