ENVIRONMENTALLY-CONSCIOUS SOCIAL HOUSING IN CYPRUS USING RECYCLED ISO SHIPPING CONTAINERS; THE DEVELOPMENT OF AN OPEN PREFABRICATION SYSTEM

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ABSTRACT

The paper describes a proposal for low-cost, low embodied energy, passively-cooled social housing in Limassol, Cyprus, using a simple universally available open prefabrication system.

This construction system, using redundant shipping containers, has already been developed by the author. It could be more appropriately described as a system of mass-customisation; the proposed pilot scheme is not viewed as a finished product, but as a continuously negotiated collection of products and their accommodation.

The system strategies, with regard to the choice of materials and their consequent transportation, its simple construction method and very short time of erection, and its provision for recycling and minimum waste, are inherently sustainable. Via the introduction of bioclimatic design strategies, the system provides an excellent solution for energy conscious affordable housing.

The paper describes the further development of the construction system by its application to the specific cultural, economic and climatic contexts of Cyprus. A series of possible strategies are proposed and evaluated climatically and one integrated pilot scheme is then developed in further detail.

This study is propositional; it does not intend to present a finalised design but rather work in progress that creates scenarios to allow further testing. The methods outlined herein allow the identification of possible configurations; a series of suitable types or options that could be further evaluated.

The proposal is both intrinsically site specific (developed/tested for Cyprus) and yet universal.

Keywords
Environmentally-Conscious Architecture, Innovative Prefabrication System, Passive Cooling/Heating Strategies, Shipping Containers

INTRODUCTION

Bioclimatic Architecture is place-driven, developing its solutions from a reading of climate deriving place at a number of scales. The prefabrication system previously developed by the author consists of elements and technology that are universally available, yet because it is an open system it has the capacity to vary locally, depending on conditions of manufacturing and assembly, related to availability of materials, labour and servicing. It was hoped that it would also be able to adapt to differing climatic conditions in a similar way.

The system utilises standard, 'twenty-foot' shipping containers as the basic module and the logistics for these are based on the existing vast shipping infrastructure. There are currently some 20 million redundant shipping containers worldwide. Containers are functionally rich systems: they are manufactured from corrugated steel sheets and a steel profile frame; built to exacting standards; exist in various standard sizes; provide structure and skin at the same time. In addition, containers are ubiquitous, thus transport costs are low; they are redundant, so really they have no new embodied energy; they allow the possibility of further recycling; their skins can be readily cut, so they are adaptable, and finally they are structurally independent and capable of being self-supporting to a height of 7-8 storeys. All these characteristics make containers an attractive component to use for a creative, low cost, energy efficient architecture. The only real challenge is their lightweight construction, which creates difficulties in making a low-energy in-use solution, particularly in warm climates. Overcoming this deficiency is one of the main aims of the Cyprus based pilot project.

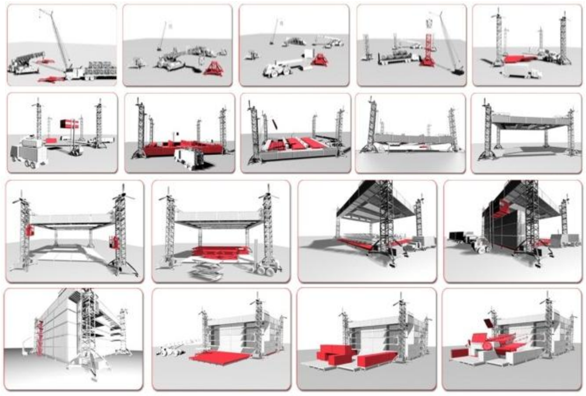


Figure 1: Proposed construction process –based on the existing shipping infrastructure

BACKGROUND / THE DEVELOPMENT OF AN OPEN PREFABRICATION SYSTEM

The open prefabrication building system is the culmination of the author's accumulative research towards a technologically inspired, instrumental architecture against the tyrannies of form and obsessive value in imageability.

Instrumental architecture aims towards a 'superlative of capability' which contradicts the reductive nature of functionalism, as functionalism approaches the idea of purpose quite narrowly. Primarily it is important to acknowledge that everything is a tool for something; utility is fundamental. What distinguishes various ways of understanding architecture depends partly on the character and quality of one's appreciation towards utility. For a truly instrumental architecture function should transcend the narrow range denoted by need and attain the flexibility of desire; not the personal desire imposed by the architect, but rather an empowerment to the user to enforce his.

The container construction system was gradually developed via a series of pilot projects using the prototypical parts of the system. Constituted by elements and technology that are universally available, it could be applied anywhere because it is not unique. The mobility of the system can be achieved by its replicability. Time is treated as a design element and the necessity of change becomes a value, which has been built into the thinking of the project.

Consequently the proposition consists of a kit of catalogue parts; it's an open prefabrication system approach. A building is not delivered complete but instead has great degree of variance and flexibility. More specifically there are two kinds of parts in the system: Pieces of a catalogue (some of them special parts) and stuff made locally. It could be more appropriately described as a system of mass-customisation.

The proposed scheme is not viewed as a finished product, but as a continuously negotiated collection of products and their accommodation. Customisation is not exhausted in the initial purchase of the products but continues through transformation of the initial choice through the many possibilities and requirements. Key to this exploration is the relationship of actual and experiential construction. The instrumentality of the proposition is a result of the aforementioned characteristics of the system.

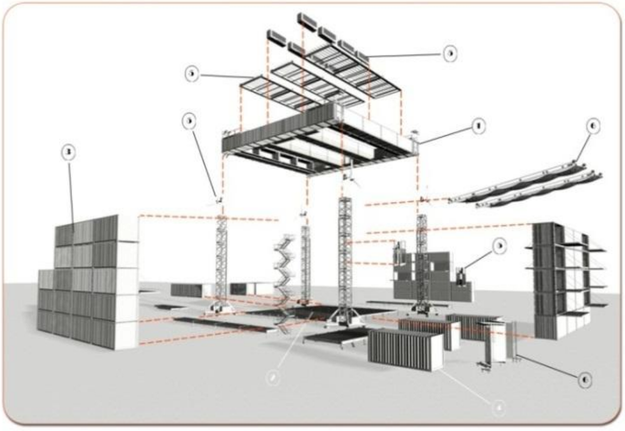


Figure 2: Open prefabrication system components.

Initially no specific site was used for the development of the system. In fact this was one of its strongest driving forces and strategies. ‘Site’ was considered as ‘climatic context’, a spectrum of climatic modifications and consequently solutions/options for them. These generate several ‘types’ responding to certain climatic issues. This specific potential of the system has been developed further via the pilot scheme presented in this paper. This study is an attempt to contextualize it for the first time by its application to the specific cultural, economic and climatic contexts of Cyprus.

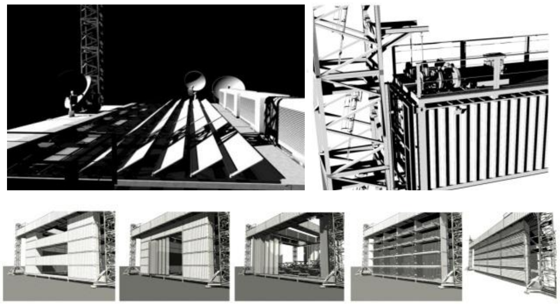


Figure 1: Climatic types/components

PROGRAMME / AFFORDABLE HOUSING

The construction system is suitable for the development of retail space, public space, small scale workspace, live-work and affordable housing. Through the interweaving of these different programmatic agendas a temporary appropriation of space and technology was explored; one informed by the particular needs and characteristics of the chosen context. For the pilot scheme presented in this paper the chosen programme is affordable social housing.

The development of housing accounts for the largest percentage of the building economy of Cyprus. The cost of entry to home ownership continues to rise so there are economic and social pressures to deal with the issue of low-cost prefabricated dwelling construction. Land values have increased since the country entered the EU. The normal trend in Cyprus to build one-off family houses is no longer cost-effective, but rents have also increased considerably. These trends, together with the current economic crisis have made it very difficult for first time buyers to afford any property. Developers have taken over the construction industry and as a result new housing developments are typically generic and poorly suited for specific needs. In general there are only a few basic prefabricated construction systems currently in Cyprus and their use is very limited.

Over the past fifty years architects elsewhere have experimented with the idea of prefabrication and modular dwelling construction yet most attempts to bring such systems to market have not been very successful. The ISO shipping containers building system is considered to be suitable as a low cost prefab option for dwellings, because it uses an existing industry that has already solved the issues raised by previous attempts, such as mass production, qualified labour, quality assurance, longevity and weather-tightness. Additionally a management and procurement structure would ensure that it is a cost effective alternative to traditional piece-by-piece contracting. Precious production management time can be saved, technical compatibility and continuity ensured. Eventually labour costs can be reduced significantly.

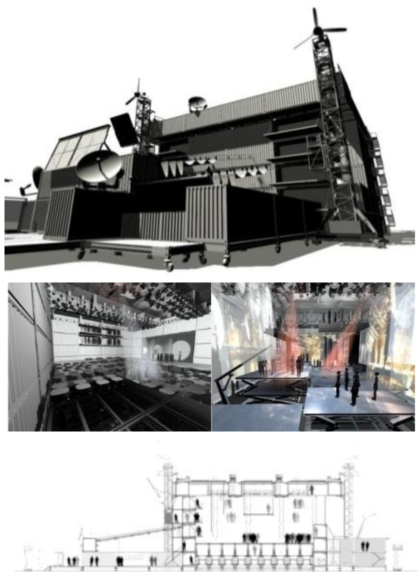


Figure 2: Actual vs. Experiential construction; a performance building pilot project.

While the construction system is suitable for various land use timescales, for the current pilot scheme an assumption was made towards a medium/long term land use. Certainly this doesn’t mean that the system loses its inherent qualities of deployability and relocatability.

PHYSICAL/CULTURAL CONTEXT

Cyprus as the chosen context / suitability

Since the Republic of Cyprus entered the European Union, it has been undergoing a crisis of conscience. As far as environmental issues are concerned, it did not meet European standards, although it has made some efforts towards a more sustainable future.

Up until 2011 Cyprus did not have any known energy resources of its own, therefore more than 95% of the total primary energy is imported to the island (fossil fuels imports, predominantly oil). In 2011 considerable amounts of natural-gas have been discovered off the coast of Cyprus, but as investigations are currently taking place it is difficult to draw concrete conclusions about the energy future of Cyprus.

Most recently-built buildings are poorly constructed from an environmental point of view and the use of mechanical cooling in particular is rising steadily, resulting in very high energy consumption. Most houses are constructed with a reinforced concrete skeleton, perforated terracotta bricks infill walls and rendered surfaces. Up until 2010 there was no additional insulation. Domestic water management is also poor, in a country where sometimes periodic droughts lead to water rationing.

The government of Cyprus is increasingly employing various policies for energy conservation in line with EU targets. Cyprus’ 2020 energy targets are to generate 13% of the gross final energy consumption from renewable energy sources and reduce greenhouse (GHG) emissions by 5%, compared to the 2005 levels. A series of financial incentives have been employed in the form of government grants and subsidies for the promotion of investments in the field of energy saving and energy production from renewable energy sources. Furthermore regulations for minimum energy efficiency requirements for new buildings have been enforced since the end of 2007. From 2012 all buildings constructed or refurbished should comply with the minimum energy performance requirements at building permit submission stage. This energy classification system for buildings operates via an official software assessment tool. Although this is a positive step, the whole procedure is still at embryonic stage with a lot of limitations.

Climatic Analysis / Suitable energy strategies in Cyprus

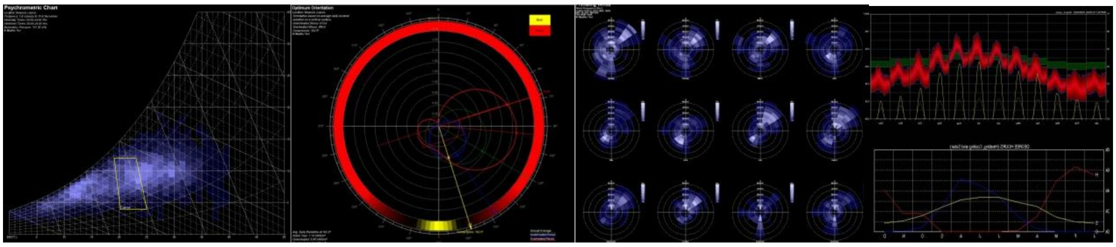


Figure 5: Limassol, Cyprus – Climatic analysis summary from EcoTect software.

- *Climate- Heating/Cooling:* Climatic analysis has been performed at Micro-Meso-Macro scales. Located at 35^0 North, 33^0 East, Cyprus has a typically Mediterranean climate, hot and rather dry, with rainfall mainly between November and March. Therefore it requires both the heating (December, January, February and March) and cooling (June, July, August and September) of buildings. Throughout the design process the aim was to maximise heat gain in winter and minimise it in summer, and to encourage heat loss in the summer and limit it in winter.
- *Humidity:* Humidity may be described as average to low (65 to 95%RH) during winter days and at night throughout the year.

Figure 6: The chosen pilot site
The site is a strip of land stretching along the main road from the port of Limassol, in close proximity to the sea. It is surrounded by a few warehouses and scattered houses to the North and to the South the site faces the port. It presently functions as a dump. The site is fringed with reedbeds, gravel pits and saltmarsh and thus features great seasonal changes. A new commercial development and a new arterial road construction in proximity to the site are expected to re-charge the area.

- *Comfort zones:* Existing research into thermal comfort (Using the psychrometric chart) concluded that, the proposed comfort zone limits of Cyprus are an average of 19.5°C – 29°C temperature and 20-75% relative humidity. The best thermal comfort is achieved in the months of April, May, October and November, with no extra heating or cooling. However certain variations are observed locally with different regional climates.
- *Wind/Wind Power:* In terms of wind Cyprus has an island climate with daily breezes that can get strong in the afternoons. It is usually calm at night. The prevailing wind direction is westerly or south-westerly and there are occasional easterly gales in the winter. Generally surface winds in summer are north-westerly or northerly. Winds are usually of light or moderate strength. Over the island of Cyprus winds are quite variable in direction due to orographic influence. Marine influences give cooler/more humid summers and warmer winters near most of the coastline and experience higher winds due to anabatic and katabatic flow (onshore wind during day, offshore during night). Two small-scale wind farms have been realised in Cyprus however local wind speeds are not the optimum for fully exploiting wind energy. It is therefore difficult to apply

domestic scale wind generators, so this study has not incorporated their use.
- *Solar Power:* Cyprus is the largest per capita solar energy user in Europe. Ninety percent of houses and a major percentage of other buildings are fitted with solar domestic water heaters. Cyprus in fact earned the "World Renewable Energy Congress Trophy," for years 2006-08, awarded by the International Energy Agency (IEA) for the highest per capita installed solar collector area of $1m^2$ per person. The latitude of Cyprus and its resulting high solar intensity of solar radiation make this technology very effective: Cyprus has well over 2,500 hours of sunshine per year.

PROPOSITION

Methodology

This paper is propositional: it does not intend to present a finalised design but rather work in progress that creates scenarios to allow further testing. The methods outlined herein allow the identification of possible configurations; a series of suitable types or options that could be further evaluated.

To test the overall strategy, a part of the site was taken and a design developed for it. This solution is paradigmatic in the sense that the strategies and design solutions developed could be adapted and applied across the whole area and of course elsewhere. The proposal is both intrinsically site specific (developed/tested for Cyprus) and yet universal.

Passive environmental strategies

The following passive environmental strategies for Cyprus were considered:
-*Shape/Orientation/Site layout:* The buildings are sited in such a way as to improve the microclimate. The longer axis of the scheme is East / West. It actually follows the South-East orientation of the site which is very close to the optimum orientation for the chosen context. The predominant wind patterns and sunpath determined the landscaping for buffering, shading and cooling. Windbreaks in the landscape and wing walls on the envelope of the dwellings can be used to change the air pressure around the buildings and channel wind to aid cross ventilation.
-*Direct Gain /Adequate Thermal Insulation:* With adequate insulation, it is possible to rely totally on direct gain to heat the dwellings.
-*Thermal Storage:* Because of the large diurnal temperature swing in Cyprus then the effect of thermal mass becomes more important. With the proposed lightweight construction system this strategy is achieved using non-structural alternatives.
-*Glazing choice/ amount etc:* Low emissivity double-glazed argon-filled, as a default choice. There is a huge variety of glazing products available in Cyprus, therefore better solutions with improved U-values could be chosen depending on budget.
-*Solar Control/ shading:* By use of orientation (adequate solar radiation in winter) and external shading devices.
-*Clever use of vegetation/ water (modulation of the microclimate of the building).*
-*Natural Ventilation:* By exploitation of breezes, use of cross ventilation, stack effect, night ventilation, fans. If there are no breezes then fans can enhance natural ventilation and cover the cooling needs.

The following requirements of building form specifically for the Mediterranean climate type were addressed and introduced to the scheme:
-Shading is of greater importance than ventilation (hot and dry climate).

-Typology: building around courtyards to provide ventilation and shade. Solar protection can be increased by the mutual shading of buildings. The distance between buildings is critical to avoid direct solar gain in the summer and enable it in winter when it is required as a passive heating strategy.
-Windows on west /east sides are minimized (to reduce heat gain in the summer). Auxiliary rooms act as thermal barriers.
-Moderate area of south wall with controlled shading devices to glazed areas (to allow winter heat gain).
-Moderate surface area (to control heat gain).
-Radiative cooling can be effective but there is additional cost, so simple strategies have been tested within the scheme.
-Ambient cooling sinks that can absorb the indoor heat build-up were tested.
-Colour (internally colours to reflect or absorb the solar radiation as needed. Externally lighter colours to reflect excessive direct insolation in the summer).

SYSTEM COMPONENTS/TYPES

Established bioclimatic principles of Passive Solar Design were adapted and appropriated as integral components of the container open prefabrication system. These principles have been used to create strategies for passive cooling/heating. The resultant configurations/types are listed in the following figures:

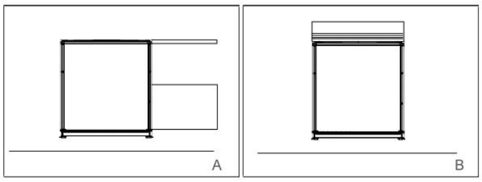


Figure 7: A. Verandas/cloisters/loggias create microclimates. Coverings to the balconies and large glazed areas below are designed so as to admit the winter sun, but to prevent it from entering in summer. The overhangs direct the cooling breezes towards the opening. Generally these various intermediate spaces in the scheme create microclimates which act as indispensable features of the project both environmentally and socially.
B. Green roof (shallow containers stacked on base container). Captures precipitation and uses the water to grow plants. Provides additional insulation.

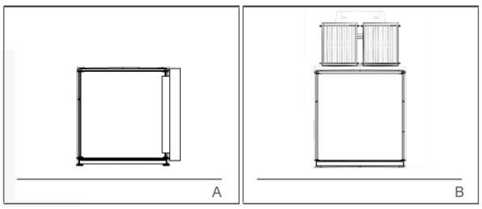


Figure 8: A. Add on vertical windows at the West side have been designed to only get some direct winter sunlight in the afternoon (3-4 pm) and the ones at the East almost no direct summer morning sunlight.
B. Solar water heaters fixed on container corner connections. A standard interface base is designed to work with standard solar water heaters dimensions.

Figure 9: A retractable louvre system of photovoltaic panels could be used on the roof in-between the containers, to generate power and for extra shading to the living space. The same module could be used at the perimeter container walls as retractable shading devices.

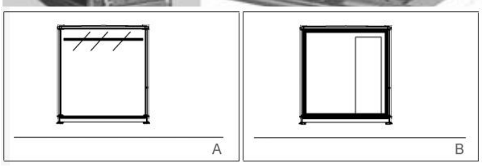


Figure 10: A. Using the metallic roof of the container as nocturnal radiator with daytime movable insulation (shutter closed in day, opened at night).
B. Water Wall (Could be used to overcome the lack of massive construction) - Either in Mass, Trombe or Remote storage configurations – these can be very efficient as water has double the heat capacity per unit volume compared to concrete.

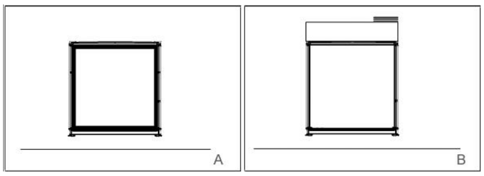


Figure 11: A. Progressive insulation: Polyurethane spray foam that is non-toxic, offers energy savings over standard insulation.
Weatherproofing: Winter heat losses can be restricted by adequate detailing. Sealing the gaps in-between containers at the envelope of the structure can be easily achieved using either pneumatic seals (seal inflated with air and conforms to the adjacent surfaces/very efficient performance) or normal rubber seals.
B. Roof ponds (shallow containers stacked on base container). The heat accumulated in a building during the day is trapped and stored in the roof pond, which is protected on the outside by movable insulation. At night, the insulation is removed to allow the stored heat to be radiated towards the sky (this is useful for cooling spaces in contact with the roof).

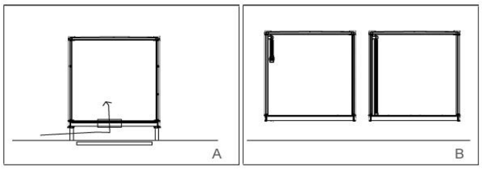


Figure 12: A. Containers elevated on jacks / Wetted surface underneath / Evaporative cooling / Cooled air enters via floor - Grey water system. Reed bed system incorporated into existing landscape.
B. Retractable internal insulating screens / curtains.

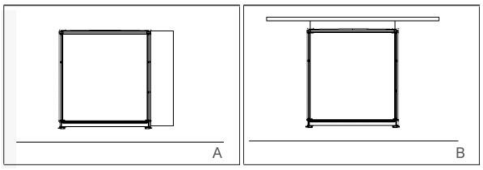


Figure 13: A. Thermal mass exo-skin (Sand/ water filled shallow container fixed on base container). This is of particular significance for the Cyprus climatic conditions, due to the characteristic of large diurnal fluctuations (5 to 25 degrees Celsius) and the potential inherent in mass for large solar contribution in winter and cooling in the summer night.
B. Exo-skin. Shading devices that can be stacked on the container. Properly angled canopy slats for appropriate winter/summer insolation. All types of solar protection proposed allow airflow through them, to avoid overheating and encourage ventilation.

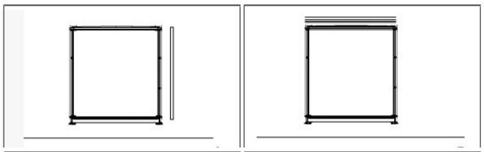


Figure 14: A. Reduction of glare provided by perforated screens, preferably placed externally so that most of the sunlight can be reflected before it reaches the glazing. The aim is to minimize unwanted solar gains but not to darken living space and force occupants to use artificial lighting.
B. Reflecting surface, necessary for the reflection of the almost vertical summer sunrays.

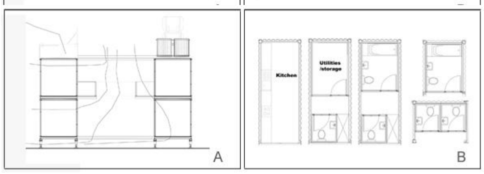


Figure 15: A. The containers are used as building blocks to frame larger spaces between. This is to ensure that the living space is not limited to the container size. Containers are strong enough (after stacking themselves up) to support additional structure in-between them. A double-height living space in the centre contributes to natural ventilation by stack effect. Hot air rises to the upper floor so that bedrooms are kept warm in winter. In summer the hot air can escape via openable parts of the roof.
B. Each container is fitted with the fixtures and furniture for each programmed room (kitchen, bedroom etc). A series of wet containers are used for different kitchen/WC/bathroom configurations. This is not complete prefabrication, but rather each container can offer infrastructural provisions that will allow the inhabitants to develop their own habitation/occupancy patterns and style.

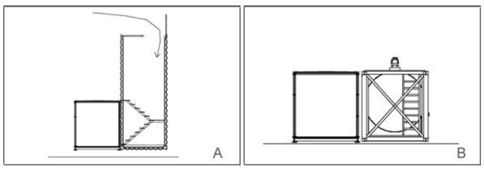
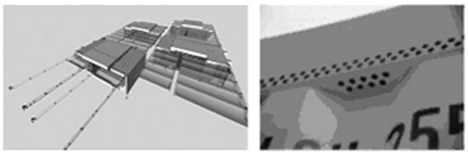


Figure 16: A. A container positioned vertically supports the staircase and also functions as a wind tower. It is located at the west side to catch the summer winds which are then distributed in the building. It is 6m high and it has an opening at the top designed in such a way as to channel the air downwards. This air passes over the



spray of a fountain which cleans and cools the air. In winter the opening can be closed.
B. Standard tank container as a water cistern, used as a heat sink (inter-seasonal heat store), shared between dwellings.

Figure 17: A. Fabric awnings are very efficient in hot places and can be used as part of the system to shade individual courtyards or public space between various dwellings, thus changing the microclimate.
B. Background ventilation from standard 'ventilated containers'. Ventilation provided by openings in the top and bottom rails. The openings are designed to not let in spray, so they would be ideal for this project.

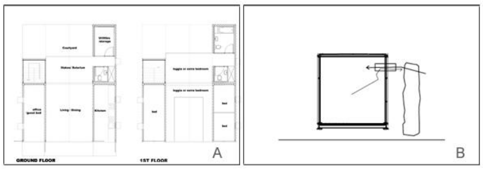


Figure 18: Also the following techniques used very effectively in traditional Cypriot architecture have been introduced as key passive design strategies.
A. The *Solarium (Iliakos)* is a predominant climatic element acting as an intermediate space between the building and its microclimate. It enables solar radiation to be utilized in winter but it also acts as a shaded external space in the summer. *Courtyards*, planted mostly with deciduous vegetation provide shade in the summer and admit the sun and act as buffers in the winter. In multiple thermal modes and design configurations, the courtyard and the solarium, combined with the immediate landscaping can lower summer temperatures and can moderate low winter temperatures. They can also modulate wind flows and can offer breezy areas in the summer and protected/calm areas in the winter.
B. *Arseres* (small openings located high on the external walls) allow lighter hot air to escape from the house and be replaced by cooler air from outside in the summer. In the winter adequate vegetation planted in relation to the *arseres* can insulate the openings.

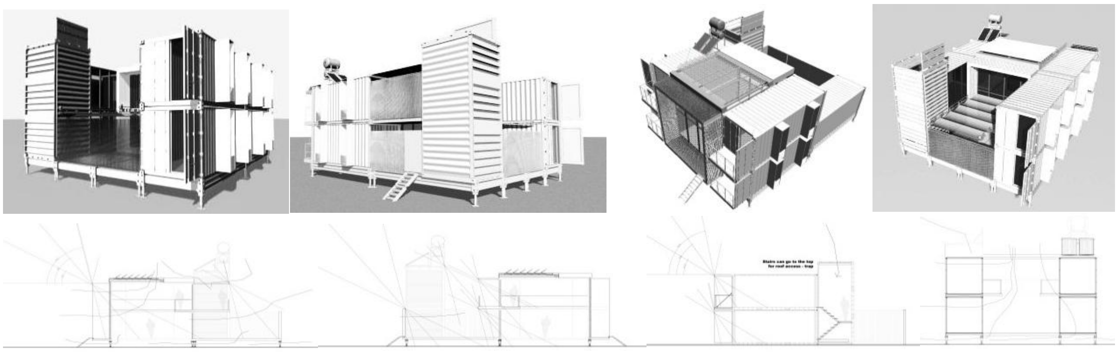


Figure 19: South courtyard and north courtyard types.
Two pilot schemes are shown as possible applications of the system: The first has a courtyard at the north side protecting the building from cold northerly winter winds and the other with a south-facing courtyard. Their detailed environmental performance is the next part of the research. Both offer certain advantages and disadvantages, therefore the comparison will depend on various other factors like the organisational strategy of the building, variations of microclimate and context, aesthetic and comfort issues, inhabitants etc.

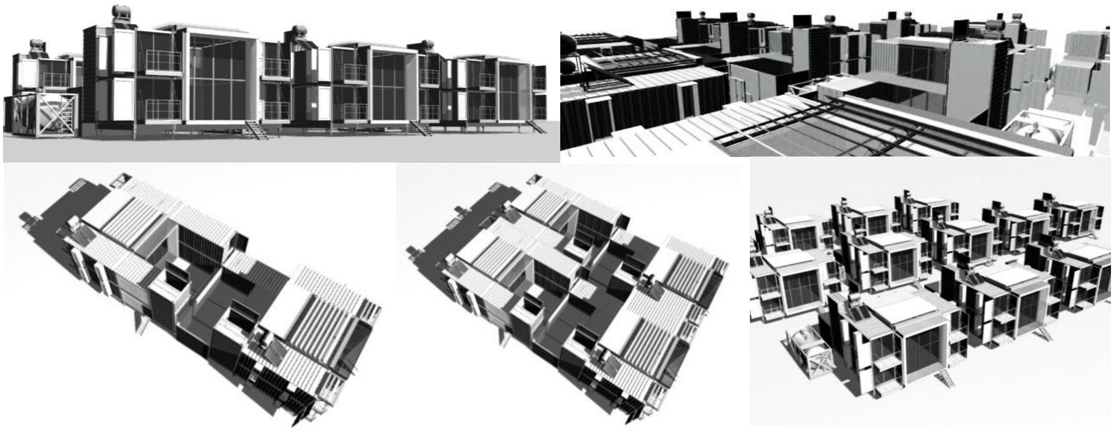


Figure 20: The environmental performance could be improved when considering multi dwellings as one entity.

CONCLUSION

Energy and environment are often mistakenly considered as technicalities best dealt with outside architecture. This work in progress shows that, far from being an issue of engineering and pure gadgetry, the environmental performance of buildings is fundamentally a matter for architects; being a direct outcome of formal, component, programmatic and operational choices made during the strategic stages of the design process. Being environmentally responsible is equally about making things that will last and can be re-used, making new things out of old things. It's about making things efficiently, with a minimum of resources. A building using reduntant shipping containers could be as environmentally sensitive as any scheme could be.

The paper demonstrates, that by carefully designing with respect to orientation and environmental performance, an array of containers and other parts of an open prefabrication construction system, a low energy passive solution can be met that creates excellent low-cost, low embodied energy housing development in the chosen context of Cyprus. This pilot scheme can be described as synergistic, where the whole is greater than the sum of its parts.

The next step in the development of the proposition will be to apply building energy modelling and simulations tools to analyse and assess its climatic performance, before it can be realized as a live pilot project.

In addition to the above, the proposition is a critique against our obsession with novelty. It doesn't take much of a step back to recognise that 'new' and 'good' are not automatically synonymous. Architecture must find a role for itself that is more in line with its nature and capabilities if it wants to make an effective contribution. Established principles and conventions can be revisited in innovative ways.

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