

UKU: CONCEPT TO CONSTRUCTION USING FLAX-FIBRE REINFORCED STABILISED RAMMED EARTH

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Abstract: Uku is a low-cost flax fibre-reinforced stabilized rammed earth walled housing system that has been designed for the rural Māori communities of New Zealand. In the year 2008, the first Uku house was built using local labour from the rural Māori community and is currently occupied by a local Māori family. Māori are the indigenous people of Aotearoa New Zealand. This paper will present the development of Uku from a low-cost, natural material concept, into a 90 m², two bedroom house located on the Southern shore of Lake Rotoiti, NZ.

Financial, geographical and legal obstacles to rural Māori land development, and the use of existing conventional housing solutions to overcome these obstacles has provided a sub-optimal housing outcome in terms of accessibility and appropriateness for rural Māori and their culture. At present a disproportionately high number of rural Māori live in sub-standard and overcrowded living situations.

The Uku research began in 1996 to develop an accessible, affordable and appropriate housing system for rural Māori. The Uku housing system has been developed to utilize locally available material resources, to be able to employ local community based labour and to equip rural Māori communities with the resources and knowledge to build their own houses independently using the Uku method.

The completed construction of the first Uku house has shown the cost of building Uku walls to be greater than equivalent timber framed walls. The construction of the Uku house was successfully completed and as more Uku houses are built, the affordability and constructability of Uku houses will improve. The Uku method's consideration of Māori culture and social values, the use of traditional and local resources, and the potential for Māori to provide their own housing, continues to attract increasing interest from Māori communities around New Zealand.

Keywords: *Rammed earth house, Uku, Flax fibre, natural fibre composite, rural housing*

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1 Introduction

This report describes the process through which a flax-fibre reinforced rammed earth housing method was developed, from a fibre earth composite material, into a 90 m² two bedroom house on rural Māori land at Haumingi 10a2b Papakainga; located on the Southern shore of Lake Rotoiti, New Zealand. The housing method was named 'Uku', one of the Māori words for earth. The Uku housing method was developed to address the difficulties and obstacles encountered when building with conventional housing methods on Māori land for the local Māori community. The Uku method increases the use of local resources, acknowledges Māori culture and traditions, and empowers the local community to provide their own housing solutions. A breakdown of the Rotoiti Uku house costs are detailed in Section 4.

1.1 The Māori people

Māori are the indigenous people of Aotearoa New Zealand (NZ) and migrated to NZ as early as 800 AD from Polynesia (Howe 2007). StatisticsNZ (2006) has indicated that there are approximately 96,000 Māori currently residing in rural areas of NZ (2.5% of the national population). Slightly more than 5% of the total land area in NZ remains in the control of Māori, but many rural Māori communities are unable to fully utilize 'Māori land' owned by their hapu (sub-tribe) to provide adequate housing and living conditions for their members.

1.2 Rural Māori Housing Obstacles



Figure 1: Photo of Māori land owned by the Waimango Papakainga Trust (Morgan 2005)

A report published by Housing New Zealand (2005) showed that a disproportionately high and unacceptable number of individuals living in rural Māori communities reside in overcrowded, substandard dwellings. Obstacles preventing the adequate provision of housing to members of rural Māori communities can be grouped into 3 areas: financial barriers, legal issues and the urbanization of Māori.

The majority of Māori land is remote which elevates the cost of development. A photo of Māori land under the guardianship of the Waimango Papakainga Trust is shown in Figure 1. In many areas, especially coastal, plots of Māori land are geographically isolated and in a natural undeveloped state. This is desirable because the land is, for the most part, untouched by human activity, but disadvantageous because it elevates the access costs and the overall cost of developing building infrastructure on Māori land to an insurmountable level. Machinery and building resources are expensive to access,

transport, and use, not just because of the distance, but because of other reasons including inadequate road infrastructure and a lack of access to amenities and utility networks (e.g. telecommunications, water and electricity). Given the extensive land loss in the past, further land alienation to generate the capital necessary for development is a highly contentious issue and not possible under the contemporary legislation for Māori land. Financial barriers are one of the main obstacles hindering rural Māori communities from utilizing their land to provide adequate housing for members of their community (Forrest 2007).

Legally, Māori land is owned by the local Māori hapu with historic ties to the land and is subject to specific laws in New Zealand (Te Ture Whenua Māori Act 1993). Māori land is collectively owned, often by over a thousand people spanning several generations and is inalienable. Lending agencies in New Zealand have been reluctant to deal with the complex and multiply owned nature of Māori land (Federation of Maori Authorities 2009). Managing building developments on Māori land is further hindered by the relocation of many owners into urban centres. These distant owners often have weak ties to their ancestral lands and lack the knowledge of genealogical links that are vital to understand in order to make progress towards a meaningful outcome (e.g. building a house).

The Māori population urbanized rapidly during the 1950's and 60's as a result of the Town and Country Planning Act (1953) that only allowed a single family that farmed each block of rural land to live on it. More recently rural Māori communities have been impacted by a second wave of urbanisation caused by the mechanisation of farming work that has reduced the number of jobs available in rural areas. Many Māori, particularly young unmarried Māori, have relocated into urban areas in order to secure work, earn money and live a more modern lifestyle. Before the Second World War more than 80% of Māori lived in rural areas. Today 84% of Māori live in urban areas (Meredith 2007). As a result, many rural Māori communities are depopulated and have a depleted local labour force. This has increased the cost of building on Māori land because technically-trained skilled labour has to be sourced from surrounding regions to fill shortages that have developed in the local workforce.

1.3 Māori Community Reference Group (MCRG)

A MCRG comprising of representatives from Māori communities and organizations was formed in 2003. Through a series of hui (meetings) five key attributes for a rural Māori housing method were identified (Morgan 2005). The development of the Uku housing method was guided by these key attributes:

1. Designs that required a minimum of input by professional engineers
2. A design-life of six generations or 150 years
3. Construction technology that can be adopted by a non-technical workforce
4. Construction technology not overly dependent on large complex machinery
5. Low cost easily transferable construction technology

2 The Uku Housing Method

A fibre-reinforced earthen construction method was chosen because it promoted the use of locally available resources. Soil, sand, flax fibres, and labour resources can be sourced from within most rural Māori communities. Earth as a housing material possesses several inherent advantages (e.g. long-term permanence of earthen structures, high thermal mass for indoor temperature regulation, and natural resistance to fire and insects). A mobile flax decortication device built in 2004 has provided the ability to process flax

sources in close proximity to the building site.

Most of the labour required to build Uku walls can be provided by non-technically trained labour. During the construction of the Rotoiti Uku house two unemployed 18 year old boys from the local whanau (extended family) were employed and trained onsite by the local accredited builder building the house. Employing and training the local workforce in this manner expands the available local expertise, benefits the local economy and strengthens relationships within the community.

Cultural needs and expectations can be better met by empowering Māori to provide their own housing. Māori have tikanga (practices) regarding many aspects of housing. All three Uku buildings that have been built so far have been named and blessed. Rules exist regarding the positioning of rooms in a house; the kitchen cannot be linked to a bedroom or a bathroom, and large living areas are needed to accommodate family gatherings. The identity of Māori is strongly associated with their ancestral lands. Using earth and flax resources from their ancestral lands to provide shelter for their family is a form of cultural revival, an acknowledgement of the indigenous knowledge possessed by their ancestors and a source of pride to the owners.

Structurally the building system comprises of three parts as shown in Figure 2:

1. A reinforced concrete slab with deeper footings beneath the walls
2. Cement-stabilized, flax-fibre reinforced rammed earth walls panels with a concrete ring beam cast insitu on top of the panels connecting them together
3. A Pacific gull-wing plywood diaphragm roof on exposed rafters



Figure 2: North face of the Rotoiti Uku house

3 Project Timeline

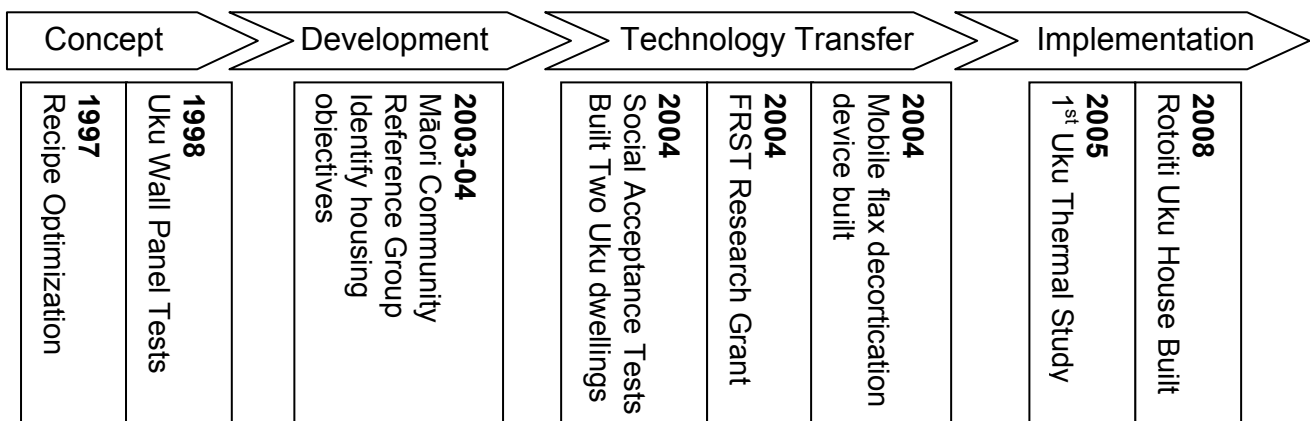


Figure 3: Diagram showing the development of the Uku method

The research has progressed through a number of stages as shown in Figure 3.

3.1 Conceptualization and Development

In 1996, a Māori research organisation secured seed funding to investigate the use of flax-fibre reinforced earth for housing. The Forest Research Institute was subcontracted to assist with the development and testing of the fibre reinforced earthen composite.

By 1997, recipe optimisation research for flax-fibre reinforced cement-stabilized cinva rammed bricks had been completed by Haab and Kingi (1998). The optimized mix consisted of 9% cement and 0.75% flax fibres (by weight) cut to lengths of 64 mm. Sisal fibres and the wet and dry treatment of fibres prior to soil compaction were also tested and revealed no significant influence on the material performance of the bricks.

The optimized mix was used to build a monolithic Uku wall panel 150 mm thick, 1.2 m wide and 2.4 m high in 1998. The wall panel was tested in a test apparatus for triple skin plywood shear walls. During the test, the apparatus failed before the wall panel and no strength value was obtained. Even without a final numerical result, the test showed the potential of using Uku as a structural building material.

3.2 Technology Transfer

A Māori Community Reference Group (MCRG) was established in 2003. After several hui (meetings), key desirable attributes of a housing method for rural Māori communities were specified. A Māori research organisation, Nga Pae O Te Maramatanga, funded the construction of two, 6 metre X 6 metre, single room Uku dwellings in 2004 to test the practical implementation and social acceptance of the Uku structures. The first Uku dwelling was built on rural Māori land on Waimango Papakainga (65 km southeast of Auckland, NZ). An onsite soil source (blended with local sand) was used but proved to be very time consuming and labour intensive. The second dwelling was built on urban Māori land in Otara, Auckland, and used soil from Lyons Quarry located in Waimauku, Auckland (Morgan 2005). The two dwellings demonstrated the positive social acceptance of Uku in the Māori community. The two dwellings were initially designated as a garage for a lawn mower and a laundry room but were changed by the owners into a music room and a meeting house / sleeping area respectively.

3.3 Implementation

In June 2004 the Foundation for Research, Science and Technology (FRST) awarded a research grant to develop the Uku method. The research had three parts:

1. To develop the technology for the earth fibre composite material
2. To optimise end-user adoption of the technology
3. To build full-scale trials

In 2004 a mobile flax decortication device was designed (shown in Figure 4). The machine enabled the fast and mobile processing of flax leaves into flax fibres (shown in Figure 5).



Figure 4: Mobile flax decortication device



Figure 5: Flax fibres after processing

Various structural tests were carried out to determine the compressive, flexural and shear strength of the Uku material through the Ngati Pikiaio Project Earth Building Composites Using Indigenous Fibres (2004), SCION Research (2005) and at the University of Auckland (2007, results shown below in Table 1).

Table 1: Summary of University of Auckland laboratory tests (Cheah and da Silva 2007)

Method of Test	No. of Samples Tested	Average Strength	95% Design Strength	Coefficient of Variance
Compression	33 Cubes	7.6 MPa	4.6 MPa	23.7%
Flexural	8 Beams	0.35 MPa	0.18 MPa	28.9%
Shear	3 Panels	0.73 MPa	0.52 MPa	17.0%

Thermal data was collected over the summer of 2005 on the Otara Uku dwelling and was input into a thermal simulation software package to predict the thermal performance of Uku walls over a range of wall thicknesses.

In 2007 the Rotoiti house design was drafted by architects, DesignTribe. The structural design calculations were done at the University of Auckland (da Silva 2007) and the building consent was approved in November the same year by the Rotorua District Council. The FRST funded Uku project concluded in March 2008 with the construction of a 2 bedroom house with an indoor floor area of 90 m² on the Southern shore of Lake Rotoiti.

4 Rotoiti Uku House Financial Analysis

During the construction of the Rotoiti Uku house, a builder's journal was kept for each working day. Each entry recorded the weather conditions, workers present, hours worked, and the work done. The journal allowed the labour and machine hours to be measured, and the rate of progress to be monitored. The total cost of construction including the foundation, walls, roof and fittings (windows, doors and a skylight) was \$84,900.

The construction of the concrete slab foundation and the timber roof were subcontracted out at \$14,000 and \$21,000 respectively. The window, door and sky light fittings (all double glazed) cost \$16,500. The financial details presented focus on the cost of building the Uku walls as they are the main variation from current conventional building practice. The Uku walls cost \$33,400 and are broken down into labour, machinery and material cost components in Table 2 below. A timber framed wall equivalent was estimated at a cost of \$19,900 (Rawlinson & Co. 2008).

The labour consisted predominantly of four local workers; a skilled builder, two non-technically trained young adults and the house owner. Under the guidance and training of the experienced builder, the other members of the team were able to provide the majority of labour required during the construction of the Uku house.

Three pieces of machinery were used when building the Uku walls:

1. A compact loader (Bobcat shown in Figure 6) – to mix, transport and lift the soil
2. An air compressor (shown in Figure 7) – to operate the backfill tamper
3. A backfill tamper (shown in Figure 7) – to compact the soil in the formwork



Figure 6: Compact Loader mixing soil



Figure 7: Air Compressor and Backfill Tamper

The use of machinery enabled the construction of a 2.4 metre high Uku wall (up to 2.2 metres long) to be built within an 8-hour working day with a workforce of four people. By reducing the number of people on-site and the amount of work required, time was saved, costs were reduced and a safer working environment was created. The costs realised during the Rotoiti house construction are listed below in Table 2.

Table 2: Costs incurred during construction of the Rotoiti Uku House

		Unit	No.	\$/unit	Cost	Total
Labour		hrs	904	15.00		13560
Machinery	Bobcat & Compressor	hrs	86	115.00		9890
Materials	Bond beam (shutters, concrete)	m	58	42.50	2465	
	Reinforcing steel & Fasteners				1276	
	Shadow clad timber walls	m2	12	201.00	2412	
	Soil	m3	21	45.00	945	
	Soil Transportation	km	3	310.00	930	
	Cement (40 kg bag)	each	77	18.00	1386	
	Flax	kg	21	25.00	525	9939
Subcontracted Work	Foundation				14000	
	Roof				21000	
	Fixtures (windows, doors, skylight)				16500	51500
TOTAL						\$84889

5 Discussions of Costs

5.1 Rotoiti Project Soil Costs

The soil costs incurred during the project are particular to the Rotoiti Uku construction. The earth material used for the house was sourced from Lyons Quarry, Auckland (310 km from site). Five suitable soil sources were identified from local quarries, however due to resource consent conditions for the quarries, none of the local soil sources identified could be used. As a result, the Lyon Quarry soil source (used for past Uku walls built at the University of Auckland) was used. Future Uku buildings will use local soil sources.

5.2 Optimisation of the Building Process

During the construction period, ways to optimise the construction process and save costs were identified. The Rotoiti house was built using one set of formwork and four labourers. Wall construction progressed at one Uku panel a day. There is the capacity to build 2 to 3 wall panels at a time (each day). The air compressor used is able to support three backfill tampers simultaneously (only one was used). Similarly, one compact loader bucket contains enough soil material for 2 to 3 layers of rammed earth but only one panel was rammed at a time. Further improvements could be achieved by improving the structural detailing and floor plan design of the house. Only one Uku wall panel can be built per day per set of formwork (due to curing). A 200 mm long wall and a 2000 mm long wall effectively require the same amount of time to build. Future Uku houses will be designed to make better use of the modular wall lengths available.

5.3 Sweat Equity

The upfront cost required to secure a loan to finance the construction of a house is an obstacle that brings many ideas of home ownership in rural Māori communities to an end. The Uku method provides a way for the owner/s to provide a larger deposit on a house loan by incorporating the value of labour provided during construction and the value of materials provided from the land. For the Rotoiti Uku house, the cost of labour, earth material and flax fibres was \$16,000 (19% of the total house cost). Using the sweat equity concept the owner/s would be able to supplement their initial monetary deposit for the loan with the non-monetary owner provided costs that would otherwise be incurred for the house. Once an agreement has been established with a lending agency regarding home loans with a sweat equity component, many more rural Māori communities will be able to secure a house loan and become house owners.

6.0 Conclusion

The construction of the first Uku house (2 bedrooms, 90 m²) on the Southern shore of Lake Rotoiti in 2008 is a key milestone in the development of the Uku method. The Rotoiti house has demonstrated that the Uku method can be built using local resources and labour. The method continues to be developed toward the goal to achieve the key objectives of a rural Māori housing solution that were identified at the beginning of the research process by a Māori Community Reference Group.

The Rotoiti house cost \$84,900 to build (39% attributable to the Uku walls). During construction, methods of optimizing the construction process were identified such as incorporating the modular construction system dimensions when designing the floor plan and to make use of the existing capacity to build more than one wall panel at a time.

As more Uku houses are built, the method will continue to improve. In turn this will result in a more affordable building method and a better housing situation for rural Māori.

7.0 References

- CHEAH, J. S. and R. DA SILVA, 2007. Material Testing of Flax-Fibre Reinforced Rammed Earth. Auckland, The University of Auckland.
- DA SILVA, R., 2007. Uku Calculations. Auckland, The University of Auckland.
- FEDERATION OF MAORI AUTHORITIES, 2009. Maori land. Retrieved 19 May, 2009, from http://www.foma.co.nz/about_maori/maori_land.htm.
- FORREST, G., 2007. Relevant Government Policies and Programmes for Maori Living in Rural Areas: HOUSING. Retrieved August 18, 2007, from <http://www.maf.govt.nz/mafnet/ruralnz/people-and-their-issues/social-research-and-welfare/programmes-for-ruralmaori/maorprog-12.htm>.
- HAAB, G. and R. KINGI, 1998. Fibre reinforced soil-cement composite. Recipe optimisation. *Earth Building Composites Using Indigenous Fibres*, Forest Research Institute.
- HOUSING NEW ZEALAND, 2005. Building the Future: The New Zealand Housing Strategy, Housing New Zealand Corporation.
- HOWE, K. R., 2007. Ideas of Maori origins. Retrieved March 27, 2008, from <http://www.TeAra.govt.nz/NewZealanders/MaoriNewZealanders/IdeasOfMaoriOrigins/en>.
- MEREDITH, P., 2007. Urban Maori. Retrieved March 27, 2008, from <http://www.teara.govt.nz/NewZealanders/MaoriNewZealanders/UrbanMaori/1/en>.
- MORGAN, T. K. K. B., 2005. Construction workshop with Uku Harakeke reinforced Soil Cement Buildings. *Tihei Oreore Monograph Series*, 1, pp.85-107.
- MORGAN, T. K. K. B., 2005. UKU - Fibre Reinforced Earth Composite For Indigenous Housing Solutions. *EarthBuild 2005*, Sydney, University of Technology Sydney, 19-21, pp. 119-39.
- RAWLINSON & CO., 2008. *Rawlinson's New Zealand Construction Handbook*. 12th ed. Auckland: Rawlhouse Publishing.
- STATISTICS NZ, 2006. Quickstats About Māori. *Census 2006*, StatisticsNZ.
- TE TURE WHENUA MĀORI ACT, 1993. New Zealand Government.
- TOWN AND COUNTRY PLANNING ACT, 1953. New Zealand Government.