Sustainable Artificial Island Concept Design for the Nation of Kiribati

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Abstract

Global warming and rising sea levels are increasingly causing major problems for low lying Pacific and Indian Ocean island nations. This paper describes a sustainable artificial island, designed for the inhabitants of South Tarawa, a coral atoll in the South Pacific and the capital island of the Republic of Kiribati. Design targets were to improve infrastructure, services and quality of life for the inhabitants, to increase island sustainability and to minimise construction costs. Transition to an artificial island is a feasible option with significant international support, and would enable survival for the population of South Tarawa with minimum disruption to their current lifestyle.

Author’s Biography (50 words)

Natasha Lister is a Naval Architect for the UK Ministry of Defence. She studied at Durham University for a MEng in General Engineering with a specialism in Civil Engineering, and at UCL for an MSc in Naval Architecture. Employed by the MOD, she has completed the DESG graduate scheme and currently works in the Submarine Naval Design Partnering Team.

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Background

The Nation of Kiribati, Fig 1, consists of 33 islands, of which 21 are inhabited. The islands are located in the central Pacific Ocean approximately 2,100 nautical miles southwest of Hawaii and 2,000 nautical miles northeast of Australia. The Kiribati population is just over 100,000, with 50,000 living on the capital island of South Tarawa. Kiribati is one of the poorest countries in the Pacific, relying heavily on foreign aid (35% GDP in 2010). The core activities are limited to copra farming, seaweed harvesting and fishing (28% GDP in 2009) with tourism still relatively low due to Kiribati’s remoteness and poor infrastructure (<2% GDP in 2009). The global spike in food and fuel prices in 2007-2008 undermined past gains in poverty reduction, with the proportion of population below the poverty line increasing from 22% to 26% from 2006-2009.[1] Unemployment is very high, so it is common for one person to financially support a large family network.[2]

Fig 1: Nation of Kiribati[3]

The country is dependent on petroleum imports for electricity generation, cooking and lighting. On South Tarawa, electricity is largely supplied by public generators but the system suffers from high losses and voltage spikes are common.[4] Groundwater is the major water source, supplied from wells and chlorinated with no preliminary treatment. Well water is often of poor quality and there are numerous leakages in the reticulated system.[1] Fishing and local crops are the primary food source, but the volume of imported food is increasing.[5] The disposal of wastewater is a major problem: saltwater flushed sewerage systems exist in three towns on South Tarawa, but are partially inoperable and require maintenance. Unmanaged discharge is causing pollution of the freshwater lenses and the lagoon. Previously uncontained solid waste is another source of water pollution.[6]

The Kiribati Development Plan (2008–11)[7] was the government's overarching plan to enhance economic growth and reduce poverty. Its main aims were to support private sector development, particularly in eco-tourism and in the fishing industry, and to create employment opportunities both domestically and abroad. Fishing license fees are a key source of income for Kiribati, and it still has untapped potential to exploit its fishing resources and reduce the volatility of fishing revenues. If basic infrastructure is put in place, Kiribati has substantial opportunities for eco-tourism with the Kiritimati and Tabuaeran Islands, and the world's largest marine protected area of the Phoenix Islands.[8] Other attractions include World War II battle sites, game fishing and the Millennium Islands, situated just inside the International Date Line.[1]

Global warming and rising sea levels are increasingly causing major problems for low lying Pacific and Indian Ocean island nations. The rate of sea level rise is predicted to increase throughout the next century, with non-uniform geographical distribution. Climate change also causes changes in weather patterns, resulting in larger storm surges locally, more variable rainfall and increased temperatures, which can exacerbate the problems experienced by susceptible nations.[9]

The nation of Kiribati, along with other low-lying Pacific nations such as Tuvalu, the Marshall Islands and Indian Ocean nations such as the Maldives, is facing growing difficulties due to rising sea levels. South Tarawa experienced an average sea level rise of 3.9 mm/yr between 1992 and 2008, with an average land rise of only 0.2mm/yr over the same period.[10] The habitable parts of the islet are underpinned by resistant paleoreef flats underlain by cemented reef limestone. If high tide levels rise above the mid-Holocene low tide level, then the paleoreef flats will submerge, known as crossover. For the Kiribati island chain, the worst case predicted crossover date is 2070. If crossover occurs, the unconsolidated sediment will no longer be protected from wave attack and overtopping, so the rate of erosion will increase dramatically.[11]

In South Tarawa, almost 50,000 people live on 15.76 km^2 of land. The island has an average width of 450 m, and no land reaches higher than around 3 m above sea level. By 2050, it is predicted that South Tarawa could be up to 54% inundated by the sea.[12] Climate change has worsened a number of concerns, including coastal flooding due to higher tides and more frequent storm surges, saltwater intrusion, coastal erosion, variation in rainfall, public health problems and living standards.[1] The government has an adaptation plan in place, but has also considered more dramatic options including building large sea defences, relocating to an artificial island, and relocating part of the population to Fiji.[13]

Fig 2: Photo of Tarawa Atoll[14]

Introduction

The nation of Kiribati is in desperate need of a long term solution to its current crisis, and the construction of an artificial island could be an option. The artificial island described in this paper is intended to facilitate the gradual relocation of inhabitants of South Tarawa, whilst minimising disruption to population lifestyle.

Design Philosophy

The approach for this project was to design an artificial island on which the South Tarawa population can keep their traditional values and lifestyle, whilst modernising infrastructure, services and quality of life. Major improvements could be made in power and water supplies by sourcing locally and sustainably, and improved treatment of drinking water and disposal of wastewater could reduce public health problems.

The philosophy for the concept was to apply the principles of sustainable community development to promote local self-sufficiency and diversity of communities. A modular approach provides robustness and allows communities to source their own power, water and food. A sustainable design incorporates town centres to satisfy social and aesthetic needs, and to provide employment. In designing a replacement town from scratch, there is an opportunity to provide great improvements in communication and transportation.

Due to the poor economy of Kiribati, a further requirement was to minimise construction costs, and also to promote local employment and grow the economy. By maximising sustainability, South Tarawa could become increasingly self-sufficient and reliance on UN aid could reduce and eventually cease. The artificial island should be a long term solution, so the design life for the structure should be long with minimal maintenance requirement.

Site Location

Fig 3 shows the proposed artificial island location. The new structure is placed within the lagoon, so that the existing island protects it from the ocean by acting as a natural breakwater. The site is close to land, connected by two bridges, to allow a gradual transition from old island to new island. The lagoon depth at the proposed site is currently approximately 20 m, allowing either fixed or floating structural options.

Prevailing winds are from the NE, so there will be build-up of small waves (typically less than 0.75 m[15]) across the lagoon. The tidal range in Tarawa lagoon varies from 0.5 m under neaps to 2.4 m under springs.[16]

Fig 3: Artificial Island Location[1]

Sustainability and Modularity

In order to achieve a long term solution for Kiribati, the artificial island should be designed to be as self-sufficient as possible. Therefore the principles of sustainable community development play a large part in all aspects of this design concept. A number of independent communities are combined to create the artificial island, enabling a modular build strategy to be employed. A single manufacturer continuously producing modules spreads construction costs over a number of years, and the artificial island will grow as the need for population relocation increases.

For the island to be habitable once the first modules are in place, each community must have its own resources, power generation and water treatment facilities, but with the ability to connect into a larger island-wide grid. This increases island resilience and achieves local diversity by integrating residential, social and commercial uses. Social stability and community spirit are promoted by increasing availability of local facilities and services. Flexibility should be built in to keep options open for future use, for example designing to meet changing housing requirements or different use of buildings.[17]

The modular approach simplifies maintenance as modules can be removed for major repair or disposal. The overall layout can be rearranged by moving modules around, and increasing island size with time will absorb long term population growth. Separation between modules benefits island flexibility and survivability. If a single module is badly damaged and sinks, the rest of the island should be unaffected. The shallow lagoon water depth should enable re-floatation and repair of the damaged module.

Concept Investigation

A number of different platform types could be applicable to the artificial island. Fixed platforms would provide a highly stable base on which to relocate the population, whereas floating structures may offer advantages in terms of cost, flexibility and survivability. To compare the options, a weighted matrix comparison was used to score some common platform types against critical design aspects. The scoring uses a 1-10 scale with 10 as the best score. Cost, design life, stability, seakeeping and survivability were determined to be the most important aspects and were therefore given high weightings. Fig 4 shows the platform comparison.[18]

Interestingly, although the fixed platforms score the most 10s, it is the mega-float option that scores the highest total. A mega-float is a very large floating platform, constructed from shallow pontoons. The reclaimed earth method has the second highest score, however to construct an island using reclaimed land, a large quantity of earth must be available locally, so this solution is not practical for the isolated island of South Tarawa.

		Fixed		Floating		
Criteria	**Weight (1-10)**	**Reclaimed Earth**	**Fixed Structure**	**Submersible**	**Semisubmersible**	**Mega-float**
Construction cost (volumes/simplicity)	10	4	5	7	7	10
Maintenance cost	10	8	5	5	5	6
Design life	10	10	7	7	7	7
Stability	10	10	10	9	7	8
Seakeeping	10	10	10	9	8	8
Survivability	10	8	5	5	8	8
Ease of transportation of structure	8	5	5	9	9	7
Ease of transportation of inhabitants	8	10	10	9	5	6
Modularity/flexibility	8	0	3	6	10	10
Wave induced loading	8	8	5	5	6	3
Tonnes per inch/Moment to change trim	8	10	10	9	4	8
Applicability to water depth	5	3	5	2	5	8
Freeboard (low assumed good)	5	8	8	8	5	9
Waterline changes with tide (assumed bad)	3	0	0	0	10	10
Totals		**819**	**749**	**774**	**772**	**857**

Fig 4: Platform selection weighted matrix[18]

A mega-float was selected for its flexibility and survivability, as well as cost advantages over fixed structures in water depths over 20 m.[19] Mega-floats can be cheaper and faster to construct than alternative offshore structures, and are less environmentally destructive than traditional land reclamation projects.[20] There are no earthquakes in Tarawa; however underwater earthquakes in the South Pacific sometimes generate tsunamis.[12] In the event of a tsunami, a floating structure is more likely to survive than a fixed structure. The main advantages of fixed structures are good stability and seakeeping performances; however these aspects are also expected to be very good for a floating island due to its large dimensions. A mega-float floating airport trial was conducted in Tokyo Bay with a 1000 x 60 m runway, as shown in Fig 5. The trial found that no significant movement was caused either by waves or the taking off and landing of planes.[21]

Fig 5: Mega-float airport project[21]

Concept Design

Layout

South Tarawa's current overpopulation is one cause of the low quality of life. To reduce population density the artificial island would need to provide a larger land area than currently exists in South Tarawa. However, with more efficient use of space, it is likely that a better quality of life could still be achieved even with a higher population density.

Community Layout

The concept island is divided into residential and strategic areas. Circular residential communities with a radius of 400 m would be ideal, as this is a recommended maximum distance to many local services (town centre, local services and employment). However, hexagonal communities were selected due to their ease of tessellation. Six triangular modules are combined to create a hexagonal community, as shown in Fig 6, and hexagonal communities are tessellated to create the artificial island.

The island is designed with 17 communities, each of 3,000 inhabitants, to accommodate the current population of 50,000. In each community, two green modules provide a food source, and are intended specifically for the production of local crops. The road layout provides a ringroad surrounding each community to prevent through traffic. Multi-modal transport options are promoted, with bus stops and cycle paths. To encourage the use of non-motorised transport, necessary trip lengths are minimised by providing local facilities and mixing land uses.[17]

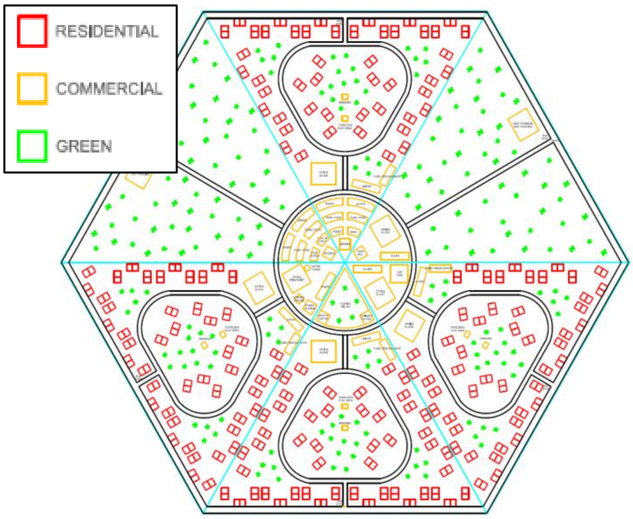


Fig 6: Hexagonal community layout consisting of six triangular modules

Module Layout

Houses are grouped in sixes to share services, and a village hall (locally known as a maneaba), park and playgroup are located at the centre of each housing module. The upper surface of each triangular block is given a slope for ease of piping and drainage, so the height of the module is 2% larger in the centre than at the edges. The highest point in each residential community is the centre, and this is where the water treatment works are located.

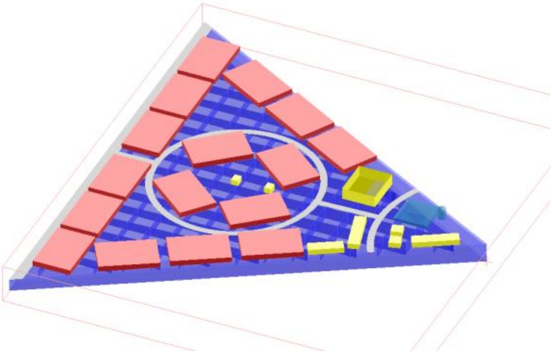


Fig 7: Triangular module design

A residential module was developed and is shown in Fig 7. Houses are grouped into red residential blocks (designed for 48 people), each containing six houses and assigned an appropriate weight to include house structure, contents, tanks and solar panels. Commercial blocks are shown in yellow, water treatment in blue and roads in grey.

The increase in platform depth towards the town centre requires additional structural material, so topside weights were placed closer to the outer edge of the town, to ensure a level waterplane. Service routes for water, electrical and data cabling were also planned.

Island Layout

Strategic areas include a political centre, holiday resort, port, hospital, airport, waste recycling and wastewater treatment centres.

The political centre contains Parliament buildings, the island control centre, communication masts, secondary schools and higher education, a fire station, stadium, post sorting office, prison, theatre, tourist accommodation, museums, larger shops and restaurants. The holiday resort is located close to the port and airport, but kept separate from residential communities. A commercial port and marina are separated, with the marina containing further tourist accommodation and attractions.

The island layout is given in Fig 8. The holiday resort, major entertainment and commercial spaces are located close to the centre of the island. The commercial port is also centralised to minimise transport distances for imported goods. The airport is built on a fixed structure close to the shore, where it can easily accessed by the current residents of South Tarawa. The airport may be relocated to floating modules as sea levels rise, and when there is a higher degree of confidence in mega-float structures.

The communities are arranged so that the majority of residential areas face either the sea or the political centre. The blue lines surrounding outer modules indicate edging modules in either the form of a beach or sea wall with guard rails. These modules protect the inner modules from erosion by sea loads, and also create a more natural island feel for the inhabitants. The edging can be detached and relocated as the artificial island develops.

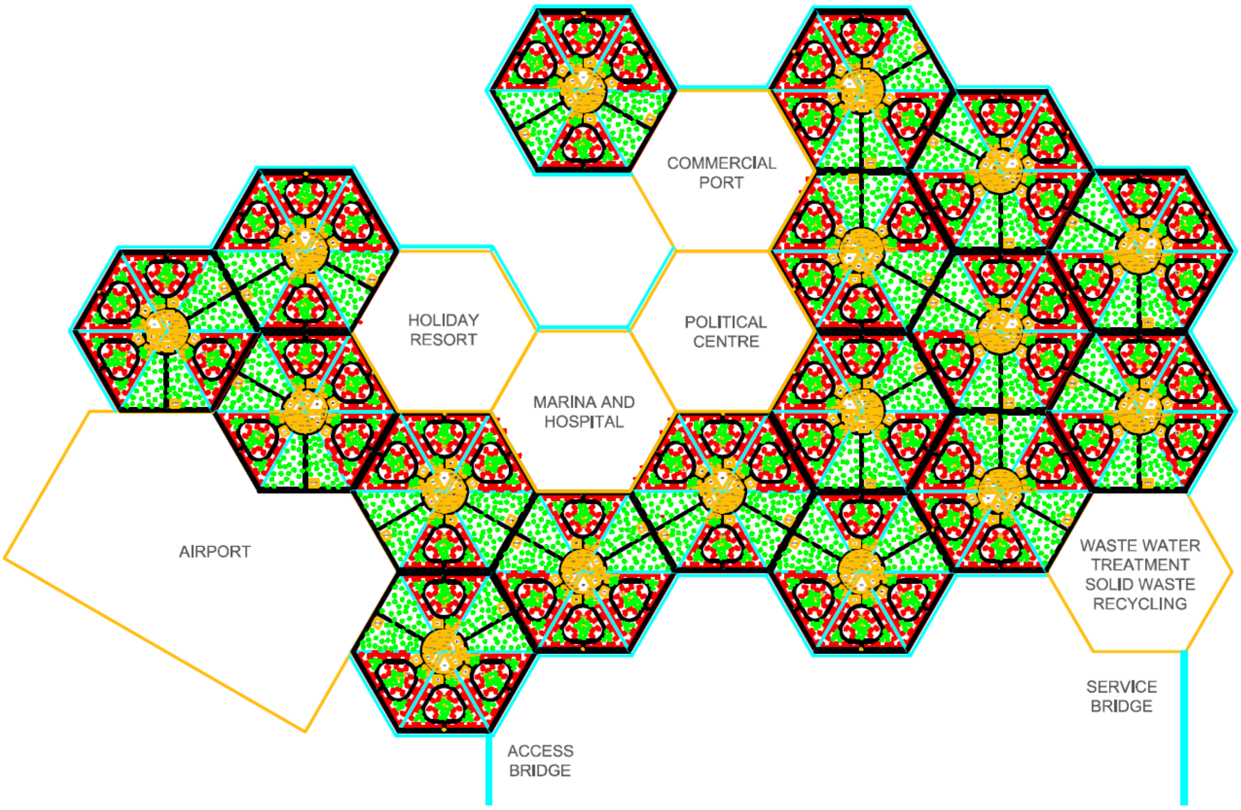


Fig 8: Island layout

A main access bridge leads to Bairiki, currently Kiribati's main administrative centre. A second bridge connects the waste treatment plant to the mainland. Waste treatment focuses on recycling and composting, thus reducing lagoon pollution, while residual materials can be used for energy generation. This part of the island is constructed early in the build sequence to serve South Tarawa's current needs, so is easily accessible from the mainland, whilst located on the outskirts of the artificial island.

The proposed design allows for a small gap between modules, with fenders to protect the structure, and connection lines and springs to prevent excessive separation or parallel sliding of modules. Separation allows each module to ballast itself, and any difference in loading condition between neighbouring modules should not cause issues. Flexible connections are recommended, so that loads are absorbed and not transmitted between modules. Also, rigid connections would have to withstand extremely large forces.

Energy Management

In 2012, the total (residential, commercial and industrial) electricity demand for South Tarawa was approximately 45 GWh.[22] An old power station at Betio provides 1.25 MW, and a new station constructed at Bikenibeu with Japanese government support provides 4.2 MW, giving a total of 48 GWh per year, just meeting the demand.[22] Small solar generation units are currently donated by the European Union to the Kiribati Solar Energy Company Ltd (KSEC) for use in rural areas on other islands in Kiribati.[23]

The electricity demand in South Tarawa has approximately doubled between 2008 and 2012 during which time the new power station at Bikenibeu started to provide electricity. However, per capita, it is still 25% of UK consumption, so it is likely that demand will continue to rise steeply (although a proportion of UK electricity consumption does provide space heating that is not required in South Tarawa).

For the concept island, a 4 kW solar PV system is proposed to serve every house. Assuming seven hours of daily sunshine and 17 communities comprising the island, the total residential generation is 66.6 GWh per year. The proposal meets the total 2012 electricity demand with a 50% margin, allowing for some future increase in demand. A 1000 kW diesel generator will provide emergency power for each community.

The artificial island design incorporates renewable energy generation and storage, and focuses on efficiency and conservation. Each community has its own energy generation and storage, but is connected to an island-wide grid. A main electricity grid connects all superstructure buildings, so that surplus solar energy from home generation will serve commercial energy requirements. Income from selling electricity to the grid should promote efficient energy use in homes. Also, smart-meters on appliances in houses can level out demand by committing to use energy when it is at a prescribed rate.

Through life costs were estimated for both PV solar panels and diesel generators. The solar panels have a significantly higher purchase cost (8.5 times higher than diesels). However over 30 years of use, a conservative estimate suggested that solar panels cost just over 10% of the through life cost of the diesels. It was calculated that the solar panels would pay back their capital investment within 3 years.

As Kiribati has warm and stable climate throughout the year, domestic heating is not required. A main gas line is therefore not necessary, as alternative methods are available for cooking and heating water. Domestic hot water can be provided by hot water solar panels, and the proposed systems are based on a 0.5 m^2 panel area per person, with appropriately sized water tanks.[24]

Solar generation is proposed as the primary electricity source, so a central control system and an energy storage facility are required to absorb the difference between supply and demand throughout a day. There are numerous methods for storing energy currently under development and in use, for example battery banks, flywheels and salt phase change. Another option is to divert surplus energy to carry out power hungry activities, such as charging electric vehicles, pumping water from lower reservoir to upper reservoir, desalinisation of saltwater or generating hydrogen.

A future increase in quality of life alongside industrial and economic development, will inevitably lead to increased electricity demand. It is likely that additional generation systems will be required before a module reaches the end of its life. Potential methods for renewable energy generation include constructing underwater turbines in the North Tarawa Channels to benefit from the tidal energy as seawater moves rapidly between the sea and lagoon;[25] or installing further solar PV systems. In addition applicability of an ocean thermal energy converter (OTEC) plant was also investigated.

OTEC makes use of the temperature gradient between warmer water at the ocean surface and colder water deeper in the ocean to power a generator. The temperature difference must be at least 20°C, so the cold water source must be located at an ocean depth of at least 1000 m. The water depth at the proposed location for the South Tarawa artificial island is 20 m, which is too shallow to incorporate an OTEC plant. However, sea depth drops to 3000 m within 20 nautical miles of South Tarawa, so a second artificial island could be constructed offshore to make use of this potential future technology. Based on an OTEC artificial island concept with over 100 MW generating capacity,[26] it was found that utilising OTEC as the sole method for producing energy is not yet commercially competitive with existing forms of sustainable energy generation, but shows great potential if issues with the extreme length of the cold water pipe design are resolved.

Water Management

Similarly to the energy management approach for the artificial island, the water supply, treatment, storage and distribution system focuses on conservation and efficiency. To minimise the water treatment requirement, potable and non-potable water are separated. The total water demand is estimated as 80 litres per person per day, and this is assumed to be half potable and half non-potable.

The average annual rainfall is high (approximately 3000 mm[1]), so the primary water supply will be from rainfall collection. Rooftop collection on houses supplies non-potable water, and potable water is supplied through a main distribution system.

Rainfall is extremely variable, so large storage tanks for containing untreated rainwater are necessary to ensure a continuous supply. Each community will have its own storage reservoirs, water treatment plant, and service reservoir tower to provide potable water. However, transfer of water between communities is possible to level out supply if necessary. Desalination of seawater will be an alternative during draught conditions.

The storage reservoirs can supply potable water for 500 days. Head for the distribution main should be between 30 and 70 m for fire-fighting purposes[27], so a 30 m water tower is provided. Medium density polyethylene (MDPE) pipes are used for all water distribution, as these are lower cost and more amenable to flexible jointing than metal pipes.

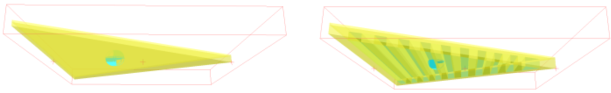
Greywater and blackwater are kept separate and piped into storage tanks, where they are collected and removed for treatment. The transformation from greywater to potable supply is technologically feasible and may be a future option.

Technical Assessment

The concept island was analysed to determine its stability and seakeeping performances. Environmental loading was assessed to design the concrete structure, the mooring systems and the connections between modules.

Concept Investigation

The structure of a mega-float can consist of a box shaped barge, a platform raised on pontoons, or an air-cushion supported platform. The pontoon and air-cushion options increase draught and decrease waterplane area, thus reducing wave induced loading. Four module options are displayed in Fig 9.



(a) Barge (b) Pontoons

(c) Large air-cushion (d) Small air-cushions

Fig 9: Mega-float model options

The main findings were that all options were incredibly stable due to their large dimensions; all had large displacements and large tonnes per inch immersion (TPI) and moment to change trim (MCT) values; and all were subject to large bending moments and shear forces.

The horizontal environmental loads were calculated using DNV guidance.[28] Inertia, drag and diffraction loadings were summed for each module option and large variations were found in the wave loading between the different hull structures. The calculated loads were highest for the pontoon structure and smallest for the air-cushion structures. The calculated wind loads are almost identical for the different hull options, and are <1% of the small air-cushion wave and current load.

Unfortunately the calculation of buoyancy distribution did not take into account the air-cushions due to software limitations. The wave induced bending moments calculated are similar for the air-cushion and barge models. However, research[19] suggested that air-cushion supported structures can significantly reduce structural loads, particularly wave induced bending moments. Drift forces are significantly reduced due to less distortion of the wave field (smaller wave diffraction loads). Mean roll and pitch responses are also reduced.

A significant advantage of an air-cushion structure is the ability to interconnect cushions and generate power from the oscillating air as waves pass through the structure.[19] This is similar to Oscillating Water Column (OWC) generation which is proven technology.

A small air-cushion supported mega-float was selected for the artificial island. This option allows the structural weight and therefore island cost to be minimised. Stability is not predicted to be an issue due to the large dimensions, and TPI and MCT are high. The internal space is not wasted as this isn't useful for the island, whereas the potential for energy generation is a large benefit.

Structure

Construction Material

A primary design aim is for the artificial island to be sustainable, so the choice of construction material and the associated resource use and impacts of disposal were considered in depth.

The choice of construction material for the artificial island must be reliable, use minimal resources, be easily repairable with low maintenance costs, and have a long design life. Steel and concrete were investigated, and concrete was found to have a number of advantages, most importantly its long service life and minimal maintenance requirement, so was selected as the construction material for all modules.

The total concrete volume required for the entire artificial island is 14.3 million m^3. To put this into perspective, the volume of concrete produced in the

UK each year is about 40 million m^3 [29], so the island would use 36% of UK concrete if it were constructed in a year. However, distributing the build over 44 years minimises the resource usage to less than 1% of UK production.

Building Strategy

The proposed build strategy is for a concrete manufacturer to continually produce modules, to spread costs over a number of years. If one triangular module is produced every four months, then every two years a hexagon is completed, and the entire island (22 hexagons) will take 44 years to finish. The structural design life is 70 years, so after 44 years the island can continue to expand if required until modules need to be maintained or replaced.

If construction is carried out at an existing manufacturer, the modules would need to be transported to South Tarawa. Transportation costs would be high, as modules are too heavy and too large to transport by current heavy lift ships, and are not designed to withstand large sea states so towing would be difficult. Options could be to sink each module and tow it underwater, thus reducing the wave loading, or to construct smaller sections and combine them on site. However in either case, all topside construction and outfitting must be carried out on site, requiring local construction facilities and skills. Therefore it is proposed to carry out all construction in South Tarawa, so that transportation of completed modules is not required. This will require major developments in local industry, but will ensure technology and skills transfer from developed countries and improve economical sustainability.

Structural Design

Wind, current and wave loading were estimated to design the structure, the mooring systems and the connections between modules. Values for maximum bending moment and shear force were calculated, assuming that wave loads are small or a breakwater will be constructed if necessary. The environmental loads calculated for the air-cushion structure were also applied.

A beam and slab concrete structure was designed to Eurocodes.[30][31] Concrete grade 55 and pre-stressed steel bars, grade Y1030, were used. The structure met DNV guidelines for concrete design[32], and water pressure was taken into account using Holand et Al.[33]

Basic reinforcement could also be used to simplify the construction process, but would require a larger steel volume. If B500A reinforcing steel was used, the area and hence volume of steel required would double. The structure was designed assuming slabs for the upper and lower box surfaces. If the solid slabs were replaced by ribbed slabs, then the structural weight and cost may be reduced.[33]

Mooring System

A spread mooring system was designed for each module using Barltrop's approach[34] Self-tensioning winches are required and high modulus polyethylene (HMPE) ropes were selected for mooring lines due to their potentially long design life, low maintenance requirement and high strength. Piled anchors are most appropriate as they are well suited to the shallow water of Tarawa Lagoon and should not need relocation. However, there will be an environmental impact due to drilling that needs to be further assessed.

Connections between modules

Rolling fenders were considered, to absorb horizontal loads and lower friction between modules. However, the chosen solution was to use fixed rubber fenders, with a thin laminate surface, to minimise maintenance requirements. For the connection system, fibre ropes are unsuitable because the connections are not kept in tension, wire is unsuitable due to corrosion issues, and so chains were selected. A load factor of 3 was applied to allow for potential uneven loading along a module edge.

End of Life Disposal

The estimated design life of a module is 70 years, after which it should be replaced or reused. Reuse could be an option if the topside and any other areas subjected to erosion could be replaced.

If a module cannot be reused, its disposal is expected to be difficult, due to the large volume of material. Landfill costs for concrete are high and rising rapidly, but recycling of concrete is becoming more economical. Concrete recycling is a relatively simple process which involves breaking and crushing the concrete into aggregate. Crushing equipment is available that can accommodate steel reinforcement. Depending on its size and quality, the aggregate can be reused in concrete construction, as erosion control or gravel, or in gabions.[35]

At the end of their design life, modules will need to be broken up and crushed on site. If it is high quality, the waste aggregate could then be used in the construction of replacement modules. It could also be used to construct sea defences and on beaches to reduce coastal erosion for other islands in Kiribati. The greatest challenge is likely to be physically breaking up the concrete structure, and it is recommended that new technologies and practises to aid this process should be investigated.

Stability

DNV regulations for Stability and Watertight Integrity[36], were applied as suitable to this type of structure. A wind velocity of 36 m/s (70 knots) is used for normal operating conditions and a wind velocity of 51.5 m/s (100 knots) represents severe storm conditions.

The heeling lever due to normal environmental loads is presented alongside righting moments for both light and heavy conditions in Fig 10 confirming that the stability criteria is met. The maximum wind heeling force was estimated as 2,850 MNm at 90° including a 20.5 MNm overturning moment caused by current.

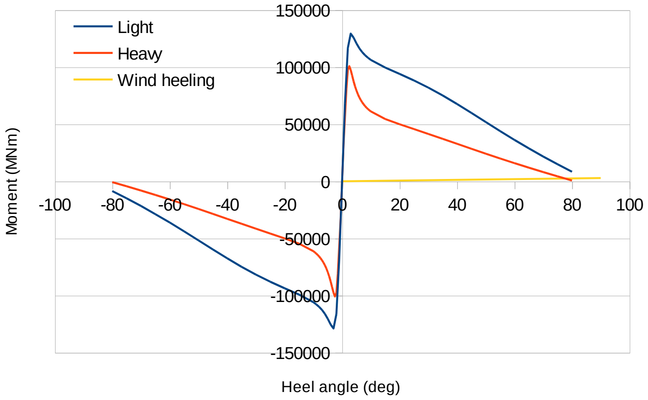


Fig 10: Righting moments and wind/current heeling moment

To cause a heel of 6°, a moment of 73,500 MNm must be applied to the platform. This is equivalent to a 37,500 te weight placed on the surface of the island at the furthest position from the centreline. It is highly unlikely that this event would occur under normal or extreme circumstances.

Motions Assessment

Platform motions for the artificial island are expected to be minimal due to the structure's large dimensions. However, mega-floats are very flexible compared to typical offshore structures, so elastic deformations are more important than rigid body motions.[21] Hydroelastic analysis should be carried out to determine the elastic deformations.

An advantage of spread mooring systems is that their natural periods tend to be considerably longer than the typical wave frequency range. A high level motion analysis was performed. The natural period of oscillation for a ship structure moored in 30 m water depth is 45 s.[34] The wave period on the ocean side of Tarawa atoll is typically 10 to 14 s, with shorter wave periods within the lagoon.[15] The natural period of the artificial island modules is expected to be significantly larger than that of the encountered waves.

Budget Estimation

A high level estimate of the weights and costs for one community (3000 people) is given in Fig 11. The total acquisition cost for one community (six triangular modules) including all superstructure and systems is estimated to be £874 million, neglecting the costs of developing infrastructure on South Tarawa, transporting the raw materials, and through life maintenance.

The cost of the concrete hull is estimated using Singh's method for costing concrete commercial buildings.[37] The material costs for concrete, steel and formwork are calculated separately, and total £295 million for a community. The cost to construct the concrete modules is estimated to be £382 million. Structural weight is a large proportion of the total weight (84% with empty tanks). This is beneficial because through life weight growth should have little impact on island draught and trim.

The total cost is estimated to be £874 million per community. If 17 communities and 5 strategic areas complete the artificial island, the total cost is £19.2 billion. If construction is spread over 44 years, the cost per year is £437 million. The 2012 official development assistance given to Kiribati was approximately £39 million, largely from Australia, Japan and New Zealand[38] so significant additional international support would be required.

Group	Margin (%)	Mass (te)	Cost (£million)
Structure	5	2,040,000	862.0
Inhabitants	10	13,200	2.8
Systems	5	353	7.1
Electrical Power	5	996	1.8
Variables	4	73,900	0
Community Total (light)		**2,050,000**	**874.0**
Community Total (heavy)		**2,120,000**	**874.0**
Island Total (heavy)		**46,700,000**	**19,200.0**

Fig 11: Weight and cost summary

Design Summary

102 triangular air-cushion supported modules are combined to produce 17 hexagonal communities, each with a radius of 400 m. Pre-stressed concrete modules are continuously constructed and fitted out on site. Each community is designed to be as self-sufficient as possible, but able to connect into an island-wide grid. Local photovoltaic and hot water solar panels provide energy, and rooftop collection and large storage reservoirs provide fresh water.

Environmental loads were assessed to design the concrete structure and determine the moorings and flexible connections required between modules. Large loads were calculated, so further analysis on large structures is recommended. Each module is highly stable and motions are predicted to be minimal.

Total island cost is £19 billion, with £15 billion for the concrete hull structure. If the island was constructed from steel instead of concrete, the structural cost would almost double. There is high financial project risk due to the new concept of a floating artificial island and the decision to construct on South Tarawa. On the other hand, Kiribati has a huge amount to gain by accepting the project, potential benefits including a strengthened economy, reduced lagoon pollution, and improved quality of life.

This artificial island concept design fully meets South Tarawa's requirements, and in some areas dramatically improves services, in particular water supply, waste water treatment, solid waste disposal and communications. Population density remains high, but with more efficient use of space a significantly improved quality of life can be achieved. The transition from South Tarawa to the artificial island will be gradual, so that traditional values and lifestyles can be respected and preserved. Costs were minimised for all aspects of this concept design, but the acquisition cost of the artificial island remains high. However, the artificial island is a long term solution and its sustainable design will enable economic growth of the country.

Conclusions

The nation of Kiribati is currently in a dire situation, and its problems are highly likely to worsen. Increasing levels of international aid will be required to maintain the population at its current standard of living.

This paper has demonstrated that an artificial island can be a feasible solution to accommodate the residents of South Tarawa in their home island. Its construction and population would require a large leap of faith by both the financiers and the inhabitants, but it has the potential to provide a range of economic, social and environmental benefits both for the population and for the country.

Alternative options could be to construct major sea defences, dredge the seabed to reclaim earth or ship earth to Tarawa Atoll, construct a platform over the island or raise all buildings on stilts, or abandon the atoll and relocate the population. All of these options would require significant financial input, but none could provide the same level of benefit provided by this sustainable island design.

This project has highlighted a number of interesting topics which could benefit from future research, in particular the analysis of loading and behaviour of mega-float offshore structures and air-cushion supported structures.

Technical Specification

Key Particulars	
Hull type	Air-cushion supported mega-float
Construction material	Pre-stressed concrete
Island area	9.15km^2
Maximum population density	7390
Island displacement	46,700,000 te
Draught	6.13 m
Cost (GBP)	£19.2 billion
Build rate	1 triangular module / 4 months
Build duration	44 years

Structure	
Concrete	Grade 55
Pre-tensioned steel	Y1030
Structural weight	84%
Mooring lines	65 mm dia high modulus polyethylene
Anchors	Piled anchors
Winches	2.5 MN self-tensioning winches
Fenders	Rubber with a thin laminate surface
Connecting lines	60 mm dia Grade 4 chain

Power and Water Supply	
Installed solar power (kW)	6528 x 4 kW
Emergency generator (kW)	17 x 1000 kW
Potable water	2142 (m^3/day)

Endurance	
Hull life	70 years
Capacity	51000 inhabitants
Fresh water endurance	250 days (with no rainfall)
Stores endurance	Continuous supply of limited farmed foods
Power endurance	30 years (design life for solar PV)

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